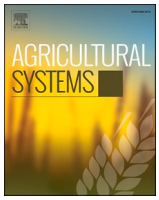
Agricultural Systems 213 (2024) 103800

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy



Farm typologies for understanding farm systems and improving agricultural policy

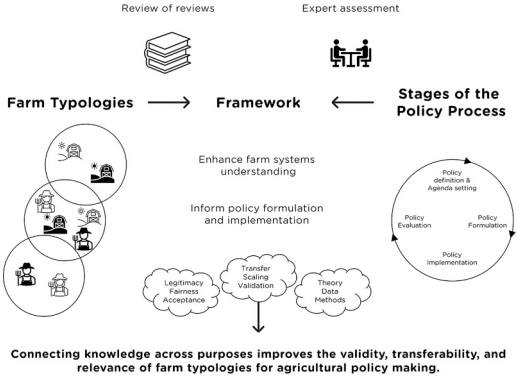
Robert Huber [a,*], Bartosz Bartkowski [b,c], Calum Brown [d,e], Nadja El Benni [f], Jan-Henning Feil [g], Pascal Grohmann [h], Ineke Joormann [i], Heidi Leonhardt [j], Hermine Mitter [j], Birgit Müller [k,l]

[a] Agricultural Economics and Policy ETH Zürich, Switzerland
[b] Helmholtz Centre for Environmental Research – UFZ, Permoserstraße 15, 04318 Leipzig, Germany
[c] Department of Economics, Martin Luther University Halle-Wittenberg, Große Steinstraße 73, 06108 Halle, Germany
[d] Institute of Meteorology and Climate Research, Atmospheric Environmental Research (IMK-IFU), Karlsruhe Institute of Technology, Kreuzeckbahnstraße 19, 82467 Garmisch-Partenkirchen, Germany
[e] Highlands Rewilding Ltd., Bunloit, Inverness IV63 6XG, UK
[f] Research Division Sustainability Assessment and Agricultural Management, Agroscope, Tänikon 1, 3856 Ettenhausen, Switzerland
[g] Department of Agriculture, South Westphalia University of Applied Sciences, Lübecker Ring 2, 59494 Soest, Germany
[h] Agricultural and Food Policy Group, Thaer-Institute of Agricultural and Horticultural Sciences, Humboldt-Universität zu Berlin, Germany
[i] Thünen-Institute of Rural Studies, Bundesallee 64, 38116 Braunschweig, Germany
[j] University of Natural Resources and Life Sciences, Vienna; Department of Economics and Social Sciences, Institute of Sustainable Economic Development, Feistmantelstrasse 4, 1180 Vienna, Austria
[k] Department of Ecological Modelling, Helmholtz Centre for Environmental Research – UFZ, Permoserstraße 15, 04318 Leipzig, Germany
[l] Chair of Modelling of Human-Environment-Systems, Brandenburg University of Cottbus-Senftenberg, Cottbus, Germany

HIGHLIGHTS

- Tailoring policies to target groups can improve their effectiveness and efficiency.
- We provide a "review of reviews" of the purposes of farm typologies.
- A framework links purposes of farm typologies to the stages of the policy process.
- This linkage improves the validity, transferability, and relevance of farm typologies.
- Cooperation between developers and users increases the usability of farm typologies.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Dr. Emma Stephens

Keywords:
Farm type

ABSTRACT

CONTEXT: Farm typologies help to identify patterns across a wide range of farm systems and describe heterogeneity in agriculture concisely. They can also support the design of agricultural policies by providing information and knowledge about policy target groups. For example, voluntary agri-environmental schemes could be

* Corresponding author.
E-mail address: rhuber@ethz.ch (R. Huber).

https://doi.org/10.1016/j.agsy.2023.103800
Received 22 June 2023; Received in revised form 26 September 2023; Accepted 30 October 2023
Available online 3 November 2023

Farm systems
Policy target group
Policy process
Policy instrument

tailored to specific agricultural landscapes and farm types. Farm typologies, however, are often developed from scratch, with limited connection to previous studies and policy making.
OBJECTIVE: The objective of this study is to clarify the purposes of farm typologies in research and agricultural policy making and to develop a framework that allows to increase the usefulness and usability of farm typologies for agricultural policy making.
METHODS: Based on a review of 13 systematically identified overview studies on farm typologies, we develop a framework that establishes connections between the purposes of farm typologies along the different stages of the policy process.
RESULTS AND CONCLUSIONS: We find multiple purposes for farm typologies, the two most common of which are for understanding the characteristics, heterogeneity, and development of farm systems and for policy making. The newly developed framework suggests that connecting knowledge across these purposes could improve the validity, transferability, and relevance of farm typologies for agricultural policy making. Our framework also provides an entry point for encouraging cooperation between developers and users of typologies, and for the improvement of typologies through new data (including behavioural data) and methods such as machine learning. We conclude that future research can build on the existing work on farm typologies but must be aware of the specific challenges that are associated with the use of farm typologies in the policy process.
SIGNIFICANCE: Knowledge of the prospects and challenges of using farm typologies allows to increase the usefulness and usabilityof these typologies and can contribute to the design of targeted and tailored agricultural policy instruments. By increasing the acceptance, perceived fairness, and legitimacy, this can improve their effectiveness and efficiency, which is urgently needed for a successful transformation to a more sustainable agricultural sector.

1. Introduction

The failure of the current Common Agricultural Policy (CAP) to achieve its environmental objectives has been attributed to a 'one size fits all' approach that does not sufficiently account for diversity between farms and farmers (e.g., Brown et al., 2020; Grohmann and Feindt, 2023; Hasler et al., 2022; Pe'er et al., 2020). This approach has also been found to erode environmentally-friendly farming practices where they already exist (Kovacs, 2021; Sutcliffe et al., 2013), and to leave farmers with constrained 'action spaces' within which they are often unable to implement sustainable practices (Gütschow et al., 2021). New policy designs that efficiently adapt to farm contexts are therefore warranted, especially with envisioned changes in the Common Agricultural Policy that foresee an increase in the funding for more sustainable farming practices e.g., related to the Farm to Fork Strategy (e.g., Schebesta and Candel, 2020; Thomson et al., 2019).

Farm and farmer typologies are one important approach to account for farm contexts i.e., the heterogeneity of farm structures and farmers' behaviour (e.g., Andersen et al., 2007; Bartkowski et al., 2022). They allow for identification and understanding of patterns in heterogeneous structures and thus enable policy makers to consider diversity in potential reactions to agricultural policies while recognizing that it is impossible to tailor incentives to each individual farm or farmer (e.g., Emtage et al., 2006).

The aim of this study is to clarify the purposes of farm typologies in research and policy making and to develop a framework that allows to increase the usefulness and usability of farm typologies for agricultural policy making. We first review existing literature on farm typologies and derive a framework to link the identified purposes of farm typologies with the different stages of the policy process. Finally, we use the framework to assess farm typologies regarding their conceptual and methodological prospects and limits. This provides a guide for researchers and policymakers in the use of typologies that best suit their purpose.

Existing literature on farm typologies has addressed agricultural diversity and heterogeneity on different spatial, temporal, and institutional scales (e.g., Bock et al., 2020; Graskemper et al., 2021; Malek and Verburg, 2020; Marshall et al., 2021; Rega et al., 2022; Upadhaya et al., 2021). While these typologies initially focused on farm structural characteristics such as farm size, production types, economic performance or socio-economic characteristics (e.g., Kostrowicki, 1977), more recent typologies also consider behavioural factors (see e.g., Bartkowski et al., 2022 for a review). A variety of conceptual approaches and methods has been used for the construction of farm typologies. However, there is currently a research gap in bringing together the different purposes of farm typologies.

In addition, empirically based farm typologies are diverse, fragmented, and difficult to compare across individual studies with different purposes as well as regional and cultural backgrounds (e.g., Bartkowski et al., 2022; Emtage et al., 2007; Graskemper et al., 2021). Consequently, typologies are often developed from scratch in agricultural policy evaluations, limiting the generalizability of these studies in increasingly complex policy programs. Thus, a second research gap results from the lack of clarity about how farmer typologies can inform policy processes, and which challenges and prospects arise in their use. For example, using farm typologies to identify policy target groups may be necessary to increase the effectiveness and efficiency of a policy instrument. However, such farm typology may create critical challenges with respect to perceived fairness, reducing the acceptance of policy instruments. For instance, Niskanen et al. (2021) and Vainio et al. (2021) found that result-based payments were perceived as less fair, less equal, and thus less legitimate than action-based payments, which should be considered when developing farm typologies to inform policy processes.

To address these gaps in the literature, we assess existing reviews of farm typologies to clarify how such typologies can directly (by affecting policy instrument formulation and evaluation) and indirectly (by furthering our system understanding) inform the design of effective and efficient agricultural policies.

In the next Section, we define the term farm typologies as we use it in our study and describe the literature review strategy. In the Results (Section 3), we first present an assessment of the identified reviews on farm typologies by summarizing the multiple purposes of such typologies in research. We then describe our newly developed framework aligning different purposes of farm typologies with different stages of the agricultural policy process. In Section 4, we discuss prospects and challenges of using farm typologies for agricultural policy making based on our framework. We present our conclusion in Section 5.

2. Material and methods

2.1. Defining farm typologies

Farm typologies result from grouping farms (e.g., farm households or farm businesses) or farmers that are relatively homogenous according to one or more specific criteria (internal homogeneity) but differ from each

other as much as possible (external heterogeneity). Farm types then refer to the formed groups sharing similar characteristics. On the one hand, they reduce the complexity of the farm(er) population without falling into what Oberlack et al. (2019) call an "ideographic trap" (i.e., having too many and too specific criteria so that every farm is indeed different from others). On the other hand, the criteria must differentiate groups of farm(*er*)s so that their abstraction leads to a meaningful generalization (Emtage et al., 2007; Oberlack et al., 2019). Thus, the main goal of a typology is to define groups of farms or farmers with minimum variation within, and maximum variation to other groups (Marshall et al., 2021).

The criteria[1] used for developing farm typologies are based on different farm (or farmer) characteristics. These characteristics can be summarized into three broad categories: socio-environmental, farm structural and farmers' individual characteristics (cf. Fig. 1).

- Socio-environmental characteristics relate to the economic, political, and environmental conditions in which a farm is embedded. Used as criteria, these characteristics allow categorizing farms and farmers according to spatial differences in the environment (e.g., production zones), and regional specificities (e.g., development state, regulations).
- Farm structural characteristics refer to farm size, type of production (e.g., livestock, crop, mixed), production intensity and technology, farming practices, land-use classes, economic orientation (e.g., subsistence farming vs. market oriented), or other farm-specific characteristics.
- Farmers' individual characteristics include socio-demographic factors such as age and education, personal traits including managerial abilities, and also behavioural characteristics such as cognitive (e.g., perception), social (e.g., norms) and dispositional (e.g., risk tolerance) factors (see e.g., Dessart et al., 2019 for a classification).

Typologies focusing on farmers' individual characteristics are often referred to as "farmer typologies" (e.g., Bartkowski et al., 2022). In contrast, typologies focusing on socio-environmental and/or structural characteristics can be referred to as "farm system typologies".

There are three important aspects related to the criteria used for developing farm typologies. First, many farm typologies rely on a combination of characteristics. Tittonell et al. (2020), for example, summarize typologies that include the three above-mentioned characteristics as functional farm typologies aiming at understanding the decision making by farmers. Secondly, criteria might be used to form groups at different levels, allowing for nested types with, for example, a main type and several sub-types (Blanco et al., 2015; Oberlack et al., 2019). Farm typologies can thus be seen as an overall classification of other concepts such as land-use, farm, livestock and land-tenure systems (Kostrowicki, 1977). Thirdly, criteria can be expressed in different metrics ranging from simple indices (e.g., farm size in ha of land), to complex indicators (e.g., economic farm performance) including latent socio-psychological constructs (e.g., productivist mindset).

Moreover, additional categorizations of farms, farmers and land-users exist such as archetype analysis[2] (Eisenack et al., 2021; Oberlack et al., 2023; Tittonell et al., 2020), farming styles (Schmitzberger et al., 2005; van der Ploeg et al., 2009) or farmer identity (Burton et al., 2021). While these categorizations do not directly refer to the term "typology", they have similar goals with respect to capturing diversity in agriculture by grouping characteristics of the farm system and the farmers using a set of criteria. To be able to consider the range of criteria used for developing farm typologies, we here use "farm typologies" as an umbrella term for different forms of categorizations including farm and farmer types.

2.2. Review of reviews: purposes of farm typologies

The development of farm typologies for policy purposes evolved in parallel to the emergence of agricultural policy in Europe at the beginning of the 20th century. Only through the collection of data (especially bookkeeping data) and their communication using different farm types (e.g., mountain farms, livestock, or crop farms) the economic struggle of family farms received political attention and justified policy incentives in the agricultural sector (e.g., Auderset and Moser, 2018). Farm typologies are still used for assessing the economic farm performance and informing policy processes. Examples include the USDA census data typology based on size, income, and ownership share (e.g., small family farms, midsize family farms and non-family farms) or the typology used in Eurostat based on type of farming (e.g., raising cattle, raising pigs, cultivating arable crops or horticulture). These typologies, however, often capture only structural and economic characteristics, reflecting the fact that agricultural policies were initially introduced to increase production and farm income (see e.g., Andersen et al., 2007; Briggeman et al., 2007).

Over time, however, farm typologies were used for other purposes including many more criteria. We here explore the foci and purposes of this currently more diverse field of farm typologies described in scientific reviews, based on a systematic literature search. To do so, we first started with studies known by the authors of this contribution.[3] Secondly, we used a search string that retrieved 255 articles from Web of Science, including those studies collected in the first step of the search (see Fig. 2).

Thirdly, we screened the titles and abstracts of these articles to determine whether each i) was a review and ii) discussed multiple purposes of typologies. We did not include studies with the purpose of developing a new typology. We excluded publications that did not explicitly stated the purposes of the typologies or that did not focus on farm systems. Finally, we excluded studies focusing on strategies to identify and group stakeholders (e.g., Grimble and Wellard, 1997). Fourthly, we cross-checked the search in Google Scholar and included reports and book chapters into our review. The search was performed twice by two independent researchers in autumn 2022. Finally, we summarized the criteria used for the typology, the research foci, and purposes of the farm typologies in the 13 relevant reviews we found (Table 1).

3. Results

3.1. Purposes of farm typologies in existing reviews

In the following, we briefly summarize the findings of our review with respect to the purposes of farm typologies. A detailed description of the different typologies presented in the reviews (i.e., according to socio-environmental, farm structural, and farmers' individual characteristics) can be found in the Online Supplementary Material.

Our assessment of the 13 reviews can be summarized in three main results. First, the reviews referred to multiple combinations of purposes for developing farm typologies. We identified eight different purposes that reoccurred in the existing reviews (see Table 2): description; understanding and explanation; modelling and scenario development; generalization; identification of policy target groups; transfer of policies; ex-ante policy assessment and planning for development; monitoring. The framing of these purposes often differed (as functions, motivations,

[1] We here understand the term "characteristics" as a description of an attribute of a farm or a farmer. For their use in a typology, these characteristics need to be measured and evaluated. We use the term criteria to describe the use of these characteristics in a farm typology.

[2] Archetype analysis is an approach to describe and understand recurrent patterns in factors and processes that shape the sustainability of specific farm systems (or social-ecological systems in general).

[3] The authors met virtually in a dedicated session on farm typologies at the Landscape Conference 2021 in Berlin and openly discussed opportunities and challenges in the development of typologies.

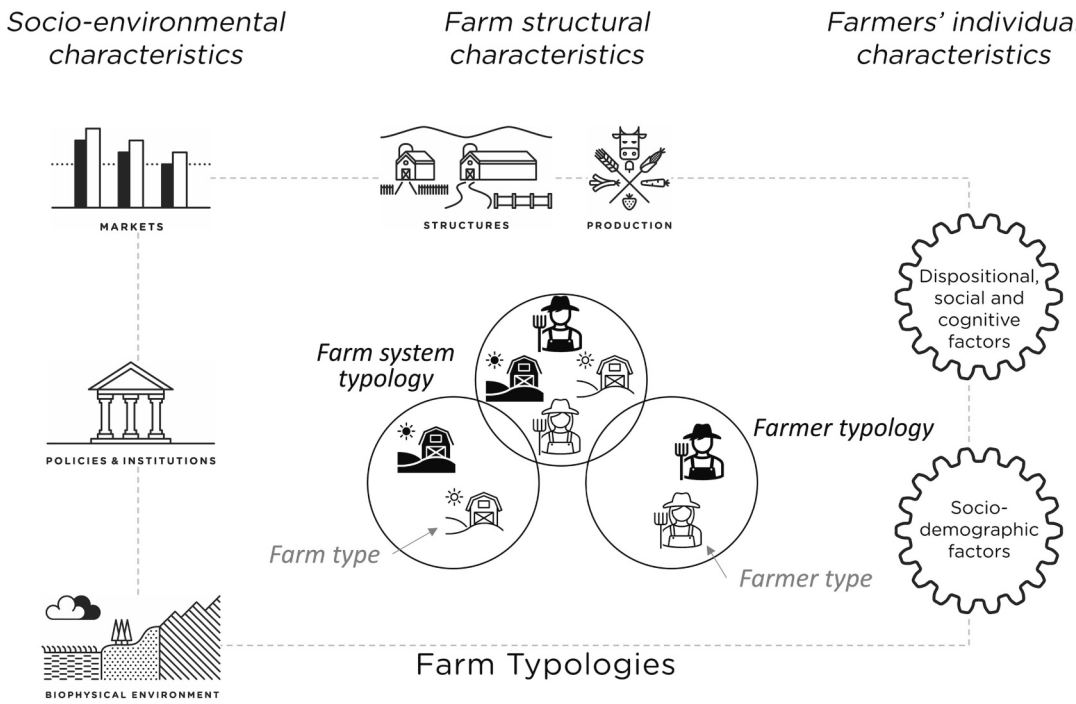


Fig. 1. Farm typologies group farms or farmers into relatively homogeneous groups according to a set of criteria. Criteria can be based on socio-environmental, farm structural and individual (farmer-related) characteristics and combinations thereof.

etc.), but there were many overlapping arguments. For example, ten out of 13 reviews mentioned that understanding and explaining heterogeneity and diversity in the farming sector is an important purpose in developing farm typologies. Eight reviews highlighted the usefulness of farm typologies for identifying policy target groups. This also resulted in overlapping conceptual and methodological approaches used to derive typologies, as most of them were at least partly derived from empirical data (e.g., taxonomic) and only in a few cases they included also theoretical considerations. Secondly, based on our assessment, the eight identified purposes can be classified into two separate overarching categories: 1) typologies that inform our knowledge about farm systems and 2) typologies that inform policy formulation and implementation (cf. the main categories in Table 2). This also reflects main characterizations in different reviews, e.g., the differentiation into *critical utility* and *predictive validity* by Emtage et al. (2007), the classification of Whatmore (1994) into taxonomic and relational/experiential groups, or the differentiation by Oberlack et al. (2019) into pattern recognition and case typologies. The differentiation into typologies for researchers and for policymakers by Matus et al. (2013) also mirrors these two categories. Thirdly, the different purposes often build on each other, such that understanding precedes policy evaluation. However, there is no obvious, generally applicable sequence that helps to organize the different purposes and disentangle the different uses of farm typologies. For example, scenario development and ex-ante policy assessment might be based on the same theoretical and methodological grounds but are very different purposes in the context of the policy process. In the next section, we link our assessment of these reviews to the different stages of the policy process to conceptually clarify the purposes of farm typologies in the context of policy making.

We suggest a framework that links the above identified purposes of farm typologies to the different stages of the policy process (Fig. 3). Classifications of these stages are based on the policy cycle model, which typically differentiates between problem definition and agenda setting, policy formulation, implementation, and evaluation (Jann and Wegrich, 2017).

Starting from the four stages of the policy process (inner circle), we extend the framework by the identified purposes of farm typologies (represented by the surrounding, grey circle) and three layers of challenges (blue circle and two outward bent arcs) when using farm typologies. The dark blue circle represents the challenges arising from theory, data, and methods faced by any development of types. The light blue arc refers to challenges specific to the use of farm typologies in policy formulation and implementation. Finally, the blue arc represents the main challenges when using typologies to improve our understanding of the farm systems and their heterogeneity. While important, these challenges are not relevant for all farm typologies. In the following, we describe each of these elements of the framework in more detail. The circular arrangement of purposes in our framework has two implications. First, farm typologies can be meaningfully assigned to different purposes depending on the stages of the policy process. Thinking about the link between any farm typology along the stages of the policy process clarifies its purpose and facilitates communication between developers and users. The following purposes per stage are considered meaningful:

- Description as well as understanding, explaining, and awareness-raising are important purposes of farm typologies in the context of the *problem definition and agenda setting* stage of the policy process. In this context, farm typologies provide important insights into the policy process through framing, raising issues, or creating political and societal awareness of possible future challenges (see e.g., Brown et al., 2013; Verburg et al., 2016). In addition, such typologies support the selection of representative farms, the formulation of (typical) archetypical farms, and/or the design of representative samples in subsequent, more detailed analyses (especially with respect to economic farm performance e.g., Sauer and Moreddu, 2020). The goal of understanding farm systems is to acquire generalizable knowledge through the construction of different farm typologies.
- In the context of *policy formulation*, typologies allow knowledge transfer from other case studies that have already experienced a particular problem and related policy. In addition, ex-ante evaluation based on farm typologies e.g., using simulation models, provides insights into potential consequences from introducing or adjusting policy instruments. As a result, typologies specifically support the

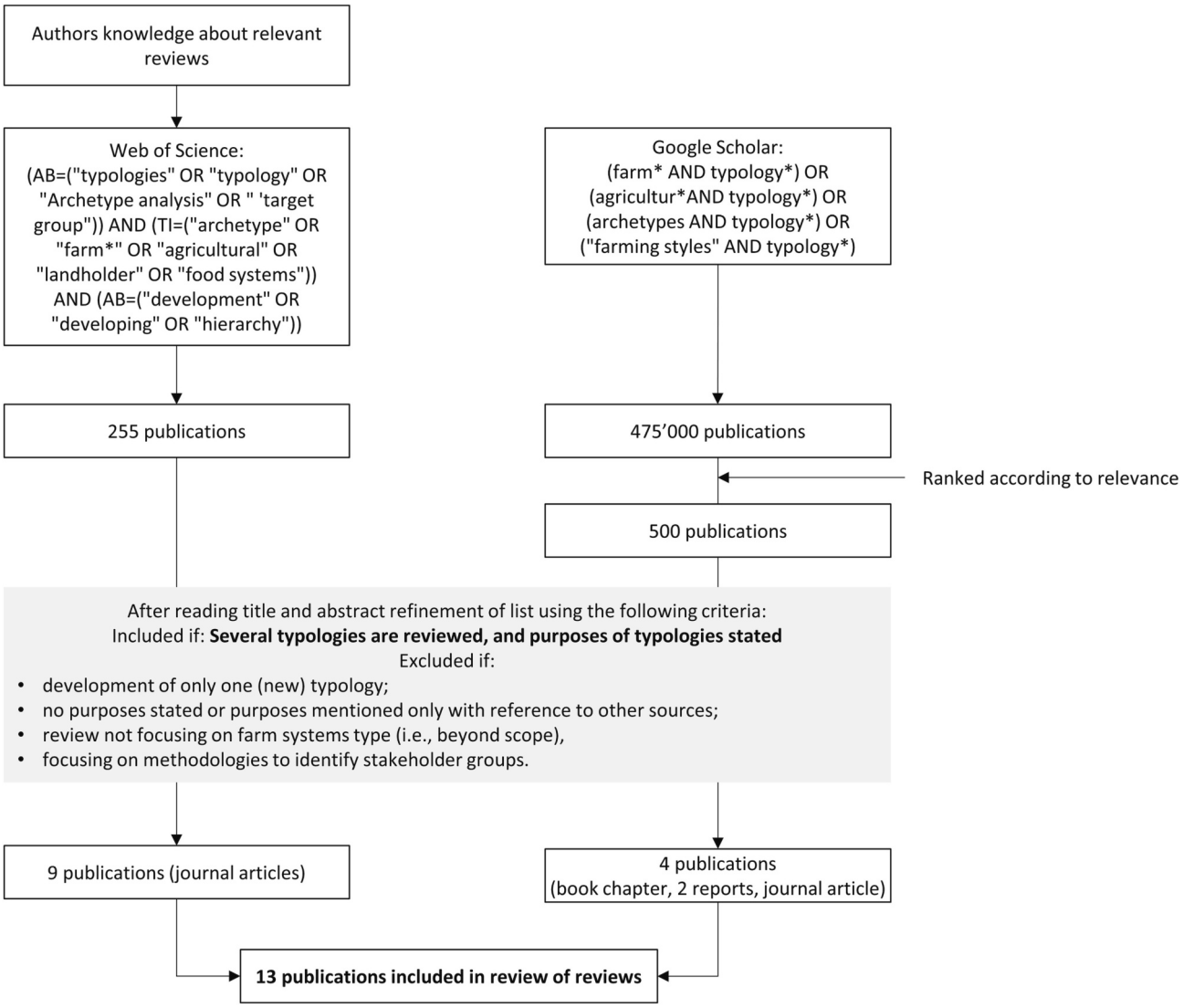


Fig. 2. Review of reviews: Documentation of literature search.

extrapolation of ex-ante evaluations to larger spatial or organizational scales (e.g., Ewert et al., 2011). Moreover, typologies can be used to design effective policy mixes (Braathen, 2007) – based on the understanding of which types are likely to respond to which policy instruments (e.g., nudges, advisory services, payments), a policy mix can incorporate instruments for all types.

- With respect to *policy implementation*, farm typologies can support the identification of policy target groups. As a result, typologies allow the policy instruments to be tailored to locations, times, or farm types.[4] Information about farmer typologies also creates opportunities to apply existing policies in different, targeted ways to increase uptake. For example, tailored information can be provided to specific farm types i.e., via advisory services or information nudges.
- Finally, typologies can strengthen monitoring and ex-post *policy evaluations*, which should improve our understanding of whether and how a certain policy incentive achieved progress towards the intended goal. This allows a more nuanced understanding of how interventions can be disseminated (transferred) across farming communities and between regions with different farm structures, production, or behavioural patterns. This also allows models to increasingly reflect heterogeneity and feedbacks between policy instruments and farmers' reactions and thus to represent the impact of policies more accurately. This can lead to general findings that can be used for policy framing (closing the policy loop).

Secondly, the development of farm typologies is an iterative and dynamic process, and some typologies might inform other uses or developments of farm typologies. This allows us to think about potential synergies between currently disconnected farm typologies. For example, typologies that are used to transfer knowledge between regions could be closely connected to typologies aiming at identifying target groups. Likewise, the use of typologies for ex-post policy evaluations might inform those used in ex-ante simulations (e.g., Möhring et al., 2022). In contrast, a direct connection of typologies used for scenario development and identification of target groups might not be meaningful given that the former informs a debate whereas the latter have direct implications for policy design.

Beyond the link between the different stages in the policy process (inner core) and the purposes (in the surrounding circle), the

[4] In the agricultural policy literature, there is a differentiation between targeting (i.e., a policy instrument targets a specific goal) and tailoring (i.e., the instrument is tailored to specific regions, or farms) (see Van Tongeren, 2008). We here focus on target groups which should not be understood as "targeting" a goal.

Table 1
Summary of review of reviews on farm typologies.

Criteria for farm typologies based on	Focus of review	Reference	Review Nr.
socio-environmental and farm structural characteristics (farm system typologies)	Farm typologies in agricultural geography	Kostrowicki (1977): Agricultural typology concept and method	1
	Farm typologies based on systems approach of farm functioning	Landais (1998): Modelling farm diversity: new approaches to typology building in France	2
	Development of international household typology	Matus et al. (2013): Literature Review and Proposal for an International Typology of Agricultural Holdings	3
	Methods, criteria, and approaches for developing smallholder farm typologies	Chikowo et al. (2014): Farm typologies, soil fertility variability and nutrient management in smallholder farming in Sub-Saharan Africa	4
	Farm system typology development	Alvarez et al. (2018): Capturing farm diversity with hypothesis-based typologies: An innovative methodological framework for farm system typology development	5
	Archetype Analysis in Sustainability Research	Oberlack et al. (2019): Archetype analysis in sustainability research: meanings, motivations, and evidence-based policy making	6
	Purposes and methods used for developing farm typologies	Graskemper et al. (2021): Farmer typology and implications for policy design – An unsupervised machine learning approach	7
	Farm typologies as part of a global food systems typology along the value chain	Marshall et al. (2021): Building a Global Food Systems Typology: A New Tool for Reducing Complexity in Food Systems Analysis	8
behavioural /farmers' individual characteristics (farmer typologies)	Purposes, disciplinary foci, methods, and types of data used to derive farm typologies	Bartkowski et al. (2022): Typologies of European farmers: approaches, methods and research gaps	13
all characteristics including socio-environmental, farm structural, and farmers' individual characteristics	Typology of farm typologies: Farming styles to assess rural development strategies	Whatmore (1994): Farm Household Strategies and Styles of Farming: Assessing the Utility of Farm Typologies	9
	Landholder profiling in natural resource management	Emtage et al. (2007): Landholder Profiling and Typologies for Natural Resource–Management Policy and Program Support: Potential and Constraints	10
	Categorization of climate change adaptation behaviour using typologies of farms and communities	Lyle (2015): Understanding the nested, multi-scale, spatial and hierarchical nature of future climate change adaptation decision making in agricultural regions: A narrative literature review	11
	Farm structural and behavioural characteristics in small farms	Bradley et al. (2021): Segmentation and typologies of farmer behaviour, especially in the UK, and any information on their use in anticipating behavioural responses	12

framework's outer circular layer represents challenges related to theory, data, and methods that arise when developing farm typologies. This challenge is linked to the different purposes of farm typologies. While there might be differences with respect to the specific weight given to theories, data and methods, the fundamental challenges must be considered irrespective of the purpose of the typology (see also next Section). Knowledge about how typologies are conceptually and methodologically developed in other stages of the policy process (and thus also for different purposes) can be used to cross-stimulate choices related to the development and application of farm typologies.

Finally, the framework illustrates the challenges emerging when farm typologies are used for the purposes of a) improving our understanding of farm systems, and b) informing policy formulation and implementation.

a. Challenges in farm systems understanding: When farm typologies are used to improve our understanding of the farm system (and thus indirectly the potential effect of policy incentives), issues of validation, upscaling, and transferability arise and may be addressed in the development of typologies.
b. Challenges in policy formulation and implementation: When farm typologies are used for direct identification of policy target groups and policy implementation, the key challenges that emerge are whether such policy incentives are perceived as fair (e.g., with respect to distributional effects on income or costs) and legitimate, with consequences for policy acceptance. While these aspects are often beyond research on farm typologies, the use of farm typologies in policy implementation has implicit consequences for them (see also next Section).

The different types of challenges for developing farm typologies are not mutually exclusive. The framework, however, visualizes challenges for different purposes of farm typologies i.e., that i) theory, data, and methods are challenges for all purposes; ii) validation, upscaling, and transferability challenges are primarily related to typologies that seek to improve our farm system understanding; and iii) acceptance, fairness and legitimacy may be unique challenges for typologies developed for policy formulation or implementation.

Overall, the framework i) serves as a reference to facilitate building on prior studies and knowledge; ii) allows for an enhanced alignment of policies with their target groups; and iii) raises awareness of challenges to tackle along the development stages of farm typologies. As such, the framework highlights the dependence between challenges and specific purposes in a structured way and provides guidance for the development of typologies. In the next section, we discuss prospects of the use of the framework and potential approaches to overcome the identified challenges.

4. Discussion

4.1. Added value of the framework for the use of farm typologies

Our framework invites explicit thought about the purposes of farm

Table 2
Purposes of farm typologies according to the existing reviews.

Category	Purpose	Description	Reviews mentioning purpose
Enhance farm system understanding	Description	Explore diversity in farming sector, detect spatial heterogeneity	[1], [2], [3], [6], [8], [9], [10]
	Understanding and explanation	Understanding and explaining heterogeneity and diversity, diagnosis of functioning (e.g., economic performance), raising awareness on heterogeneity and diversity in the farming sector (e.g., on environmental aspects)	[1], [2], [4], [6], [8], [9], [10], [11], [12], [13]
	Modelling, scenario development	Upscaling information e.g., via agent-based modelling, developing future scenarios	[1], [2], [6], [12], [13]
	Generalization	Generalizing contextually explicit results from case studies, causal identification (ex-post analysis)	[6], [9], [11]
Inform policy formulation and implementation	Identification of policy target groups	Understanding the structure of farm or farmer population for target-group oriented policy measures	[3], [4], [6], [7], [10], [11], [12], [13]
	Transfer of policies	Transferability of policy actions and instruments or technological or institutional innovation to other regions (i.e., in space) and contexts	[3], [5], [6], [8]
	Ex-ante policy assessment, planning for development (including modelling)	Guidance for farm advisory services, regional development, or farm performance	[1], [9], [2], [10], [12], [7], [13]
	Monitoring	Monitor farm performance and environmental indicators over time	[3], [10]

Note: [1] Kostrowicki, 1977; [2] Landais, 1998; [3] Matus et al., 2013; [4] Chikowo et al., 2014; [5] Alvarez et al., 2018; [6] Oberlack et al., 2019; [7] Graskemper et al., 2021; [8] Marshall et al., 2021; [9] Whatmore, 1994; [10] Emtage et al., 2007; [11] Lyle, 2015; [12] Bradley et al., 2021; [13] Bartkowski et al., 2022

3.2. The framework: Aligning purposes of farm typologies with stages of the policy process.

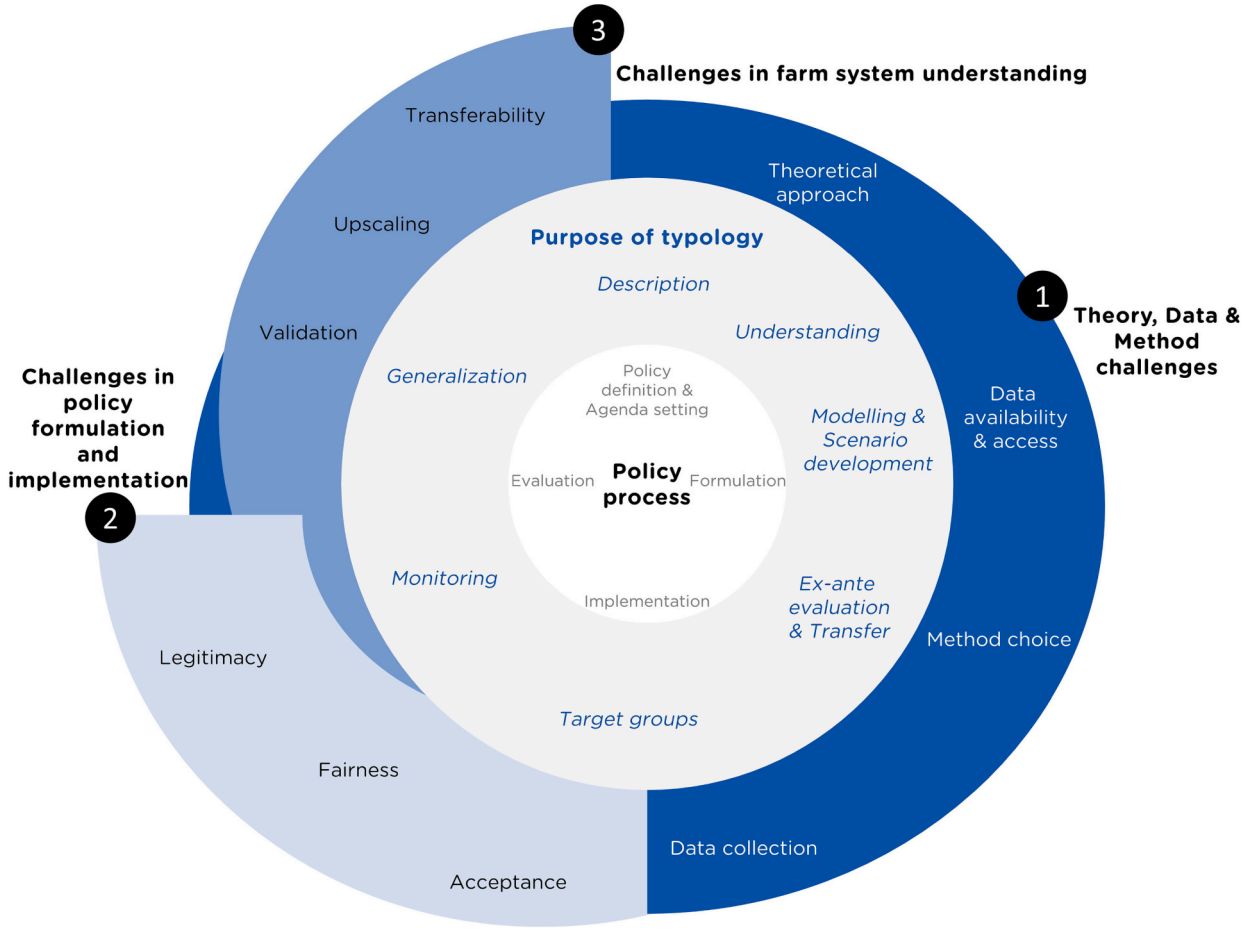


Fig. 3. Framework for assessing the use and implementation of farm typologies. The framework organizes the purposes of farm typologies and three related challenges in developing them along the different stages of the policy process. The core represents the four main stages of the policy process. The first circle (grey) arranges the different purposes of farm typologies along the four stages of the policy process. The second circle (dark blue) summarizes main challenges for all farm typologies. Arcs represent challenges with respect to the two main categories of purposes of farm typologies: farm systems understanding (blue) and policy formation and evaluation (light blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

typologies in the different stages of the policy process. Thus, our framework provides five insights for their development outlined below.

First, the framework clarifies that farm typologies have a common "raison d'être" for supporting agricultural policy making. Thus, the currently rather loosely connected literature could benefit from paying more attention to previous efforts in developing typologies. The development of typologies could build on existing approaches and methodologies even if their purpose is different. This would be especially meaningful if the development of a farm typology would allow to increase the understanding of farmer decision-making and at the same time build a fundament for the identification of policy target groups. Farm typologies then might provide a better understanding of target group heterogeneity and reveal important (often unintended) side-effects when policies are tailored towards farm types. For example, combinations of typologies used for monitoring (e.g., farm performance) and typologies developed to understand farmers' decision-making (see Bartkowski et al., 2022) could be used in ex-post policy evaluations (see e.g., El Benni et al., 2023 for a discussion). This could be particularly helpful in analysing policy mixes (several instruments address one or more objectives), because an improved understanding of the behaviour of target groups helps to design instruments that could contribute to an increased effectiveness and efficiency (Pedersen et al., 2020).

Secondly, a closer connection of understanding and identifying policy target groups could improve not only the transferability but also the validity of farm typologies and as such improve agricultural policy comparison and learning. Typologies that are based on a thorough farm system understanding (including behavioural aspects) and at the same time inform policy formulation and implementation may allow something akin to benefit transfer in economic valuation (Johnston et al., 2018) – by knowing details about the farmer population for which a new policy is planned, it is easier to transfer insights from a "study population" (where the policy is already in place), even though the latter may differ from the former. Identifying farm typologies along the stages of the policy process thus helps to attract much needed attention for the value of easily extendable and verifiable typologies in agricultural policy making. For example, knowledge of how different farm types react to voluntary agri-environmental measures in a specific country (e.g., Mack et al., 2020 for Switzerland) could be used as a basis for assessing the potential of these policy measures in other countries with similar farm type patterns.

Thirdly, the identification of specific challenges associated with the purpose of using a typology along the stages of the policy process can reenforce the cooperation and interactions between developers and users of farm typologies (e.g., policymakers). Thinking about the challenges early in the research process not only creates transparency but also allows to make informed choices about data collection and methodological approaches. Thus, knowledge on farm typologies and the specific challenges associated with their development and use will make it easier to select the appropriate approach and methods. This increases the relevance of the typologies in the policy process and reduces potential bias towards specific topics (as discussed in Alvarez et al., 2018; Beckmann et al., 2022). For example, considering behavioural characteristics in farm types used to assess farm performance (see e.g., Kaiser and Burger, 2022 for an analysis of crop farms) can increase our understanding of the underlying decision-making and its impacts. Such combinations rarely exist in the current literature on farm typologies.

Fourthly, the emergence of open and accessible data sources in combination with new methos such as machine learning have a great potential to bridge the use of typologies for farm system understanding as well as policy formulation and implementation. Ultimately, this would not only allow to extend and fine tune existing approaches but also to develop farm typologies that capture temporal and spatial dynamics. Access to temporally and spatially granular databases (e.g., IACS[5] data in the EU, or remote sensing data) could not only help to improve regulation (see e.g., Mesnage et al., 2021 for the case of pesticide regulation) but also to develop farm typologies that can inform policy making throughout the different stages of the policy process. More specifically, the combination of existing typologies with the use of unstructured data in machine learning approaches (see e.g., Storm et al., 2019; Wang et al., 2022) could leverage the temporal and spatial robustness of farm typologies.

Finally, our framework perspective can contribute to agricultural policy evaluations by raising awareness of using farm typologies for modelling. For example, typologies can improve models (see e.g., Brown et al., 2017; Huber et al., 2018) needed to identify response options to grand societal challenges such as climate change, technical innovation including digitalisation, or trends in agriculture such as reducing its environmental impact, increasing food security, or upscaling organic farming. The key contribution of typologies in this context would be their potential to bridge spatial and institutional scales bringing together micro and macro perspective in modelling (see e.g., Müller et al., 2020). Typologies can also be used to make models more transparent and more accurate in representing the farm population and its behaviours. A promising approach would be to exchange agent types between e.g., different agent-based models (Arneth et al., 2014). This would, on the one hand, allow to bridge the gap between understanding farmers' individual behaviour (currently often done with micro-economic or agent-based models) and the collective behaviour of groups of farmers, thus informing policymakers about potential targeting and tailoring of incentives. On the other hand, farm types can provide a robust background for attempts to generalize knowledge across individual modelling studies (see e.g., Václavík et al., 2016). In that context, nested typologies may be required, starting from more coarse, large-scale categorizations (e.g., Malek and Verburg, 2020), within which the more detailed typologies from individual case studies would be embedded (but see Section 5.2.3 on the challenges associated with this).

4.2. Challenges and first solutions for developing farm typologies

4.2.1. Theory, data, methods

The development of farm typologies can be based on many different combinations of theories, data collection and analysis approaches (see Table 3 for an exemplary list of different combinations of data and methods). While reviews of the different methodological approaches to developing typologies exist (Mądry et al., 2013; Nyambo et al., 2019), specific challenges arise since decisions on data collection, variable selection and techniques for clustering have a strong influence on the resulting typology and hence on its reliability for any purpose (see e.g., Alvarez et al., 2014; Alvarez et al., 2018).

One solution addressing this challenge is to be explicit about the theoretical and conceptual underpinning of the typologies, e.g., by formulating the purpose, which is key for the development of robust farm typologies that are relevant to inform agricultural policy making. The integration of new empirical data, e.g., on psychological characteristics, may improve the usability of farm typologies in the policy making process. This becomes even more pressing with new opportunities offered by machine learning and big data.

When focusing on understanding decision making or the transfer of management practices or policy instruments, the identification strategy for developing typologies must ensure their interpretability to inform policy making (which might be difficult when using machine learning techniques due to selection bias or unobserved factors). In this context, the concept of predictive validity (Emtage et al., 2007) or the notion of relational/experiential groups that explain causal processes (Whatmore,

[5] IACS: Integrated Administration and Control System including georeferenced agricultural parcels in EU Member States.

Table 3
Exemplary studies illustrating the combination of data collection and analysis methods to infer typologies.

Data analysis to derive typologies ***Data collection***	Descriptive (qualitative content analysis, indicator thresholds, expert, or stakeholder discussion etc.)	Statistical tools (Cluster, PCA, latent class etc.)	Machine Learning (supervised and unsupervised clustering)
Qualitative interviews, focus groups, expert based	Mitter et al. (2019): Semi-structured interviews combined with content analysis to derive groups of farmers differing in perceptions of climate change and adaptation intentions.	Bakker and van Doorn (2009): Interviews with farmers and cluster analysis to develop a typology of land-use decision-making.	Tittonell et al. (2020): Interview data analyzed with unsupervised learning method (archetypal analysis) to define functional farm household typologies.
Structured survey	Schmitzberger et al. (2005): Survey based criteria classified in a group discussion process to identify farming styles.	Barnes et al. (2022): Farm survey across European countries and latent class analysis to derive farm typologies with a focus on ecological self-identities.	Graskemper et al. (2021): Survey data clustered using an unsupervised machine learning approach with Partitioning Around Medoids (PAM) to identify target groups for policy incentives.
Secondary data (e.g., census)	Daskalopoulou and Petrou (2002): Secondary data on farms using the average of each variable to create types of adopters of alternative farming activities.	Sauer and Moreddu (2020): Analysis of EU FADN data using a production function based on a latent-class estimation procedure and a principal component analysis to form groups that allow to monitor farm performance across European countries.	Beckmann et al. (2022): Self-organizing maps based on environmental data to derive archetypes of agri-environmental potential.
Literature review, Meta-analysis	Bartkowski et al. (2022): Literature review and content analysis to derive generic farmer typologies.	Malek and Verburg (2020): Meta-analysis and multinomial logistic regression to derive global land-use decision-making types.	–
Structured surveys & secondary data	–	Valbuena et al. (2008): Combination of survey information with census data to derive agent types for scenarios and ex-ante assessments.	Adenle and Ifejika Speranza (2021): Combination of land-use and population data to derive archetypes of agricultural land degradation.
(Economic) Experiment	Blazy et al. (2011): Choice experiment data used for typology of farmers using the two major discriminating factors.	Myyrä and Liesivaara (2015): Choice experiment data analyzed using the latent class approach to reveal latent groups and differences in farmers' WTP for crop insurance.	–

1994) should receive more attention. While straightforward statistical or machine learning approaches might reveal patterns in the data even without a specific theory or concept in mind, linking the typology to the stages of the policy process might clarify the underlying objectives and purposes of the typology. To address this challenge, comparisons of typologies derived from the same or related data, but with different methods could improve understanding and robustness of typologies (see also Section 4.2.3).

In addition, a well-structured and comprehensive description of the theoretical background, data collection and analysis that covers all aspects mentioned above is an important prerequisite to enhance cross-fertilization and build on prior work. This requires, for instance, that meta data including questionnaires and other details of the structure of survey samples are made open access (e.g., in the Appendix of a publication). Up to now this is often not the case partly because of data protection regulations (cf. Bartkowski et al., 2022), but also due to the slow diffusion of open science standards in general (e.g., Gewin, 2016).

Finally, integrating different methodological approaches could help to leverage the benefits of different knowledge systems for developing farm typologies. For example, Landais (1998), Berre et al. (2019), and Assogba et al. (2022) highlight the advantage of expert knowledge or participatory approaches in a quantitatively-driven identification of farm typologies. This underpins the claim for building on prior studies and for fostering collaboration between developers of typologies.

With respect to data collection, we identify the following three challenges to consider: First, farm typologies could make use of and include behavioural factors such as cognitive, dispositional, or social characteristics of farmers (Dessart et al., 2019; Schaub et al., 2023). The collection of such data may be resource intensive (e.g., in economic experiments, interviews or structured surveys), but their use for developing farm typologies could build a theoretical basis and make underlying conceptual and theoretical assumptions explicit e.g., in simulating farmer behaviour (e.g., Appel and Balmann, 2019; Huber et al., 2022). Also the use of serious games allows to gather more varied data on decisions alongside socio-environmental and farm structural characteristics. In addition, insights in human behaviour (e.g., in cognitive biases) gained by different scientific disciplines such as psychology or sociology could be fruitfully integrated.

Secondly, in survey data, the problem of strategic behaviour arises (Goodhart's law): Once a measurement becomes a target (e.g., environmental attitude measures in a survey as a proxy to tailor payments) it may cease to be an appropriate measurement as farmers may start responding strategically to survey questions, e.g., underreporting their willingness to take part in an agri-environmental scheme. More generally, anything other than observation of actual behaviour can be misleading, but observational data are scarce, difficult to obtain and prone to endogeneity issues such as selection bias.

A crucial third point related to data collection is the consideration of temporal aspects. Do types change over time? If so, how can the necessary data be collected, and what are the implications for policy (see also Landais, 1998; Matus et al., 2013)? Diachronic analysis of farm typologies (see e.g., Davies and Hodge, 2012; Landais, 1998; Valbuena et al., 2015) show that trajectories of change may affect the affiliation to certain types. Longitudinal quantitative studies for farmers are rare or even non-existent, and connecting them to existing secondary data (i.e., farm structural information) can only be done if sensitive information (such as the register number of the farm holding) is available. Data imputation from machine learning approaches could provide a solution to this challenge (Storm et al., 2019). In addition, triangulations of methodological approaches in the development of farm typologies might capture some of the dynamics inherent to farm systems.

While these challenges might not be equally relevant for all purposes of farm typologies, a more comprehensive compilation including a critical reflection on the appropriateness of methods for data collection and analysis would be a valuable next step but is beyond the scope of this article.

4.2.2. Policy formulation and implementation

Addressing target groups in agricultural policy making and thus treating individual farms and farmers differently may support the effectiveness and efficiency of agricultural policy instruments. However, it might also reduce farmers' acceptance of the policy, its perceived fairness and even legitimacy. This aspect is rarely addressed in studies that develop and use farm typologies to define policy target groups.

If at all considered, fairness is often roughly divided into two components – procedural and distributive justice (Vatn, 2015). The latter is most relevant for policy design, as the use of typologies can lead to differentiation of payments or regulations. It can be difficult to assess ex ante which fairness perceptions apply in the context of various societal institutions (Elster, 1992). Perceptions of fairness are known to affect the acceptance and (perceived) legitimacy of environmental policies (Vatn, 2015). Especially in the case of voluntary policy instruments, such as agri-environmental schemes, legitimacy concerns can negatively affect the willingness of farmers to participate (Mettepenningen et al., 2013). In the context of typology use for policy purposes, issues of acceptance, fairness and legitimacy arise when it comes to their use for design, implementation, or evaluation of policies. In these stages, typologies have "tangible" consequences for those affected by policies and their perceptions of fairness and legitimacy gain particular importance. The effects of differentiation on perceptions of fairness have been studied in the context of differentiation relation to effort (Loft et al., 2020) or environmental conditions beneficial to ecosystem service provision (Pascual et al., 2010). However, little explicit attention has been paid to differentiation of the environmental policies based on participants' characteristics, e.g., through typologies.

In an analysis of a spatially differentiated regulation in Denmark, Thorsøe et al. (2017) show how legitimacy was undermined by a failed communication of the science underlying the differentiation in combination with a top-down design and lack of stakeholder engagement. The use of typologies to differentiate payments or regulations may well encounter similar problems. Involving farmers in the formulation and implementation of differentiated policy instruments and communicating the scientific and societal rationale appears crucial. At the same time, Thorsøe et al. (2017) stress that communication and stakeholder involvement are unlikely to make perceptions of unfairness disappear.

Niskanen et al. (2021) and Vainio et al. (2021) investigated the perceived legitimacy of result-based vis-à-vis action-based agri-environmental payments, and found that the former are considered less fair, less equal (indirect differentiation), and thus less legitimate than the latter. This suggests that using typologies for agricultural policy design and implementation might be challenging in terms of perceived legitimacy, as in that case, the deliberate differentiation would go against egalitarian perceptions of fairness.

In extreme cases, perceived illegitimacy may provide incentives to leverage the information asymmetries between them and the regulator regarding the characteristics relevant for type assignment, and thus achieve an individually more "beneficial" assignment than would be relevant in the absence of said asymmetries. This, however, would only affect typology use that actually restricts the applicability (e.g., of regulations) or eligibility (e.g., for payments) of instruments. Conversely, it would not affect the use of typologies to create a more complementary and coherent policy mix where all farms are eligible and affected by the same regulations, but there are incentives tailored to each type that are particularly "attractive" to them and that they are likely to respond to. Acceptance-related challenges point to the need for involving affected actors in the development and use of typologies, so that their role in policy design and implementation is communicated transparently (e.g., El Benni et al., 2023; Hofmann et al., 2023). Thereby, obvious violations of the fairness perceptions of the affected actors could be avoided or at least met with appropriate arguments e.g., highlighting trade-offs between efficiency and fairness that may arise in some contexts (see Markova-Nenova et al., 2023).

4.2.3. Using typologies for improving farm system understanding

When using farm typologies for improving our understanding of the farm systems, one may encounter challenges with respect to their validity, upscaling, and transferability.

Validity of farm typologies can refer to aspects such as i) how well the typology fits its purpose, ii) how well the input data represents the study population (considering, for example, selection bias), iii) to what extent typologies match the set of characteristics predicted by theories explaining a phenomenon (in the sense of predictive validity as defined by Emtage et al., 2007), iv) how well the typology represents observed patterns of decision-making, v) how stable or robust the typologies are towards different statistical procedures or assumptions (e.g., Alvarez et al., 2018), or vi) how sensitive typologies are to changes in boundary conditions (e.g., environmental, or economic changes) or over time.

While some of the reviews explicitly refer to participatory approaches or expert assessments as means to increase the validity of farm typologies (as described in e.g., Alvarez et al., 2018; Emtage et al., 2007; Kumar et al., 2019; Matus et al., 2013) and applied e.g., by Berre et al. (2019) or Assogba et al. (2022), there is room to increase the use, transparency and scrutiny of validation exercises. Only few studies let farmers assign themselves to a certain, pre-defined farm identity (Burton and Wilson, 2006) or self-identity (Wilson et al., 2013). Such "validation" approaches would be an important step in establishing farm typologies that increase our understanding of reality and should be further developed and used in studies addressing policy formulation and implementation.

A second challenge that is closely linked to the validity of farm typologies is their potential to transfer knowledge from a study group to other situations and thus to generalize across individual case studies.[6] Knowledge about recurrent patterns could make empirical results more applicable to decision making in different settings or on a higher spatial level (upscaling). Considering the challenges of validity and the context dependency of data collection (see Section 4.2.1.), the extent to which farm typologies can be used for upscaling and generalization across cases certainly remains an empirical question. A potential solution could be that more farm typology developments build on each other (including nested approaches). This would increase their potential for cross-validation and application.

However, farm typologies are not a silver bullet, and a trade-off between generalization and context sensitivity will remain even with more data and improved statistical tools. Especially since typologies usually need not be binary, but can well be probabilistic (i.e., each farm or farmer is member of a type with a certain probability). Our framework suggests that generalization might not always be the main challenge for the corresponding farm typology (and sometimes not even a necessary one). Thus, the framework provides an orientation for developers and users of farm typologies, and can sensitize them to questions of validation, upscaling, and transferability.

The trade-off between generalization and context sensitivity will become more important as the interactions of farmers with up- and downstream actors in the food value chain become increasingly complex. While e.g., Marshall et al. (2021) show how farmers can be considered to be a nested sub-type within food system typology (see also Fanzo et al., 2020), the consideration of nested and multi-scale spatial hierarchies in farm systems remains difficult, especially due to complex dynamics and feedback loops (Lyle, 2015). Again, the usefulness of food system typologies is an empirical question. However, our framework shows that aggregation, upscaling, and generalization of farm typologies need to be carefully implemented and data as well as methodological approaches should be developed further, documented and transparent.

[6] Transfer of an invalid typology would be meaningless.

5. Conclusion

Understanding how the targeting and tailoring of policy instruments (e.g., payment differentiation or targeted advisory services) can make agricultural policies more effective and efficient is key for a successful transformation towards a sustainable agricultural sector. Farm typologies can play a critical role since they allow for identifying and understanding patterns in heterogeneous structures and processes that determine the impact of agricultural policy incentives. We have reviewed 13 review articles that provide an overview or description of farm typologies, farming styles, or archetypes. We found that understanding farm systems through typologies and using typologies for the development and planning of policies are the two purposes mentioned most often in the reviews. To further analyse the different uses of farm typologies, we developed a framework that helped to identify these main purposes of farm typologies along the different stages of the policy process.

The added value of our framework is that it enables researchers and policy makers to identify to what extend farm typologies have a common motivation, and how linking the purposes of understanding decision-making and the identification of policy target groups could provide mutual benefits. Furthermore, the framework illustrates how such a connection could improve the transferability and validity of farm typologies and thus contribute to improve agricultural policy comparison and learning. Thus, the framework provides an entry point for cooperation and interactions between developers and users of typologies. Finally, developers of farm typologies should consider new data, including behavioural data, and methods such as machine learning and expert validation to increase the robustness of farm typologies.

However, developing farm typologies further and making the best of the two worlds (i.e., improving the understanding of the farm system and contributing to the formulation and implementation of policy instruments) comes with important challenges. First, more data and methods do not automatically improve the usefulness and usability of typologies. The theoretical and conceptual underpinnings of farm typologies become even more pressing with access to more and more differentiated data. Moreover, discussing the acceptance of a policy, its fairness and legitimacy when tailored to specific groups of farms remains an open spot in many studies that identify policy target groups. Finally, we argue that typologies will always have to balance the trade-off between generalization and context sensitivity and that typologies per se are not a silver bullet.

Future research should build on the existing and extensive work on farm typologies and be aware of the specific challenges associated with the use of farm typologies in the policy process. This will increase the usefulness and relevance of farm typologies for agricultural policy making.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

We thank the anonymous reviewers and the editor for constructive feedback on earlier versions of the paper. Open Access Funding provided by Eidgenossische Technische Hochschule Zurich.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2023.103800.

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