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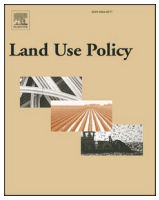

Drivers to adopt agroforestry and sustainable land-use innovations: A review and framework for policy

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ABSTRACT

What influences individuals' decisions to adopt sustainable land-use practices? The drivers of such complex decisions are manyfold. We develop a conceptual framework of the predictors that are external (contextual), related to the innovation, and internal or intrinsic to individuals. This framework can guide the design and evaluation of policies to encourage such decisions and subsequent behaviour. The conceptual framework is based on a literature review that includes empirical qualitative and quantitative analyses, mainly focused on agroforestry and its subtype, silvopasture. We inventoried 207 adoption drivers (predictors) used across the studies reviewed. We grouped these predictors into key concepts along these categories: farm and household characteristics, social environment and institutions, individual objective and subjective factors, and variables related to the land-use practice (knowledge, technical feasibility and economically rational motives). The concepts in the framework incorporate and enhance those proposed in earlier reviews of adoption of a range of sustainable land-use practices (soil conservation, organic farming, conservation agriculture, ecological farming practices, etc.). The framework is also interdisciplinary and comprehensive by including behavioural, socioeconomic and biophysical factors. It is applicable to a range of sustainable farming innovations. It can be used to evaluate policy ex-ante, by assessing what place-based conditions or barriers may need to be addressed through tailored policy instruments, as well as to inform the selection of explanatory variables in ex-post evaluations.

1. Introduction

Identifying what drives adoption of agricultural innovations is a long-standing research and policy question (Dagang and Nair, 2003; Thompson et al., 2023) that is becoming increasingly urgent to transition to climate-smart and sustainable agricultures globally (Meyfroidt et al., 2022). Understanding the potential drivers is instrumental to identify what specifically hinders and favours adoption of sustainable farming practices in a given social and environmental context—a place-based knowledge critical to design and implement policies to promote land use with local to global sustainability implications (Wauters and Mathijs, 2014; Martín-López et al., 2020).

Literature on adoption of agricultural innovations blossomed around four decades ago (e.g. Feder et al., 1985; Feder and Umali, 1993). That on agroforestry bloomed in the 1990s, mostly on the tropics and in Asia and Latin America (Montambault and Alavalapati, 2005). The contrast between the advances in science on agroforestry innovation and the lack of widespread adoption (Jera and Ajayi, 2008; Pagiola et al., 2008, 2007) motivated much of this work (Mercer, 2004).

Typically, empirical studies analyse—either quantitatively, qualitatively, or both—the influence of a set of predictors over an outcome. The outcome operationalises farmers' adoption of a practice at a point in time (measured in terms of, e.g., intention to adopt, first trial and, exceptionally, long-term adoption). The reasons for the (non)adoption of innovation in agriculture, and agroforestry in particular, have been synthesised in several seminal works (Fujisaka, 1994; Mercer, 2004; Pannell, 1999; Pannell et al., 2006; Pattanayak et al., 2003). Efforts to review the myriad drivers of adoption of sustainable farming practices

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more broadly continues to date (e.g. Amare and Darr, 2020; Dessart et al., 2019; Thompson et al., 2023). This understanding is important because it can directly inform the incentive design of agri-environmental policies, among others.

Several reviews (e.g. Knowler and Bradshaw, 2007; Wauters and Mathijs, 2014) have concluded that there are no main predictors of adoption of sustainable farming to be generally applied. This is due, among others, to the variability of place-based practices and social-ecological specificities. Rather, a distinct battery of factors may influence in each case and at each stage of the adoption process. It then becomes necessary to have a clear, synthetic view of what those factors might be, in order to identify with precision what are key drivers in a given context and inform policy design accordingly.

Zooming in on a specific type of sustainable land use can help overcome the challenges of such syntheses while maintaining broad relevance. For example, silvopastoral systems are a type of agroforestry that integrates trees in pastureland. Few articles have analysed the adoption predictors of this practice beyond external characteristics—those explicitly and objectively measurable and predominant in studies from an economic lens, also called *extrinsic* (Osbaldiston and Schott, 2012). Studies that consider internal or *intrinsic* characteristics, such as behavioural or psychological ones are mostly qualitative (e.g., Calle et al., 2009) although there are exceptions (e.g., Frey et al., 2012).

Here we (a) synthesise the predictors used in the literature to understand silvopasture adoption (and more generally of agroforestry) and (b) develop a conceptual framework of drivers of adoption of sustainable land-use practices. This is based on a literature review that includes reviews and empirical literature. The main outcome of our study is the identification and classification of the key factors, variables or constructs (Miles et al., 2014) that can influence sustainable land-use adoption. Because these potential predictors are manyfold, we simplify our conceptual framework by not including relationships or interactions among the predictors, although some of these relationships are discussed in the text. This framework can help inform policy design and implementation strategies for a range of sustainable farming practices and for specific contexts, and systematically review empirical literature to assess whether there are gaps in the coverage of potentially important predictors. A carefully designed approach for literature sampling allows us to highlight factors overlooked in previous research and reviews, such as internal variables, while maintaining an interdisciplinary balance that gives similar visibility to variables respectively predominant in economic, psychology and agronomic studies.

2. Background and scope of the literature review

2.1. Lessons from existing conceptual frameworks

The present review and framework builds on a rich body of earlier reviews that have proposed categories of drivers of the adoption of a range of sustainable farming practices. Thompson et al. (2023), for example, distinguish the following variable groups: socio-demographic, characteristics of the farm and compatibility of the practice, formal institutional, personal behavioural (cognitive, attitudinal and dispositional) and social behavioural variables. Amare and Darr (2020) group factors linked to agroforestry adoption into characteristics of the innovation (e.g. profitability and compatibility with current practices), system level features (e.g. communication, markets, policies and the constellation of stakeholders) and farm household-specific descriptors. While cognate, these two approaches focus on somewhat different practices (the former on "ecological farming practices" broadly, and the latter on agroforestry), and that is the case with most reviews of sustainable land-use adoption.

Several observations can be made from earlier reviews, regarding major groups of variables that are used to explain adoption of sustainable farming practices. Socio-economic/ demographic variables are very often included in empirical studies, but they are not found to be statistically significant in most of them (Thompson et al., 2023). Several reviews highlight that social variables (those that reflect the relation of individuals with their peers, networks and other relevant actors) have received little attention, even less than individual behavioural ones (like attitudes or perceptions), but are considered to have much potential (Sulaiman et al., 2021; Thompson et al., 2023). Further, many authors have underscored non-economic motivations or non-rational (e.g. profit maximization) behaviour, which seem to be better reflected by behavioural variables (like risk tolerance or perceptions; Carlisle, 2016, Dessart et al., 2019, Foguesatto et al., 2020). Dessart et al. (2019) go further and provide specific policy recommendations to encourage adoption by targeting behavioural drivers, which are classified depending on their cognitive distance to the adoption decision. They synthesise what specific drivers from each category are associated with higher adoption and, importantly, how to stimulate them through policy design. For example, accounting for heterogeneity in farmers' dispositional characteristics (attitude to risk and new experiences, environmental concern, etc.), communicating descriptive norms to spur the effect of social factors (following others' opinion or what neighbouring farmers do) or providing social recognition, and increasing awareness of the practices and their costs and benefits.

Reviews have tended to stress certain groups of variables (e.g. mainly behavioural, or mainly socioeconomic). The focus on specific practices (e.g. soil conservation) also determines emphasis on some drivers over others.

A simpler yet comprehensive inventory of drivers can help more immediately policies for sustainable farming innovation. We consider that such inventory should (a) have easily distinguishable, non-redundant and clear drivers; (b) give similar prominence and detail to drivers derived from behavioural, economic and agronomic research traditions; and (c) simplify interactions between drivers, unlike reviews that either place drivers into a hierarchy or are based on specific theories (like the Theory of Planned Behaviour, TPB, where behaviour is preceded by behavioural intention, which in turn depends on beliefs, attitudes and perceived behavioural control). This is what we develop next.

2.2. Scope of the studies reviewed

To map drivers of adoption of sustainable land-use practices, we centred on silvopastoral systems as a case in point, and then broadened the thematic scope to achieve conceptual saturation of types of drivers. Practices scoped ranged from silvopasture to agricultural conservation and eco-innovation more broadly, the latter gathering practices such as for soil conservation, water management, or pollution and energy technologies (see below).

We searched studies in Scopus and Web of Science, in English, using the keywords *adopt**, *agrofor** and *silvopast**, and relevant studies were selected based on the title and abstract. We also searched for silvopasture adoption literature in Spanish and in French. This yielded relevant references of studies in Latin America. While agronomic silvopasture research published in French is abundant, only one reference on adoption modelling was found, which is strictly focused on household income and forestry productivity, and we excluded it for consistency. A snowball sampling continued; we searched further relevant articles within the bibliographies until we reached a saturation point. We excluded grey literature because a preliminary search did not yield relevant case studies additional to those reported in peer-reviewed literature; grey literature on silvopasture about adoption incentives tended to be either of a technical nature or diffusion material for practitioners and adopters, rather than novel research.

We classified reviewed articles into reviews and empirical studies. Among the empirical, we distinguished qualitative (e.g. using interviews or focused-group discussion), quantitative modelling using regression, and other quantitative studies (e.g. using descriptive or correlative statistics). Studies are labelled as *regression* if they sufficiently report model variables, including coefficients and significance test values.

Outcome variables across studies are predominantly binary (e.g. practice implemented or not) rather than continuous (e.g. intensity of adoption). This pattern is similar to that found in other reviews of farming adoption studies (e.g. Thompson et al., 2023). Due to the nature of the outcome variables, the models are typically logistical, and rarely models that allow researchers to represent sequential steps or processes in stages, which we call here *process-based* (such as tobit or selection models).

The literature can be grouped into economic studies, psychological studies, and hybrid (combining both). This classification coarsely indicates whether predictors are external variables (more frequent in economics), internal constructs such as attitudes and perceptions (typical in social psychology and cognitive economics), or a mix of both. To ensure a comprehensive list of drivers from different disciplines we included empirical studies on agroforestry and sustainable agricultural innovation adoption using qualitative methods and quantitative methods other than regression if they (1) analyse motivations and attitudes for conservation behaviour, (2) are based on social-psychology theories and/or (3) refer to the role of livelihoods, which is a topic rarely discussed in other reviews. The selection of studies on adoption drivers is therefore not a representative sample, but instead it aims at diversity and to comprehend approaches that were not included in previous reviews. Hence the emphasis on these topics in our synthesis may appear greater than it is in the average literature.

A total of 79 peer-reviewed studies were identified that met the criteria, which are summarised in Fig. 1 (full list in Supplementary Information C). Studies on adoption of silvopasture include all the empirical papers found until 2015 (21 more empirical peer-reviewed papers were found until 2024, but theoretical saturation was achieved at this threshold) and reviews until 2024 that aim at explaining predictors in developing countries. All review papers on adoption of agroforestry and (sustainable) agricultural innovations have been included. Previous reviews under-represented studies that integrated approaches from psychology, beyond economic rationality, or that use process-based explanations. In order to represent the breadth of approaches, the thematic threshold is set at a broader category of literature on agricultural innovation, but leaves aside adoption of eco-innovation in general (e.g. Kemp and Pontoglio, 2011), unless they had a unique theoretical or sequential approach that was not found in studies of practices closer to silvopasture (Arslan, 2011; Bosselmann, 2012; Woersdorfer and Kaus, 2011).

The literature can be navigated using three classification criteria that correspond to the axes in Fig. 1: the range of practices adopted (*y* axis, from broader to more specific), theoretical (and methodological) approaches (*x*), and approaches to depict the complexity of the process (*z*). The latter indicates whether predictors are assumed to have a varying

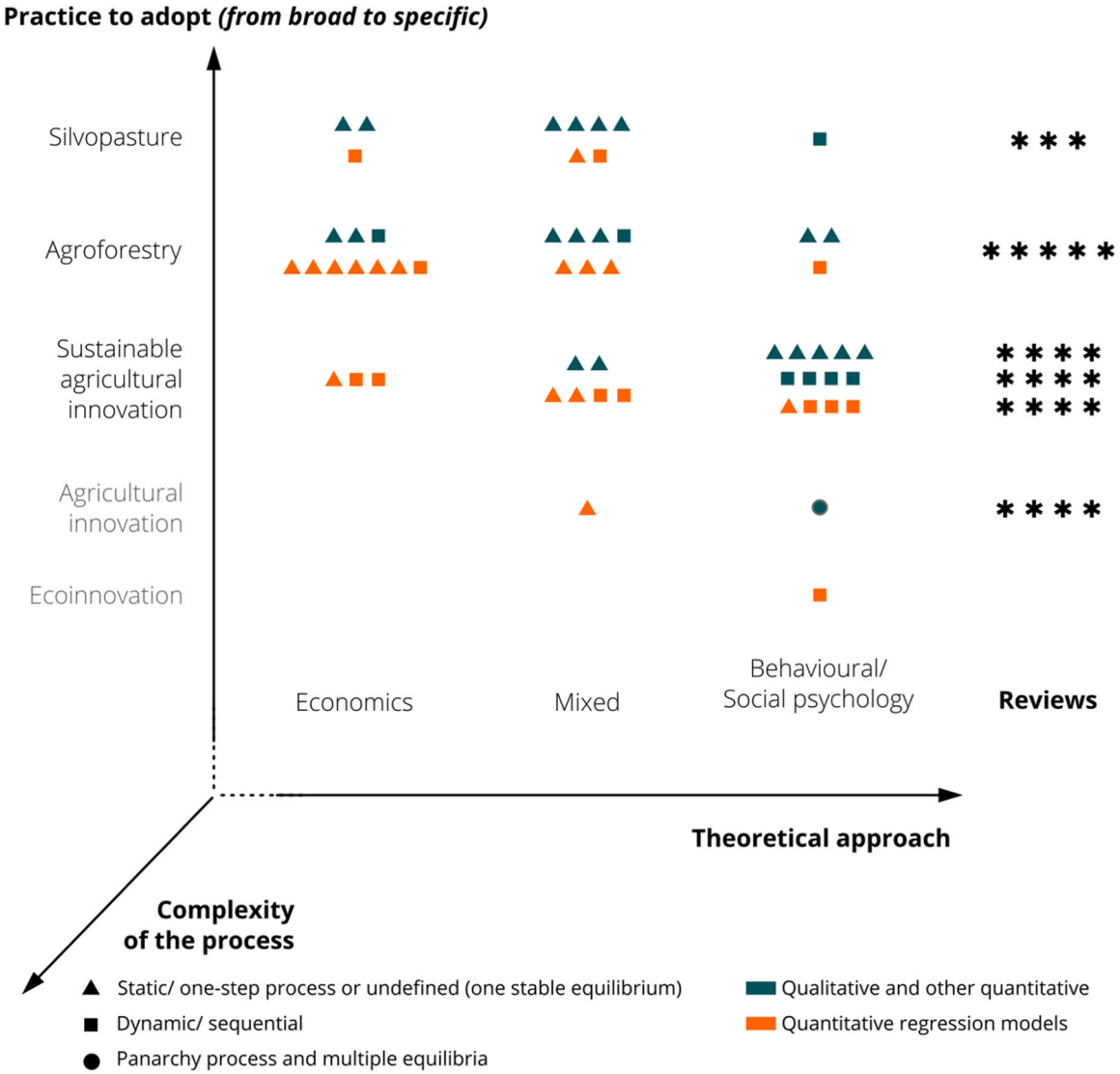

Fig. 1. Scope of adoption studies reviewed, by practice, theoretical approach, and complexity of the process. Each icon represents one study.

impact throughout time. The static view assumes that predictors affect the outcome in a single step and this impact does not change throughout the process of adoption and continuation. Next we provide an overview of each of these classification criteria.

2.2.1. Practices adopted: from agricultural innovations to silvopasture

Silvopasture is a subtype of agroforestry so, as expected, more published studies model the adoption of agroforestry than silvopasture, and this is reflected in our sample. At the other end of the spectrum, sustainable agricultural practices (those whose main benefit is an environmental one) are distinct from more general agricultural innovation (such as yield optimisation practices, e.g. precision farming; Dessart et al., 2019), which are sometimes included in sustainable farming reviews. However, these do not have environmental benefits as the main goal and therefore the framework of what drives their adoption can differ considerably.

Studies on adoption of agroforestry define and measure predictors in highly variable ways and often also the outcomes. Just a few studies model the level of adoption beyond binomial measurements of adoption vs. non-adoption (e.g. Bosselmann, 2012, Zabala et al., 2022). Variables that represent the same type of predictor are often measured in different ways. For example, available labour is operationalised in different studies as the number of males in the household, available on-farm labour, or ratio of adults per child in the household.

Consequently, the diversity of predictors and outcomes in this body of evidence lacks comparability and it would be unreliable to draw more rigorous and generalizable conclusions. Thus although abundant, the published peer-reviewed literature on agroforestry is unsuitable for quantitative meta-analysis due to the reasons already identified long ago by Pattanayak et al. (2003). In turn, the number of studies that regress adoption of silvopasture barely reached twenty by 2024 (e.g. Frey et al., 2012; Jera and Ajayi, 2008; Zabala et al., 2022).

2.2.2. Theoretical approach: economics, social psychology, and hybrid

Empirical econometric studies are more abundant than the rest, and predominantly focused on directly measurable variables of a socio-economic nature (Adesina and Chianu, 2002; Adesina et al., 2000; Amsalu and Degraaff, 2007; Bannister and Nair, 2003; Jera and Ajayi, 2008; Scherr, 1995), farm characteristics such as land (Mangabat et al., 2009; Marenya and Barrett, 2007), or human capital (Casey, 2004). A second body of empirical literature draws primarily from theories in psychology, such as the TPB (e.g. Läpple and van Rensburg, 2011; Lokhorst et al., 2011; McGinty et al., 2008; Wauters et al., 2010). These studies construct predictors as proxies of the abstract concepts specified in behavioural equations.

Some economic studies integrate behavioural constructs in their analysis (e.g. Edwards-Jones, 2007; El Tayeb Muneer, 2008; McGinty et al., 2008). We classify these as studies employing hybrid approaches that address the shortcomings of using only external variables and aim to increase explanatory power by including variables related to bounded rationality, such as the influence of risk, uncertainty, intertemporality on choice, and judgement problems (Gsottbauer and van Den Bergh, 2011). Scherr's (1995) work pioneered this strand of the literature by engaging with the ideas that household livelihood strategies influence adoption of agroforestry, that these strategies may be driven by motivations other than profit maximising, and that individuals' heterogeneity induces highly variable responses. Further, while economic studies predominate in research on agricultural innovation adoption, in adoption of environmental conservation and eco-innovation there are relatively more hybrid examples that include a behavioural approach. This is arguably because environmental studies deal with issues of higher complexity.

2.2.3. Time-wise complexity of the process: from static studies to "panarchy"

Most studies assume a single-step, static process of adoption, arguably due to its simplicity and empirical ease using cross-sectional data. Advances beyond static explanations were summarised as early as 1985 from previous work on adoption of agricultural innovations (Feder et al., 1985) but have not seen much empirical application. These included time-varying elements such as changing preferences after learning. We refer to sequential explanations of adoption as *process-based* models (as opposed to *static* models). These account for temporal dynamics or *"changes in driving forces (…) through time"* (Veldkamp and Lambin, 2001, p.3). Therefore, the outcome can change from participation to adoption, and then to whether the practice is continued. Under this lens, the effect of predictors may be dynamic, influencing the outcome(s) differently at each step of the adoption process. Studies taking this approach often also acknowledge the heterogeneity of adopters and/or of spatial diffusion. Process-based models, e.g. proxied by multiple-step approaches, are less frequent in empirical studies (more so in simulation studies). Among other reasons, they require two or more outcome measurements, or data about a number of decisions or events (such as initial participation in a programme and subsequent success of implementation, like in Zabala et al., 2022).

The cost and difficulties of gathering panel data also discourage empirical studies that represent more complex social-ecological processes such as that of "panarchy" cycles (Gunderson and Holling, 2002). Through this lens, the outcome does not just evolve, but is path-dependent, turns into discontinuance and returns as a new practice with some traits from the previous one. Such framework has been used only qualitatively in this sample of studies (Atwell and Schulte, 2009).

2.3. Adoption decisions embedded in household decisions

The majority of empirical studies of agroforestry adoption conceptualise this decision as "detached" from other household decisions (Amare and Darr, 2020). Yet, decisions to adopt sustainable land-use practices in general, are inherently related to decisions on livelihood strategies (the combined allocation of assets to activities that provide a means for living, and the subsequent portfolio of income sources). It is therefore important to acknowledge that decisions to try new land-use practices —and to continue doing so— are embedded in a broader decision-making context (Fig. S0).

Rural households use their closest natural environment as a source of livelihood, and their decisions directly impact local natural resources and habitat conservation dynamics (Nainggolan et al., 2013). When deciding whether to implement more sustainable land-use practices, farmers and landowners have a wide range of considerations regarding their livelihoods. These decisions are influenced by a number of factors, such as how members of the household perceive the costs and gains of alternative activities, constraints imposed by social norms and human capabilities, perception about alternative income sources, or risk concerns. This implies that decision-making for sustainable land use should not be isolated from the context within which it occurs, especially if the ultimate objective of a policy is to have a long-lasting effect on the natural resources that sustain those same livelihoods.

For instance, decisions for more sustainable land-use practices are made alongside decisions to allocate assets into different activities. From these decisions, some will affect off-farm activities, others on-farm. Both activity categories are influenced by opportunities for income or fulfillment of other goals, which are in turn shaped by external interventions (e.g., policies and programmes to encourage agroforestry). However, only decisions about on-farm/ on-land activities will translate into a land-use portfolio with effects over the ecosystem, which public policy for public goods ultimately aims for. One consequence of this framing of embedded decisions is that a wide suite of drivers needs to be considered to understand and support them.

3. Results: conceptual framework

We present a conceptual framework of drivers of sustainable land-

use practices. We developed this deductively, based on the reviewed literature, and inductively, on the emergent conceptual structures from the empirical studies. Over two hundred predictors were used in the 79 studies reviewed. The reviews often suggested frameworks (see Supplementary Information B and F), but as explained above, we found these frameworks insufficient to cover the breadth of predictors found across the literature. To develop this framework, we grouped into the same concepts, predictors that had been operationalised slightly differently.

We categorised predictors into three blocks (external, related to the practice and intrinsic) and nine broad groups (underlined in Fig. 2): farm and household characteristics (including biophysical and demographic factors), social environment and institutions, policy intervention, knowledge and information, technical feasibility, economically rational motives, and individual characteristics (objective and subjective). In a few of the studies reviewed, some predictors were very context dependent and unlikely to be extrapolated to other studies, therefore these were excluded from this framework. All the predictors in the framework can potentially influence the adoption of sustainable land-use practices, albeit the direction of influence can vary (e.g. like with age or farm size) and so we have not included in the figure the direction of the association with the outcome. We nest the concepts according to general groups. While all predictors may have a relationship with the outcome, these predictors are not all independent from each other and there may be relationships between them (e.g. technical feasibility is related to the perception about the technique's complexity). However, for simplicity, we exclude from the figure any indication of relationships between the concepts across groups, although some are discussed in the text.

Fig. 2 shows groups or categories of predictors in the literature on adoption of sustainable land-use practices. As appreciated, this literature considers a breadth of predictors when modelling attitudinal and behavioural outcomes, albeit with varying frequency (see frequencies within the literature reviewed in Supplementary Information E). These categories are explained next. They are not exhaustive and categories are not fully exclusive, however the description should be sufficient to categorise any further predictors (see examples in Supplementary Information D).

3.1. *External/ contextual*

Farm characteristics comprise land, biophysical characteristics, and quantity of production (current productivity). Variables related to land are endowment and tenure security (status and rights). The biophysical variables usually considered are those related to ecology and geography, such as current land cover(s), land pressure and shortage, proportion of already-cleared land, topography, soil quality, climate and erosion intensity, the area or scale of farm, access by road, distance of plot to home, and physical access to markets.

At the interface between farm and household characteristics are livelihoods: the livelihood strategies and pathways related to the farm-cycle. Livelihood strategies include, from broad to specific, the level of household pluriactivity (livelihood diversity), crop diversity, on-farm income dependence (or similar measures such as ratio of off-farm versus on-farm income), main occupation, main type of farming, major crops, importance of livestock as a source of income, or livestock herd size. Farm pathways include past experience, previous adoption

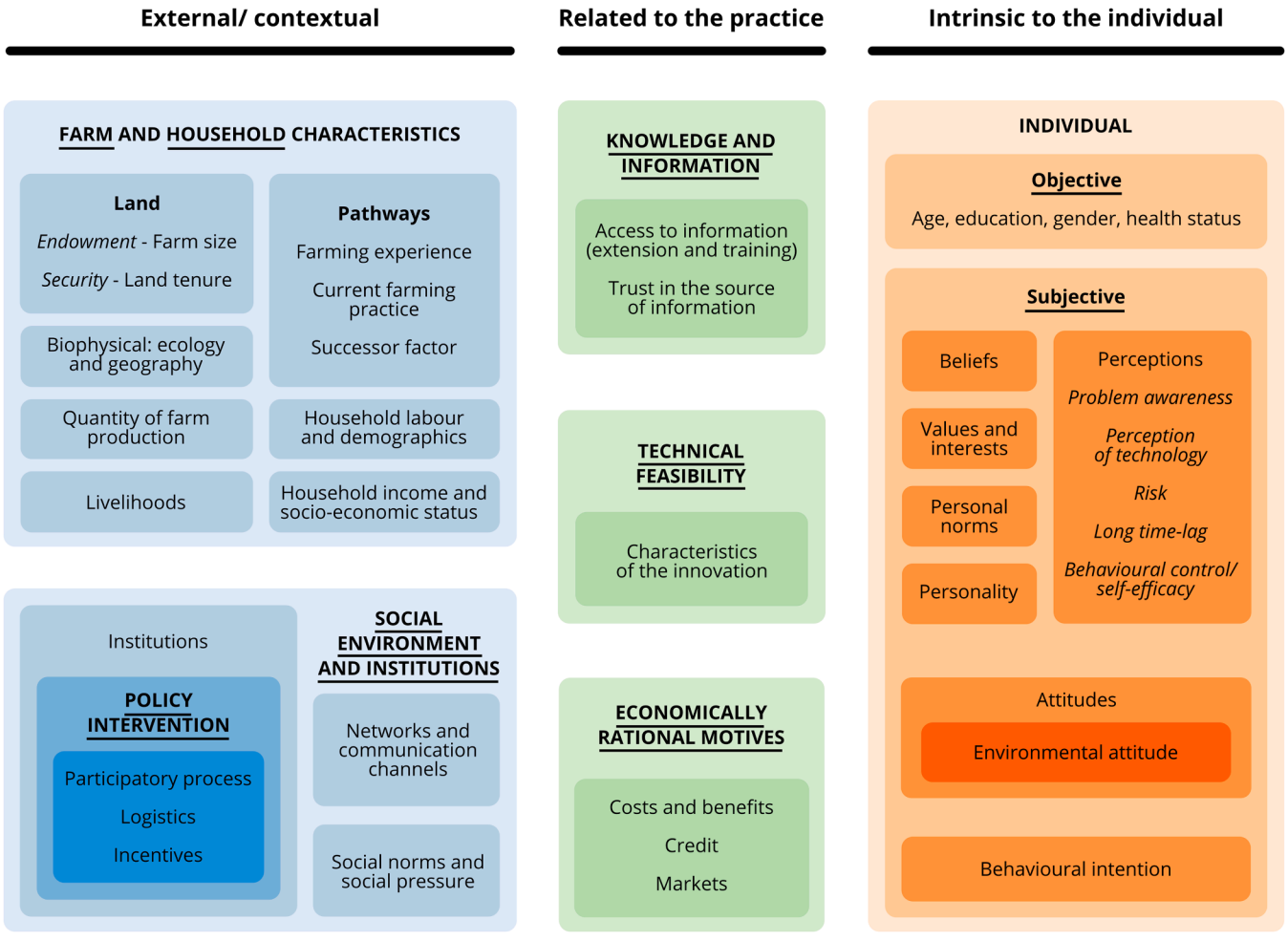

Fig. 2. Groups of predictors in the literature on sustainable land-use practice adoption.

history, current practices, current stage in the farm life cycle, and the future prospect of the farm in the business. They also include the *successor factor* (Wilson, 1997): future expectations about the farm and whether heirs will continue farming. This expectation may be mediated by the length of residency of the farmer; if the family has lived in the location for generations, the farmer is likely to have stronger place attachment and long-term expectations. Consequently, the farm's future in the business may be linked to variables in other categories, namely the age of the head of the household, the number of descendants, and the probability of them staying at the farm.

Household characteristics are divided into demographics and those related to the household economy. Demographic variables include family size and the various ways to measure household age and available labour, like average age of the household, number of youth (usually those below 15, also referred to as students or dependent children), number of elderly (above 65), number of adults (15−64), or ratio of adults to dependants (youth and elderly). Household income and socio-economic status include mean income, wealth level (in the form of livestock or other assets), loans, savings, and remittances. The direction of their effect on adoption (if any) tends to vary across empirical studies, but they are very commonly included.

The review reveals only a few but important factors related to **institutions**, including specific policies to promote adoption of the innovation: institutional transparency, incentives (subsidies, etc.) and facilitation in terms of logistics and participatory processes. The social context and institution category also includes predictors such as the presence of conflict, in the understanding that conflict degrades institutions. No consideration of the broader institutional context was found across studies, such as whether other subsidies may interfere or synergise, but we cannot discard a potential effect, e.g. where farmers have the option to choose from diverse subsidies for different purposes.

The **social context** and how the person engages in social networks are deemed very important to predict adoption. These overlap somewhat with the flow of knowledge (see below). Engagement in networks has been operationalised in studies as participation in collective action events, membership of associations, contacts outside the community, and cosmopolitanism. Social influence (norms and pressure) can be divided into what others do (descriptive norms), what others think one should be doing (injunctive norms), and an individual's willingness to keep social cohesion. On *what others do*, variables include presence of the technology among peers, rate of neighbour participation, *'follow the leader'* attitude or attitude of trusted friends or influencers. *What others think of the self* include aim to keep a public image or status, whether the person is accepted in the community, showing one's environmental commitment to others, being highly perceived by others, and satisfying landscape users.

3.2. Related to the practice

Knowledge variables capture the amount, quality and flows of information that the individual has access to. These affect the acquisition and enhancement of skills to command the innovation. Information usually increases perceived feasibility and reduces perceived complexity of the technology, ultimately affecting self-efficacy (the confidence in one's own capacity and the persistence in the face of challenging tasks; see below). Knowledge variables are divided into access to information and trust in the source of information. Access to information is operationalised in ways such as access to technical assistance; attendance at meetings, workshops, training courses, etc.; contact with extension agents and research institutions; or frequency of consultation with advisers. Trust in the source of information includes one's perception about the sustainable innovation scheme and about the person presenting it, the competence of those administering the programme, and source(s) of information about the technology.

The **technical feasibility** of the innovation depends on its complexity, whether the materials are readily available and suitable (e.g. seeds), and whether its use is known by or familiar to the potential adopter. It is also crucial that the innovation is compatible with farmer's previous experience and knowledge and with farm priorities and practices and current farming practices. These technical characteristics are mediated by flows of knowledge and by internal variables, to shape the perception of the technology (see below). Current farming practices (earlier in Farm characteristics) also determine how compatible the new practice may be.

Variables related to **economic rationality** are divided into cost and benefits of the practice (profitability), access to credit, and macroeconomic context (markets). The first includes standard financial considerations such as cost, amortisation time, opportunity costs, and comparative advantage with respect to the activity which will be superseded (if any). The macroeconomic context includes the price and demand of products associated to the practice and also to products relevant to opportunity costs.

3.3. Intrinsic to the individual

Objective **individual characteristics** are those conventionally considered in econometric modelling of individuals' behaviour: age, gender, marital status and education. These are widely discussed in previous reviews. Health status is useful to understand capacity and labour availability, which determines how much effort a person can do, although it is rarely considered in studies.

Individual subjective variables comprise perceptions, attitudes, and motivations. These are shaped by beliefs, values and interests, personal norms, and personality. While apparently similar, it is important to distinguish these concepts with precision. *Beliefs*, *values*, and *personal norms* comprise ideas such as stewardship motivation, doing what is considered right, not feeling guilty about one's own choices, cultural values, fulfilling various livelihood welfare objectives simultaneously, individual aspirations, plans for the future, and *psychic income* from the activity (Arslan, 2011) such as personal satisfaction, happiness, well-being and emotional benefits arising from performing the activity (sometimes captured as warm glow).

Perceptions may be about many subjects, also those in the earlier categories. These include awareness of the seriousness of the problem (sometimes measured as exposure to the problem), perception of the technology, perception about time-lags and time-discounting (particularly important for activities with benefits after a certain period, like tree planting), risks perceptions (about changing prices, natural catastrophes, and uncertain benefits), and self-efficacy.

Perceptions of the *benefits of the technology* include whether it is worth trialling, whether the innovation promotes a farmers' objectives, its comparative advantage versus current practices, whether it is functional and effective (it works), and perception of immediate profitability. The perception of a technology *over time* is also critical for continuance: how it is perceived after adoption, and whether the practice is adaptable to specific or to changing farming conditions.

Attitudes may be towards risk, the environment, information gathering, management styles, confidence in interpreting information, experimenting, and regarding engagement with policy instruments. Notably, attitudes and behavioural intention can be discussed as either predictors of behaviour or the actual outcomes modelled in empirical studies. The former occurs where a particular theory of behaviour is applied, such as TPB. The latter occurs where observing behaviour is not feasible in the context of the study, and attitudes or intentions are elicited instead.

Psychological, cognitive, and motivational variables (individual subjective) require using abstract constructs in psychological tests or the use of stated values. Both features are a source of uncontrolled variability that generates uncertainty in empirical research, therefore many studies exclude them. However, their power to predict behaviour is potentially very high and it is imperative that these are not overlooked.

4. Discussion and application

Understanding what can affect adoption is instrumental to select an appropriate set of key variables in empirical analysis. It can also support discussion of how the affecting factors can be influenced through policy. This comprehensive and structured inventory advances in a number of ways earlier reviews about adoption of silvopasture (e.g. Dagang and Nair, 2003, on Central America) and agroforestry (e.g. Pattanayak et al., 2003; Amare and Darr, 2020, on Sub-Saharan Africa). It does not have a geographic focus, and it provides a structured framework of the possible predictors. Future work will help overcome potential bias derived from analysing literature in English only.

Two decades after the key review by Pattanayak et al. (2003), further evidence has contributed to a better understanding of agroforestry adoption processes. In particular, more recent studies have included behavioural theories and internal variables as well as process-based explanations. These have uncovered the importance of predictors previously ignored, and have also helped scholars begin to distinguish the role of predictors at different stages.

The internal (intrinsic) variables are cognitive and to a great extent, subjective; they respond to an individual's mental processes, which can usually be measured only via statements from the respondent. The relationship between internal variables and behaviour is abundantly addressed in psychology models, such as those based on expectancy theories of behaviour (e.g. TPB), diffusion of innovations or Unified Theory of Acceptance and Use of Technology (see Zabala, 2015; Meijer et al., 2015; Rosário et al., 2022). However, the empirical application of these constructs in agroforestry adoption and conservation practices in farming is still less common (Fischer and Vasseur, 2002; Lokhorst et al., 2011, Meijer et al., 2015). This is plausibly due to the harder methodological challenges posed by internal variables (Blazy et al., 2011; Meijer et al., 2015). The present framework strives to give similar weight to both, to promote balance in future practice and empirical research.

The framework helps us identify drivers that affect decisions to adopt sustainable land-use practices. For example, having an appropriate and safely tenured plot of land and perceiving that benefits (also non monetary) outweigh the costs. If absent or unfavourable, any of these drivers could become a barrier. This inventory of factors that influence decisions can be used as a checklist for ex-ante policy design and assessment. As an example, in a given context land security may not be an issue because land ownership is secure through reliable institutions, whereas the main problem might be the lack of information. Accordingly, a policy intervention in that context may focus on providing this information from a trusted source. In other cases, farmers might have knowledge and self-efficacy regarding the new practice, but no savings to buy materials. In such cases, an intervention that provides access to credit may be the leverage.

The present framework does not indicate the interlinkages between these variables, other than the thematic nesting. This is to avoid excess complexity; this structure is parsimonious and sufficient for policy evaluation and to help researchers identify what variables to assess. To determine adoption drivers in empirical models, it is important to acknowledge and consider what are key predictors and how some mediate or interact with others in their influence over adoption. For example, in a review of farmer decision-making about agroforestry, Meijer et al. (2015) distinguish extrinsic and intrinsic variables, where the latter (knowledge, perceptions and attitudes) mediate the influence on adoption of the former (characteristics of the farmer, the external environment and the innovation). Amare and Darr (2020) in contrast, propose that the household context is the closest influencer of a given decision to adopt, and this in turn is affected by system-level features and, more broadly, by the characteristics of the innovation.

Another important consideration to explain what drives adoption is that adoption is usually a process in stages, with outcomes potentially varying across steps (e.g. from an initial binary outcome of "participation in a pilot trial" to a continuous "hectares of trees grown"). These stages as well as the intensity of adoption (rather than a binary observation of yes/ no adoption) need to be distinguished to understand the influence of drivers (e.g. Amare and Darr, 2020). This has been highlighted for long, but empirical application continues to be scant.

Carlisle (2016) is most explicit on this point, suggesting that early adopters, potential and uninterested non-adopters may encounter different motivations and barriers to adopt. Consequently, the strength of influence of each predictor in the framework may depend on the stage of the process, from early to late adoption. Indeed, the complexity granted by predictors influencing differently at each stage of the process might explain partially why no predictors have been found to universally or regularly explain the adoption of conservation agriculture—a caveat concluded by both Knowler and Bradshaw (2007) and Wauters and Mathijs (2014), for soil conservation.

The variability in how and when in the process the outcome is operationalised appears to be a reason for the lack of conclusivity of the influence of predictors, whereby apparently comparable empirical studies may actually model slightly different outcomes. For example, in their review, Piñeiro et al. (2020) find that adoption of sustainable practices (very broadly understood) is much more likely in the short term if there are direct economic benefits, productivity or profitability, whereas in the long term, perceived benefits for the farm or the environment are more influential.

On individual subjective (behavioural) drivers specifically, recent reviews have emphasised the need to choose and adapt socio-psychological constructs that are most suitable to explain innovation adoption in agriculture, such as knowledge, efficacy, trust and awareness (Rosário et al., 2022). The need to measure these constructs robustly with a sufficient number of items has also been emphasised (Foguesatto et al., 2020). These two strategies should further allow empirical studies to achieve more satisfactory explanations of adoption drivers. From these variables, those related to risk perception have been singled out as ones with most explanatory promise (Dessart et al., 2019).

5. Conclusion

When deciding whether to adopt a pro-environmental practice, one can imagine an inventory of drivers that influence this decision. We have mapped and synthesised these predictors for the case of sustainable land-use practices, based on a structured review of 79 peer-reviewed papers, mainly about agroforestry and silvopasture adoption. By including in the framework also predictors that are rarely seen in the literature (such as health status or social environment), our framework can facilitate overcoming current gaps in future adoption studies.

This framework serves as a checklist of all the potential drivers that may affect a specific practice in a specific context. This will enable practitioners and researchers to identify what predictors to use to explain adoption *ex-post*, or to conduct a comprehensive *ex-ante* assessment of what levers to incentivise and barriers to overcome, among other uses. A systematic, comprehensive synthesis of these predictors—as presented here—may be useful for further research on uptake and for developing and adapting adoption programmes.

Many frameworks have been proposed that explain, to great extents, the adoption of sustainable farming. The one we present here goes beyond existing frameworks in the following ways: a) it encompasses in a structured way, all the factors and concepts presented in earlier frameworks, b) it gives visibility to factors often overseen, particularly behavioural (individual and social), c) it conceptualises these factors within the broader decision space of households, and d) it guides practitioners to pre-empt potential challenges to implement adoption facilitation programmes, by highlighting relevant drivers and emphasising what needs to be in place for adoption to happen (and inversely, what may become a barrier to adoption if absent).

The latter point suggests a reformulation of the aims of ex-ante policy evaluation. Instead of (or complementary to) aiming to appraise the

potential effects of a given policy, we suggest evaluating the pre-conditions that would facilitate its implementation: whether certain drivers are present in the specific case(s) and, if absent, how severe that might be and how it can be mitigated.

Declaration of Competing Interest

The authors have no conflict of interest to declare.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2025.107468.

Data availability

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

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