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Governing spillovers of agricultural land use through voluntary sustainability standards: A coverage analysis of sustainability requirements

Gabi Sonderegger [a,b,*], Andreas Heinimann [a,b,c], Vasco Diogo [d], Christoph Oberlack [a,b]

[a] Centre for Development and Environment, University of Bern, Switzerland
[b] Institute of Geography, University of Bern, Switzerland
[c] Wyss Academy for Nature, Switzerland
[d] Swiss Federal Research Institute for Forest, Snow and Landscape Research (WSL), Birmensdorf, Switzerland

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ABSTRACT

Voluntary Sustainability Standards (VSS) are prominent governance instruments that define and verify sustainable agricultural land use at farm and supply chain levels. However, agricultural production can prompt spillover dynamics with implications for sustainability that go beyond these scales, e.g., through runoff of chemical inputs or long-distance migrant worker flows. Scientific evidence on the governance of spillovers through VSS is, however, limited. This study investigates the extent to which VSS regulate a set of 21 environmental and socio-economic spillovers of agricultural land use. To this end, we assessed the spillover coverage in 100 sustainability standards. We find that VSS have a clear tendency to cover environmental spillovers more extensively than socio-economic spillovers. Further, we show how spillover coverage differs across varying types of standard-setting organizations and VSS verification mechanisms. Finally, we discuss the role and limitations that VSS can have in addressing the revealed gaps.

1. Introduction

With rising global demand for food, feed, and energy, agricultural land use has become pivotal in causing and addressing many pressing sustainability challenges, such as biodiversity loss, climate change, deforestation, and human rights violations (IPBES, 2019; IPCC, 2020; IRP, 2020). Governments, civil society, and businesses are developing governance interventions to promote sustainable agricultural production and supply chains (Garrett et al., 2021; Lambin et al., 2014). Among these, Voluntary Sustainability Standards (VSS) have become a prominent type of market-based supply chain intervention (ITC, 2021a; Meier et al., 2020). VSS are "voluntary, usually third party-assessed (i.e. certification) norms and standards relating to environmental, social, ethical and food safety issues, adopted by companies to demonstrate the performance of their organizations or products in specific areas" (Lamolle et al., 2019, p. 265). They are developed by different types of standard-setting organizations, including NGOs (e.g., Fairtrade), companies (e.g., ADM Responsible Soybean Standard), governments (e.g., China Green Food), or multi-stakeholder initiatives (e.g., Roundtable for Sustainable Palm Oil). Typically, agricultural VSS grant certifications at the level of production units (plot, farm, or concession) and producer groups, but increasingly also at other supply chain stages.

Syntheses of evidence of on-the-ground impacts of VSS have shown mixed results, revealing different challenges related to the design and implementation of VSS (Blackman and Rivera, 2011; DeFries et al., 2017; Johansson, 2012; Meemken, 2020; Oya et al., 2018; Traldi, 2021). One of the key challenges regarding VSS design is spatial scale mismatches (Tscharntke et al., 2015). These arise when the spatial scale at which VSS seek to foster good practices are incongruent with the scale at which sustainability issues occur (Cumming et al., 2006; Folke et al., 2007; Galaz et al., 2008; Tscharntke et al., 2015). Spillover processes, which are prompted by farm-level practices and have positive or adverse sustainability impacts in near or distant locations, are situated at the core of this VSS challenge (Meyfroidt et al., 2020). A wide range of scientific knowledge demonstrates the relevance of spillovers to sustainability beyond the farm level (Diogo et al., 2022). Cunha et al. (2012), for instance, showed that pesticide spray drift from citrus orchards in Spain can pose significant risks to surrounding aquatic habitats, pollinator populations, and rural communities. Marks and Miller (2022) point to the spread of agriculture-driven air pollution in Thailand, crossing both urban–rural and jurisdictional boundaries. Deininger and Xia (2016) found evidence of positive spillovers from

* Corresponding author. Centre for Development and Environment (CDE), University of Bern, Mittelstrasse 43, CH-3012, Bern, Switzerland.
E-mail address: gabi.sonderegger@unibe.ch (G. Sonderegger).

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large farm establishments in Mozambique on nearby small farms in terms of access to inputs, knowledge, and work opportunities. Being confined to a certain scale of implementation, VSS and other types of supply chain interventions create "islands of good practice" (UNDP, 2019, p. 12), potentially neglecting spillover processes that could support or undermine their sustainability objectives. As a result, the need for governance instruments that are capable of addressing sustainability outcomes beyond farm and supply chain levels has been increasingly recognized (Glasbergen, 2018; Parra-Paitan and Verburg, 2022; Tscharntke et al., 2015).

Despite this importance of spillovers for agricultural sustainability, VSS practice and research has, so far, paid limited explicit attention to spillovers of agricultural land use (Meemken et al., 2021). Related ongoing scientific debates have evolved around indirect effects of VSS adoption (Heilmayr et al., 2020; Heilmayr and Lambin, 2016; Schleifer and Sun, 2020; Smith et al., 2019) and the implementation of VSS in telecoupling contexts, in which land systems are connected across distances (da Silva et al., 2019; Eakin et al., 2017; Garrett and Rueda, 2019). In this emerging field of research, a comprehensive assessment of environmental and socio-economic spillover processes that are triggered by agricultural land use and their regulatory coverage by VSS is currently lacking. There is no evidence of the extent to which existing VSS are already regulating spillovers of agricultural land use and of how this varies across different VSS systems (e.g., private vs public standards). Such knowledge is needed to trigger and inform a critical discussion on the potential role and possibilities of VSS in addressing spillovers, as well as to develop complementary mechanisms to effectively govern them.

This study addresses these gaps by investigating the role of VSS in governing spillovers of agricultural crop production. We ask: 1) To what extent do VSS requirements regulate different types of spillovers? 2) Which VSS characteristics are associated with a higher/lower degree of spillover coverage? We address these questions in four steps. First, we propose a conceptualization of agricultural land-use spillovers tailored to VSS (Section 2). This includes a working definition and its operationalization through a literature review to identify the major types of environmental and socio-economic spillovers. We distinguish 21 spillover processes. Based on these categories, we then conduct a coverage analysis of 100 VSS related to agricultural production, using the Standards Map database of the International Trade Centre (ITC) (Section 3). Accordingly, we assess the extent to which VSS regulate this set of 21 spillover processes, investigate their coverage for environmental and socio-economic spillovers, and explore the linkages between spillover coverage and different VSS characteristics (Section 4). Finally, in Section 5 we deliberate the relevance of addressing spillovers of agricultural land use in research and policymaking, and thereby critically discuss whether VSS can and should address a broad range of spillovers.

2. Conceptualizing spillovers of agricultural land use

Various disciplines have brought forward different concepts that reference spillovers of land use and related cross-scalar processes, as well as their impacts (Lewison et al., 2019; Liu et al., 2018; Meyfroidt et al., 2020; Truelove et al., 2014). In this study, we apply an interdisciplinary land system science perspective to define spillovers of agricultural land use. Recent scientific contributions on telecouplings, i.e. distal connections between socio-ecological systems, have drawn particular attention to the spillover concept (Eakin et al., 2014; Liu et al., 2013, 2018; Meyfroidt et al., 2020). Yet, different conceptions of spillovers exist in land system science. Liu et al. (2018, 2013) defined spillover systems in reference to a telecoupling connection (e.g. trade flows) between a sending and receiving system. They describe them as systems that affect and/or are affected by the respective telecoupling process (e.g., by being an intermediate stopover place in commodity trade flows). Meyfroidt et al. (2020, 2018) focused on land-use spillovers, defining them as processes by which direct interventions or changes in land use in one place have impacts on the use of land in another place. Furthermore, in the context of VSS, the notion of spillovers is sometimes also used to refer to the unintended consequences of the adoption and/or implementation of VSS schemes (Oosterveer et al., 2014; Steering Committee, 2012).

For the present study on VSS, we build upon the definition of Meyfroidt et al. (2020, 2018) and define spillovers of agricultural land use as *socio-economic or environmental processes that are triggered by agricultural land use and affect sustainability in near or distant places outside the farm*. They can be manifestations of socio-ecological flows (e.g., of goods, materials, people, species, capital, information) or actor interactions that interlink the certified farm with nearby and/or distant places (Munroe et al., 2019; Sonderegger et al., 2020). Spillovers can be intended or unintended, and have positive or negative effects on human wellbeing and the environment (Bastos Lima et al., 2019; Meyfroidt et al., 2020). In line with the spillover definition proposed by Meyfroidt et al. (2020, 2018), this definition places emphasis on socio-economic and environmental processes that lead to effects in nearby or distant places (rather than the effects themselves). As shown below, we distinguish 21 such processes. It further focuses on spillovers that occur across geographic rather than temporal scales (for information on temporal spillovers, see e.g. Garrett and Pfaff, 2019; Jacobson, 2014). However, the proposed definition noticeably differs from that of Meyfroidt et al. (2020, 2018) in two main aspects. First, we consider spillovers that have implications for sustainability, rather than for land use only. This more comprehensive approach aligns with the broad scope of VSS and their mission to foster sustainability. Second, we consider only spillovers that are triggered by agricultural land use practices. This includes both land use changes and farming practices, but not governance interventions (e.g., policies or programmes affecting land use). We thus do not focus on leakage processes, a subset of the broader spillover notion which are caused by environmental policy interventions (Bastos Lima et al., 2019). In this sense, we also do not account for spillover processes that are triggered by the adoption of VSS (for example, relating to how VSS adoption affects global and local food security (Oosterveer et al., 2014; Schleifer and Sun, 2020) or deforestation in non-certified properties (Heilmayr and Lambin, 2016)). Instead, we focus on spillover processes that are triggered by on-farm practices and assess those spillovers in terms of the extent to which VSS address them. The farm is thereby considered as the reference system to identify spillovers, as it is also the primary unit of intervention of most VSS.

We use the term "spillover" as an umbrella concept and thereby apply a land system science perspective. In this sense, we adopt a comprehensive approach to define and identify spillovers that considers a wide range of processes potentially affecting the sustainability of agricultural land use beyond the boundaries of a farm. We thereby draw on research that explicitly uses the term "spillovers" or describes related phenomena or processes. This allows for the integration of insights from various scientific disciplines dealing with a range of concepts relating to cross-scalar processes and their impacts, such as: economic externalities (Buchanan and Stubblebine, 1962; TEEB, 2018); pecuniary externalities (Shubik, 1971); spatial externalities (in the sense of Lewis et al., 2008; Parker and Munroe, 2007); agglomeration benefits (Richards, 2018); social interactions, including private life, work, and business relationships (Bernard et al., 2014; Janker et al., 2019); displacement processes (Cernea, 2005; Lewison et al., 2019; Meyfroidt et al., 2013); off-site effects (Van Noordwijk et al., 2004); off-stage ecosystem services burdens (Pascual et al., 2017); interregional ecosystem services flows (Bagstad et al., 2012; Koellner et al., 2018, 2019; Schröter et al., 2018; Serna-Chavez et al., 2014); and cross-boundary subsidies between ecosystems and related edge effects (Cadenasso et al., 2003; Polis et al., 1997). We further draw on literature from the field of telecoupling research, which identifies and discusses distant flows and interactions in relation to agricultural production (see e.g., Eakin et al., 2017, 2009; Friis and Nielsen, 2017; Garrett and Rueda, 2019; Rulli et al., 2019; Zimmerer et al., 2018). Finally, Diogo et al. (2022) point to a number of socio-ecological flows and interactions that are triggered by activities at the farm level and affect sustainability outcomes at multiple geographic scales.

We operationalized the spillover concept by combining a review of literature discussing spillover phenomena in agriculture (in the broader sense as described above) with expert feedback and the coding of VSS requirements. Through an iterative process, we identified a set of major types of spillover processes of agricultural crop production (see Tables 1 and 2 as well as Appendix 1 for more details). We then excluded those spillovers that had insufficient coverage in the database from our analysis (as indicated in Tables 1 and 2 and further detailed in Section 3.4). This set of environmental and socio-economic spillovers is intended to support the process of characterizing a broad range of spillovers of agricultural land use, but it is not exhaustive. Although we chose a comprehensive approach to spillovers, the scope of our study did not cover all potential socio-ecological flows and interactions. For instance, spillovers can also occur along different stages in supply chains, e.g., through commodity or monetary flows or supply chain actor interactions (Barbieri et al., 2021; Malik et al., 2020; Sachs et al., 2019; Xiong et al., 2018). However, we did not consider them in this study as there have already been established efforts to investigate them (see e.g., research on Life Cycle Analysis (Guinée et al., 2011; Hellweg and Canals, 2014) and Material and Energy Flow Accounting (Haberl et al., 2004; Krausmann et al., 2017; Schaffartzik and Kastner, 2019)). Hence, as illustrated in Fig. 1, we focus our analysis on horizontal spillovers that affect sustainability beyond scale at the agricultural production stage of the supply chain, rather than focusing on the vertical spillovers along the supply chain. In addition, we did not consider spillovers relating to norms and values as a separate category (Nash et al., 2017). Any farm-related activities have a normative aspect, and furthermore, all VSS requirements are normative. Hence, the transfer of norms and values is omnipresent in all listed spillovers.

3. Materials and methods

We performed a coverage analysis of VSS requirements to assess the extent to which they cover spillovers of agricultural crop production (see Bissinger et al., 2020; Blankenbach, 2020; Elder et al., 2021; Potts et al., 2014 for similar methodological approaches). Using data from the Standards Map database, we followed a three-step approach: VSS selection; VSS requirements selection and coding; and VSS spillover coverage calculation. We conducted the research in an iterative way, with verification processes built into each of these three steps.

3.1. Data source: the ITC Standards Map

The Standards Map (https://standardsmap.org/) is an interactive web platform providing information about more than 300 VSS in the fields of sustainable trade and production (ITC, 2021b). It is administered by the International Trade Centre (ITC), an agency of the United Nations based in Geneva, Switzerland. It covers a wide range of VSS, such as civil-society-led or industry-led private standards, voluntary public standards, codes of conducts, and international reference documents. The Standards Map is the most comprehensive, standardized dataset on VSS available[1], covering 1650 variables per standard. It contains data on the standards' content (i.e., their sustainability requirements, covering environmental and socio-economic sustainability themes such as soil, energy, waste, human rights, labour practices, and economic viability) and their characteristics (particularly their operating system). The data collection, analysis, and publication processes follow a strict quality assurance protocol that involves independent expert reviews and the respective standard organizations. The database is updated biannually (ITC, 2021c).

For this study, we used the raw data files that feed into the online database. We carefully selected relevant variables, and then cleaned and compiled the data in R. Throughout this process, we were in continuous exchange with the ITC team that manages the database, to ensure adequate use and interpretation of the data. Where data was lacking on VSS characteristics, we completed it with information retrieved from the standards' websites and official documents.

3.2. VSS selection

Using the inclusion and exclusion criteria regarding the VSS scope, use, and implementation shown in Fig. 2, we selected 100 VSS from the Standards Map (see Appendix 2). In this process, we identified VSS that apply to the agricultural sector and the primary production stage (n = 145). We then omitted generic VSS, whose product scope goes well beyond agricultural crops (e.g., also covering products such as diamonds or televisions). Furthermore, we excluded VSS that do not have any conformity assessment system in place (e.g., international guidance documents), to ensure that fulfilment of the standards' requirements is verified. Finally, we excluded those VSS that will expire within 2021 to ensure the actuality of the VSS.

3.3. Selection and coding of VSS requirements

To facilitate the comparison of standards, ITC has developed a set of 659 categories of VSS requirements, against which the contents of individual VSS are mapped. More specifically, the ITC's Standards Map team and the respective standard-setting organization review the standard documents in detail and then allocate individual requirements posed in the standards to a unified set of categories. For each requirement category, an additional set of characteristics (e.g., on degrees of obligation or degrees of criticality) is further noted. Examples for categories of VSS requirements regarding water-related issues are "water extraction/irrigation", "quality of water used in production", and "water dependencies and water scarcity".

We reviewed and coded all 659 VSS requirement categories (hereafter referred to as VSS requirements). Thereby, we selected those relevant to our study (n = 445) and assessed their link with different spillovers (see Fig. 3). Taking a similar approach to Bissinger et al. (2020), we excluded overly broad VSS requirements that could not be assessed in terms of their relevance for our study, as well as those not applicable to the agricultural sector or the primary production stage. We further coded VSS requirements in terms of their correspondence with one or multiple types of spillovers of agricultural crop production (cf. Tables 1 and 2 in Section 2, n = 214). We considered a VSS requirement to correspond with a spillover if they implicitly or explicitly target or affect an immediate trigger of the spillover, the spillover process itself, or a direct impact thereof. For example, for the spillover "water flows", examples of relevant VSS requirements include those relating to soil management measures that affect water infiltration (Smith et al., 2016), water extraction and irrigation (Lankford et al., 2020), water reuse and harvesting (Simons et al., 2015), or assessments of risks and impacts on water levels of water resources used (e.g., groundwater). For the spillover "knowledge dispersion", VSS requirements that fed into our analysis were, for instance, relating to the provision of worker trainings (e.g., fostering knowledge transfers across places as workers may apply the newly learned skills and knowledge in their home (Deininger and Xia, 2016; Zähringer et al., 2018)), or the promotion and use of certain production practices and technologies (e.g., potentially being picked up by other farmers through imitation or knowledge exchange (Albizua et al., 2021; Junquera and Grêt-Regamey, 2019)). VSS requirements targeting indirect triggers or indirect impacts of the spillover processes were not considered for the analysis. Two of the authors of this study

[1] Another topically related database is the Ecolabel index (http://www.ecolabelindex.com/), which covers a large number of ecolabels (more than 450 as of December 2021), but presents less in-depth information on the content of the standards and is hence less suitable for our analysis.

Table 1
Environmental spillovers of agricultural crop production.

Spillover category	Spillover	Spillover description	Selected references	Analysis
Water spillovers	**Water flows**	On-farm land changes and/or farming practices changing the quantity of surface runoff/excess water or groundwater/aquifer level, affecting nearby/downstream areas (e.g., through limited water availability or floods).	(Bonsch et al., 2015; Bravo de Guenni et al., 2005; Haddeland et al., 2014; Rogger et al., 2017; Stoate et al., 2009)	☑
Pollution spillovers	**Chemical pollutants dispersion**	On-farm land use changes and/or farming practices leading to the emission of chemical pollutants (e.g., chemicals, gases, particulates, or biological molecules) into soil, water, or air, which are then dispersed to nearby or distant areas.	(Felsot et al., 2011; Harrison et al., 2019; Kros et al., 2011; Novotny, 1999; Sagasta et al., 2017)	☑
	Biological pollutants dispersion	On-farm land use changes and/or farming practices leading to biological pollutants (e.g., GMOs, pathogens (viruses, bacteria, parasites) and pests) that are dispersed to nearby or distant areas.	(Bebber et al., 2014; Belcher et al., 2005; Bianchi et al., 2006; Ceddia et al., 2009; Garcia-Yi et al., 2014; Hanson et al., 2004; Woodcock et al., 2016)	☑
Climate spillovers	**Greenhouse gases dispersion**	On-farm land use changes and/or farming practices affecting levels of GHG emissions or sequestration (CO_2, N_2O, CH_4), with respective (avoidance of) climate change impacts elsewhere.	(IPCC, 2020; Pärn et al., 2018; Reay et al., 2012; Schaufler et al., 2010)	☑
	Microclimatic spillovers	On-farm land use changes and/or farming practices affecting the microclimate in the surroundings of the farm (e.g., through changes in air temperature and humidity levels, as well as local wind pattern).	(Laurance and Yensen, 1991; Smith et al., 2013; Stoate et al., 2009)	☑
Soil/earth spillovers	**Soil dispersion**	On-farm land use changes and/or farming practices affecting the risk of water- or wind-borne erosion of organic and in-organic materials (incl. landslides), which are transported to and impact nearby or distant areas.	(Colombo et al., 2005; Quinton et al., 2010; Sagasta et al., 2017; Smith et al., 2016)	☑
	Land subsidence	On-farm land use changes and/or farming practices affecting the sudden or gradual sinking of the ground surface, also outside of the farm area.	(Bagheri-Gavkosh et al., 2021; Galloway et al., 2016; Galloway and Burbey, 2011)	☑
Fire spillovers	**Fire spread**	On-farm land use changes and/or farming practices affecting fire risk, which can spread beyond the farm, with related impacts.	(Barlow et al., 2020; Bravo de Guenni et al., 2005; Cano-Crespo et al., 2015; Leal Filho et al., 2021)	☑
Ecological spillovers	**Species movement**	On-farm land use changes and/or farming practices affecting the ability of organisms (e.g., free roaming predators, pollinators, birds, plant species) to thrive, move and interact across habitats.	(Blitzer et al., 2012; Luskin et al., 2017; Tscharntke et al., 2005; Woodcock et al., 2016)	☑

coded each of the 445 VSS requirements relevant to our study in terms of spillover correspondence and spillover type, resulting in a percentage agreement intercoder reliability of 92.81%. Their coding results were cross-checked, and disagreements were resolved by discussion. In this process, we consulted ITC's detailed guidance information on the VSS requirements and relevant extracts from the VSS documents. In Appendix 3 and 4, the codebook and a summary of the coding outcomes on spillover correspondence are provided.

3.4. Calculation of VSS spillover coverage

We conducted two consecutive steps of data aggregation to obtain the extent to which VSS cover different spillovers (see Fig. 4). First, we calculated the standards' coverage of the selected VSS requirements. To this end, we combined data from the Standards Map regarding 1) their degree of obligation (i.e., does the VSS requirement need to be fulfilled immediately?) and 2) their degree of criticality (i.e., how critical is compliance with this VSS requirement?). We assigned scores to different degrees of obligation and criticality, distinguishing between three levels of coverage: mandatory coverage (score = 10), optional coverage (score = 5), and no coverage (score = 0). We then used arithmetic mean to obtain scores for the individual VSS requirements. Secondly, for each spillover type we aggregated the relevant VSS requirements scores to calculate the overall spillover coverage of the standards. We thereby used linear aggregation and equal weighting methods, allowing for compensability between the different scores of VSS requirements. These methods are compatible with each other (OECD and JRC European Commission, 2008) and fit the scale of measurability of our dataset (Ebert and Welsch, 2004; Pollesch and Dale, 2015). As the use of equal weight bears the risk of double counting (OECD and JRC European Commission, 2008; Singh et al., 2012), we tested the VSS requirements allocated to the same spillover types for statistical correlation. We then reviewed pairs of high correlation (>0.8 correlation coefficient) and removed the requirements with the lower score if there was a strong thematic overlap between them.

For the calculation of the individual VSS requirements scores in step 1, we considered three different scoring schemes that account for different degrees of obligation and criticality at varied levels of detail (Fig. 5). We discussed the different scoring options with experts from the ITC Standard Map team to identify potential biases. We adopted scoring scheme A, as it retains important information provided by the database (i.e., whether requirements are mandatory, optional, or not covered), while best accounting for the diversity of VSS and sustainability topics covered in the study. The urgency and criticality of VSS requirements are highly dependent on the type of sustainability issue that they address. While some sustainability challenges call for immediate action and are critical to the standard's mission (e.g., child slavery), others might be more feasibly and purposively addressed through a stepwise implementation of the requirements (e.g., recycling). In addition, different standard systems have different approaches to urgency and criticality (Dietz et al., 2018). For example, besides the more classic pass/fail models, standards systems increasingly incentivize continuous improvement and learning (Rainforest Alliance, 2022; Schmidt et al., 2019). A more detailed score gradient (as in scheme B) would thus bear the risk of introducing a bias in our study, as different degrees of obligation or criticality do not necessarily represent a "better coverage" than another but would otherwise receive higher or lower scores in our analysis. Conversely, a more simplified score gradient such as scheme C would give a similar score to both optional and mandatory requirements, thus fully ignoring different degrees of obligation and criticality. In this sense, selecting scheme A represents a trade-off between making use of the detailed information available in the database and its suitability to our study scope and focus. Nevertheless, we performed a sensitivity analysis to evaluate how the selection of the scoring scheme may influence the results of this study (Section 4.2.3).

The resulting VSS spillover coverage scores (VSCS) indicate the

Table 2
Socio-economic spillovers of agricultural crop production.

Spillover category	Spillover	Spillover description	Selected references	Analysis
People movement spillovers	**People displacement**	Farm-related land tenure changes triggering the displacement/resettlement of people (with certain norms and values, demands for resources, demands for/supply of goods and services), with potential sustainability impacts in the host communities.	(George and Adelaja, 2021; Sridarran et al., 2018; The World Bank, 2014; Verme and Schuettler, 2021)	☑
	Worker migration	On-farm employment practices leading to incoming and potentially returning staff and worker flows (with certain norms and values, demands for resources, demands for/supply of goods and services), with potential sustainability impacts in their place of origin/return.	(King et al., 2021; Levitt, 1998; Rye and Scott, 2018; Seneduangdeth et al., 2018)	☑
Social interaction spillovers	**Knowledge diffusion**	Farm-related activities and interactions leading to a diffusion of knowledge from and to external actors (e.g., through informal knowledge-sharing activities, training for workers or other farmers, imitation), possibly affecting farming practices elsewhere.	(Albizua et al., 2021; Besley and Case, 1993; Junquera and Grêt-Regamey, 2019; Pomp and Burger, 1995)	☑
	Institutional development spillovers	Contributions of farm-based actors to the development and/or shaping of institutions, for instance at community level (e.g., community-based natural resource management), landscape/sectoral level (e.g., cooperatives, labour unions) or at policy levels (e.g., elites' formation, marginalization, political self-organization and representation).	(Candemir et al., 2021; Gruber, 2010; Leach et al., 1999; Oberlack et al., 2016; Ostrom, 2010; Saz-Gil et al., 2021)	☑
	Stakeholder interactions	Engagement of farm-based actors in interactions with communities and other external stakeholders (e.g., worker-community-interactions, or community development and engagement processes which the farm initiates).	(Civera et al., 2019; Janker et al., 2019; McManus et al., 2012; Tunon and Baruah, 2012)	☑
Non-material services spillovers	**Non-material services spillovers**	Farm's (non-)provision of non-material services (e.g., learning and inspiration, physical and psychological experiences, supporting identities), with potential effects beyond the farm level.	(IPBES, 2019; Reid et al., 2005)	☑
Livelihood spillovers	**Resource access spillovers**	Farm-related land tenure changes or activities affecting the access of other people to land, natural and/or cultural resources (through non-market mechanisms), with potential impacts on their livelihoods or wellbeing.	(Cernea, 2005; Dell'Angelo et al., 2017; The World Bank, 2014)	☑
	Services and infrastructure access spillovers	Farm-related land tenure changes or activities affecting the access of other people to basic facilities, services and infrastructure (through non-market mechanisms), with potential impacts on their livelihoods or wellbeing.	(FAO, 2012; Lay et al., 2021; The World Bank, 2014)	☑
Market-mediated spillovers	**Agricultural market spillovers**	Farm-related activities influencing the demand, supply and/or prices for agricultural inputs (e.g., consumable inputs, fixed capital assets, financial capital, labour), outputs and post-harvest services, thus affecting other farmers' access to these markets.	(Ali et al., 2016; Brüntrup et al., 2018; Deininger and Xia, 2016; Heilmayr et al., 2020; Prakash, 2011)	☑
	Non-agricultural market spillovers	Farm-related activities influencing the demand, supply and/or prices for non-agricultural goods (e.g., housing, food) and services, for instance through the presence of migrant workers, thus affecting other people's access to these markets.	(Depetris-Chauvin and Santos, 2018; Doyon, 2009)	☒
	Production displacement	On-farm land use changes and activities triggering a geographic shift in agricultural production through market-mediated mechanisms, with potential sustainability impacts in affected production landscapes.	(Lambin and Meyfroidt, 2011; Meyfroidt et al., 2013; Schoneveld, 2011)	☒
Financial flow spillovers	**Incoming licit financial flows**	Farm-related activities triggering incoming financial flows (e.g., loans, credits, or investments), with implications for the potential private, public, and civic financial sources of the respective flow.	(Lowder et al., 2012; Nolte et al., 2016; Shames et al., 2019)	☒
	Disposable income spillovers	The dispersion and spending of the disposable income of farm-based actors, including remittances, affecting local or distant economies.	(Angelsen et al., 2020; Lambin and Meyfroidt, 2011)	☑
	Farm expenditure spillovers	The farm's non-supply chain-related expenditures affecting local or distant economies (incl. payments of taxes and royalties) with respective impacts on local or distant economies.	(de Janvry and Sadoulet, 2009; Lay et al., 2021; Pangbourne and Roberts, 2015; Roberts et al., 2013)	☒
	Compensation and offsetting spillovers	Farm-related compensation or offsetting payment activities, affecting people and economies in nearby or distant areas.	(German et al., 2013; Lamb et al., 2016; Lay et al., 2021)	☑
	Illicit financial flows	Farm-related activities involving incoming or outgoing illicit financial flows such as bribery payments, e.g., to/from politicians or business partners, or tax evasion.	(Anik et al., 2013; Fink, 2002)	☑

extent to which a certain spillover is covered by a respective VSS. A score of 0 denotes that a VSS does not cover a given spillover at all and 10 denotes full coverage of all VSS requirements relevant to a given spillover. We calculated the scores for spillovers presented in Tables 1 and 2 if they were sufficiently covered in the Standards Map, i.e., we did not consider spillovers that were not covered at all or only covered through a very limited number of VSS requirements (≤5). As a result, we did not consider the following spillovers in the data analysis: spillovers of non-agricultural market mechanisms, production displacement, incoming licit financial flows, and farm expenditure. We presented the methodological approach and results to members of the ITC Standards Map team, discussing their validity and potential interpretations.

In response to research question 2, we linked the VSCS with data on VSS characteristics through means of an exploratory descriptive analysis. We thereby focus on the two characteristics of VSS that are most commonly used to distinguish VSS systems (Fiorini et al., 2019; Lambin and Thorlakson, 2018): 1) the type of standard-setting organization (i.e., company-based, public and other private standards); and 2) the verification mechanism used (i.e., third party and non-third party verification). We used data from the ITC Standards Map regarding the

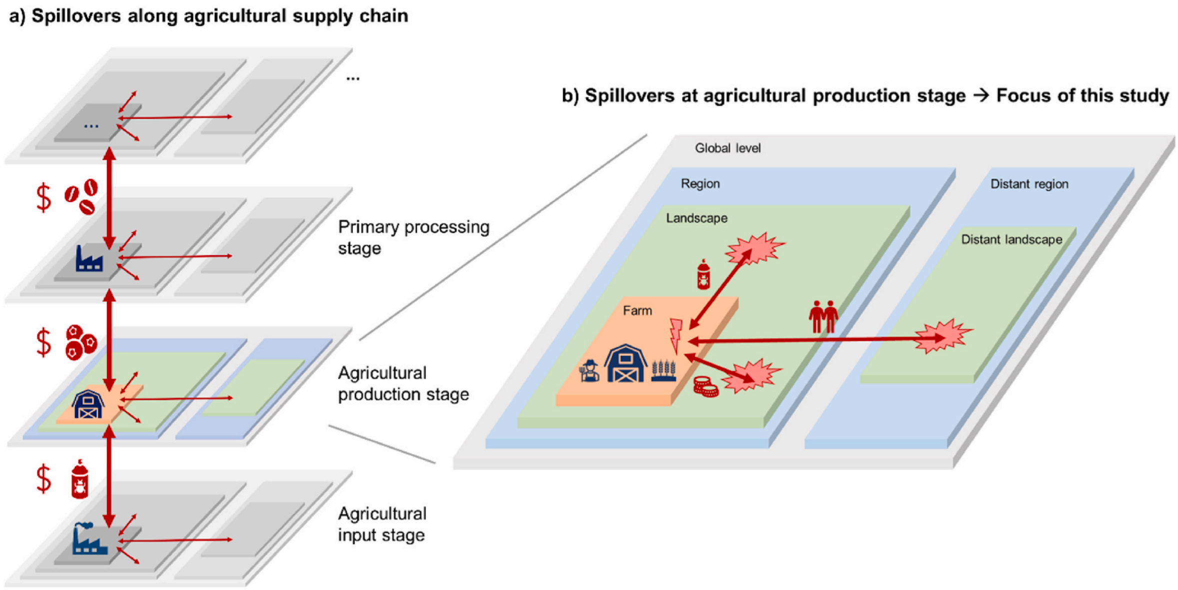


Fig. 1. (a) Spillovers of agricultural production can occur vertically along the supply chain or horizontally across different geographic scales at each stage of a supply chain. (b) This study focuses on horizontal spillovers that triggered at the agricultural production stage and take effect in nearby or distant places through non-supply chain mechanisms (e.g., spillovers relating to pesticide dispersion, worker migration or income spendings). Source: Authors, inspired by Bolwig et al. (2010).

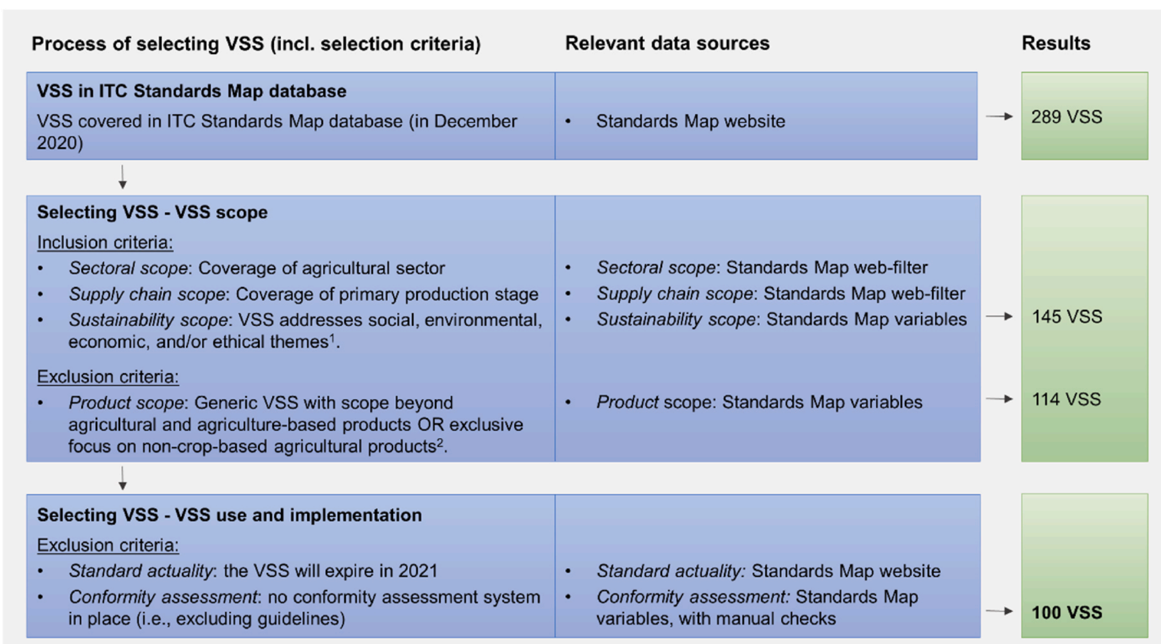


Fig. 2. VSS selection.
[1] We did not include standards that merely focus on product quality, as our research does not focus on spillovers occurring along the agricultural supply chain (see Fig. 1 in Section 2).
[2] This selection was based on the definitions for agricultural crops used for the FAO agricultural census (FAO, 2020).

characteristics of the standards, which we complemented with additional coding based on consultations of VSS documents and the websites of the respective standard-setting organizations.

3.5. *Limitations*

This study covers VSS that vary largely, for example in terms of the nature and intention of the standard-setting entity or the scope of the products covered (see Section 4.1). The Standards Map database has specifically been designed to compare diverse standards. It thus serves the purpose of this study well, providing a birds-eye view of the subject of spillover coverage in VSS. Nonetheless, the interpretation of our results needs to account for the following limitations in our data source and methodological choices:

First, our sample covers a wide range of VSS that primarily includes private sector initiatives, with less emphasis on public voluntary standards (see Section 4.1). Among the private sector-driven VSS, the Standards Map database has a less extensive coverage of company-based initiatives. In this study, we thus do not aim to cover a representative sample of VSS, but rather to make use of the most comprehensive and

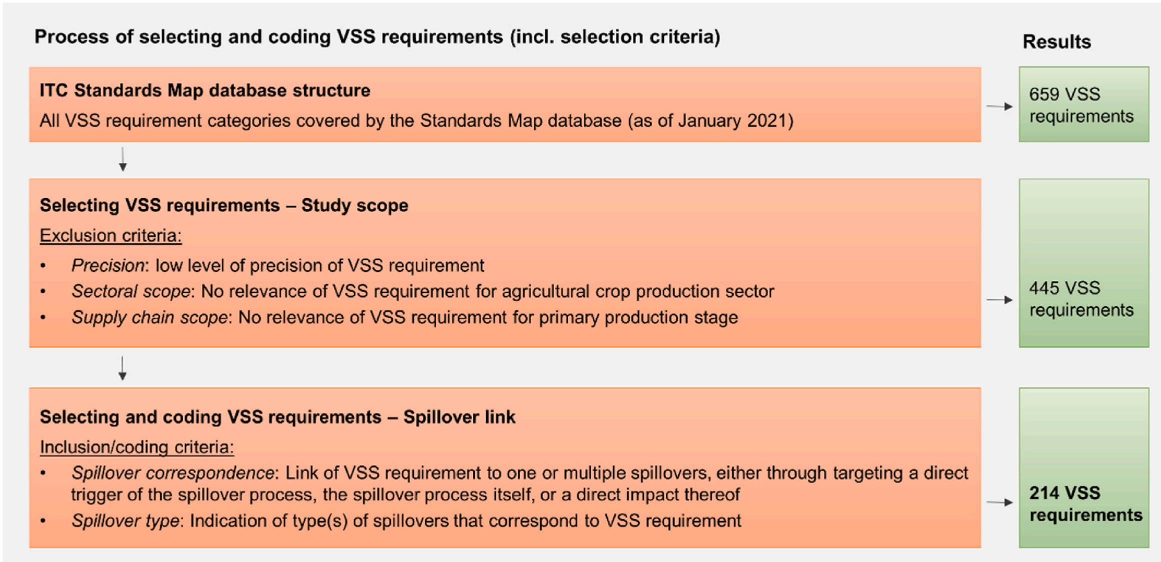


Fig. 3. Selection and coding of VSS requirements.

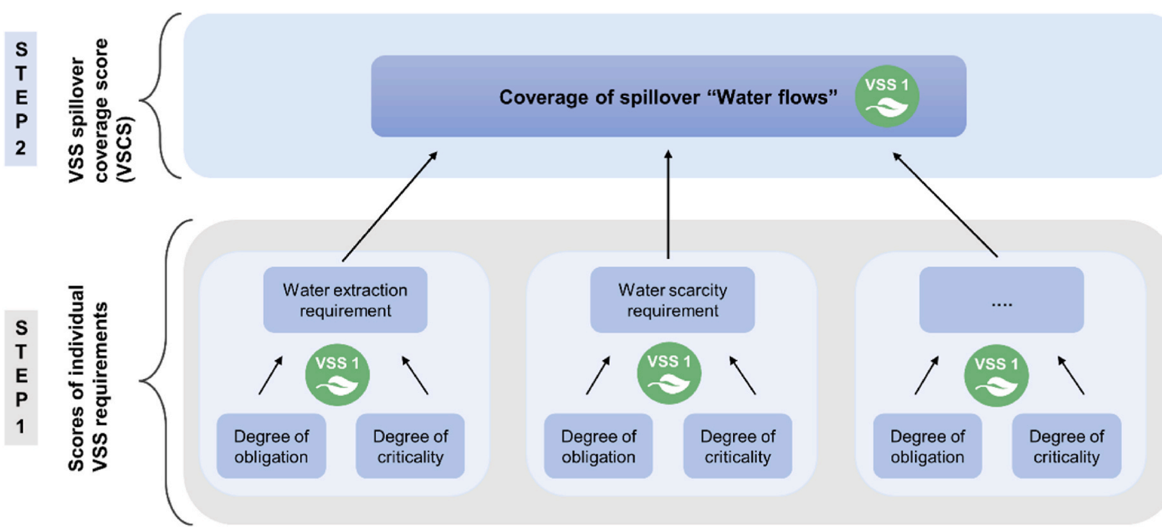
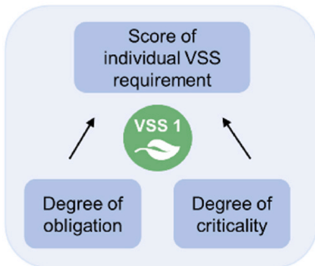


Fig. 4. 2-step approach for calculating VSS spillover coverage, illustrated with the example of the spillover "water flows". Step 1: calculation of the standards' coverage of individual VSS requirements relevant for this spillover, based on their respective degree of obligation and degree of criticality. Step 2: aggregation of the resulting scores of individual VSS requirements to obtain the overall VSS coverage score for the spillover.

extensive global dataset of VSS available to explore the role of VSS in the governance of spillovers.

Second, the ITC database has not been explicitly designed to map VSS content on spillovers, which poses the risk that it may not cover all spillover-relevant contents of the represented standard documents. To assess this issue, we discussed the spillover list with members of the core team of the ITC Standards Map and conjointly deliberated the risk for thematical mismatches with the database. We concluded that this risk is minimal, also based on the wide thematic coverage of the database and regular adjustments of its structure to new standard developments. In addition, during our coding process, we consulted the extracts of standard documents which served as main input to the data presented in the ITC Standards Map, in order to feed our coding decisions with knowledge on the content of the standard documents. Despite these efforts, a certain risk that the database does not fully capture all spillover-related contents of all standards remains. We nonetheless consider the ITC data suitable for this study, particularly given that our study objective is to provide an overview of the spillover coverage of VSS, rather than an assessment of individual standards.

Third, the information that the Standards Map database provides regarding the different types of spillovers varies in both its extent and level of detail. For common regulatory topics (e.g., the use of pesticides in farming practices), information is provided with a greater level of detail. This can result in the presence of multiple variables in the database that address very similar VSS contents. For topics that are less commonly regulated (e.g., incoming financial flows), limited amounts of data points were available. Consequently, the number of VSS requirements used for calculating the spillover coverage of VSS differed considerably across spillovers (as indicated in Fig. 7 in Section 4.2.1). With the applied aggregation method, this can introduce a certain bias in the results. To minimize this risk, we identified the highly correlated variables and removed those with less coverage to prevent double counting. Furthermore, we excluded spillovers with insufficient data availability from our analysis. As a relatively large range of data points for calculating the different spillover types remained, this should be considered when the results are interpreted.



	Scores	Varying degrees of obligation	Varying degrees of criticality	Scores
Scoring scheme A	10	Criteria for immediate action or to be met within 1 year, 3 years, or 5 years	Deal-breaker, major non-compliance, or minor non-compliance	10
	5	Recommendations	Optional compliance	5
	0	Not covered	Not covered	0
Scoring scheme B	10	Criteria for immediate action	Deal-breaker	10
	8	Criteria to be met within 1 year	Major non-compliance	7.33
	6	Criteria to be met within 3 years	Minor non-compliance	4.66
	4	Criteria to be met within 5 years	Optional compliance	2
	2	Recommendations	Not covered	0
	0	Not covered		
Scoring scheme C	10	Criteria for immediate action, to be met within 1 year, 3 years, 5 years, or recommendation	Deal-breaker, major non-compliance, minor non-compliance, or optional compliance	10
	0	Not covered	Not covered	0

Fig. 5. Different scoring schemes for calculating scores of individual VSS requirements, based on different degrees of obligation and criticality. Scoring scheme A was used in the analysis.

4. Results

4.1. VSS sample description

The 100 VSS in our sample differ in terms of scope and implementation (Fig. 6). They have primarily been developed by private standard-setters such as non-governmental organizations, industry associations, and multi-stakeholder platforms. Less common are voluntary standards led by private companies (e.g., codes of conduct) or public institutions. Our sample predominantly covers VSS that use independent third-party auditing schemes to assure compliance, but also includes those applying second-party or first-party verification schemes. The majority of included VSS cover multiple agricultural products (e.g., EU organic farming or Rainforest Alliance), whereas others are specialized in certain product groups or sectors (e.g., Florverde, which focuses on the flower sector) or single products (e.g., Buonsucro with sugarcane or 4C with coffee). The large majority of selected VSS are characterized by not-for-profit standard-setters and the use of labels for communication purposes.

4.2. VSS spillover coverage

4.2.1. Degree of coverage for individual spillover types

VSS regulate different types of spillovers to largely varying extents (Fig. 7). Spillovers of land subsidence have the highest overall degree of coverage (av. VSCS = 4.20) and largest share of VSS with high coverage (28%). VSS mainly regulate this spillover through requirements relating to water extraction and irrigation as well as the conservation of wetlands. The other most frequently covered spillovers are those relating to soil dispersion (av. VSCS = 4.02), water flows (av. VSCS = 3.96), chemical pollution (av. VSCS = 3.79), and biological pollution (av. VSCS = 3.72). Conversely, greenhouse gas dispersion is the environmental spillover type with the lowest average coverage (av. VSCS = 2.68), while fire spread and micro-climatic spillovers present the largest share of VSS with no coverage (22% and 23%, respectively). Pollution-related spillovers are covered extensively by the Standards Map; chemical pollution is addressed by 77 VSS requirements, and biological pollution by 50. In contrast, fire spread and microclimatic spillovers are only addressed by 7 and 8 requirements respectively.

Our analysis has revealed that illicit financial flows have the lowest overall coverage in existing agricultural VSS (av. VSCS = 0.70), with 73% of all analysed VSS not covering any of the related VSS requirements (mainly addressing anti-corruption and anti-bribery requirements). Other spillovers with low coverage are those relating to compensation and offsetting payment schemes (av. VSCS = 0.91) or non-material services (av. VSCS = 1.37). Of the socio-economic spillovers, disposable income spillovers have greater coverage by VSS (av. VSCS = 2.99, with 8% of the analysed VSS having a high coverage).

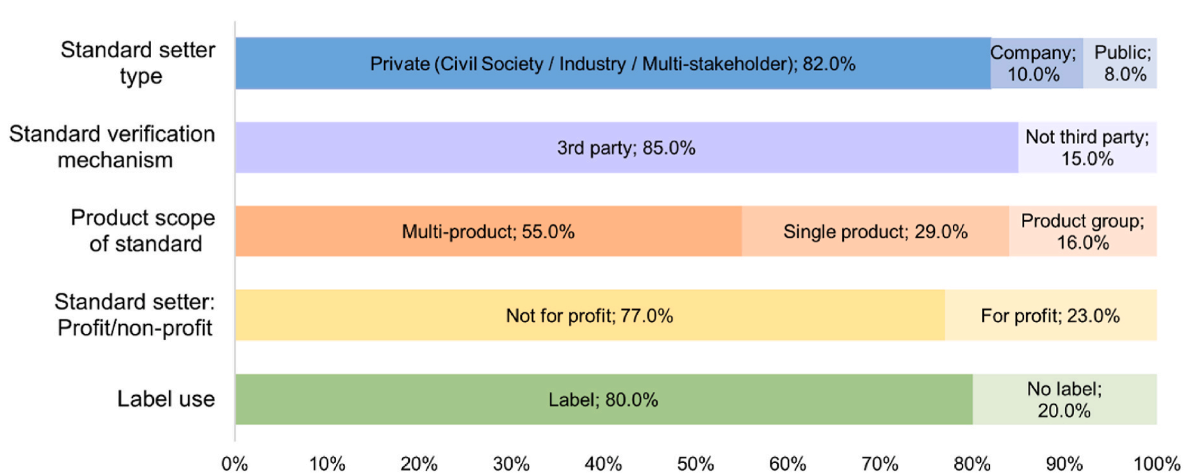


Fig. 6. Relative frequency of VSS characteristics in our sample. (Source: ITC (2021b), completed with information from the standards' websites and official documents and based on calculations by authors).

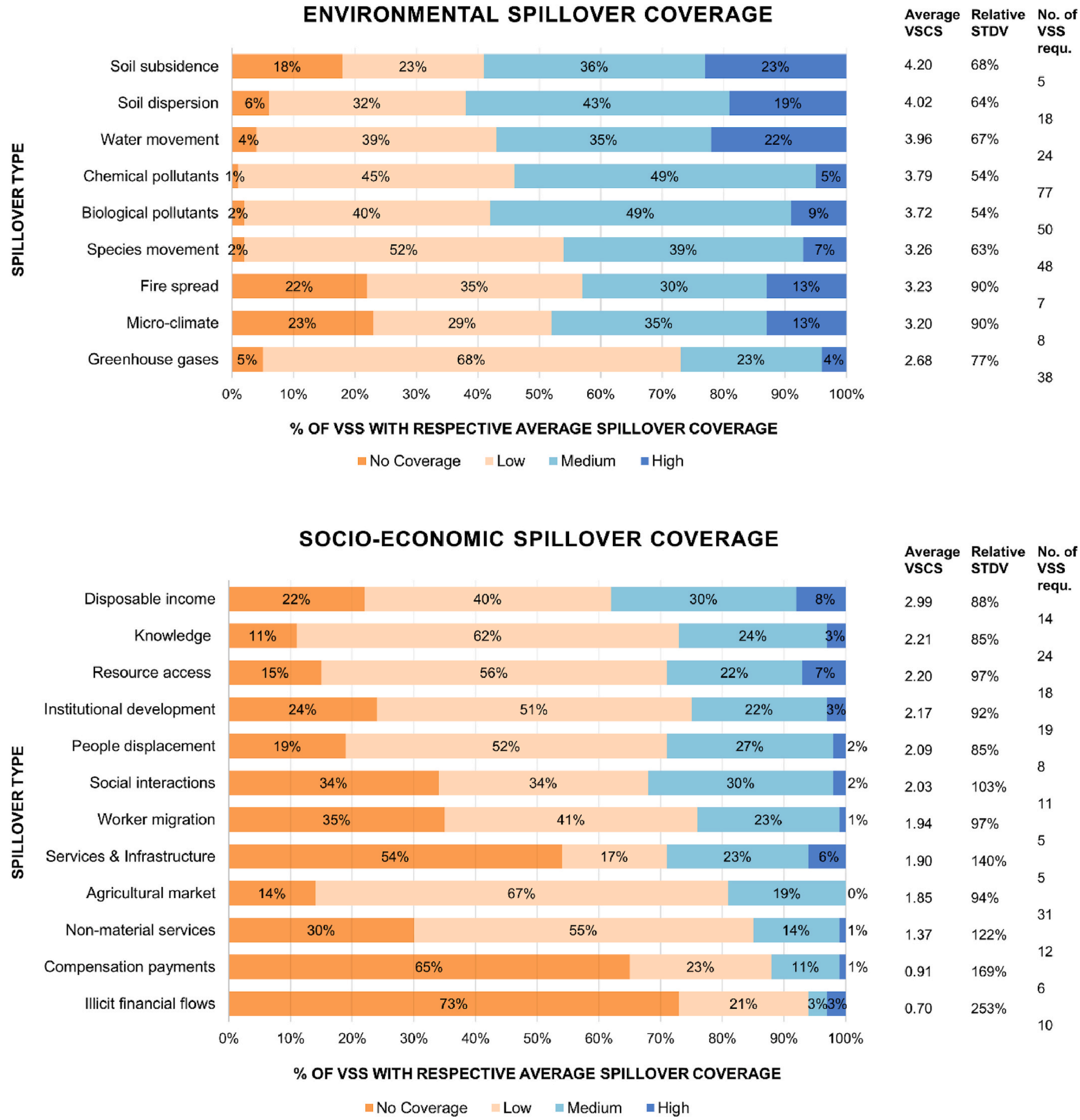


Fig. 7. Relative share of VSS with different levels of spillover coverage, by spillover type and ordered by average VSS Spillover Coverage Scores (VSCS). VCSC scores are grouped into different ranges of coverage: "No coverage": VCSC = 0; "Low": VCSC = 0–3.33; "Medium": VCSC = 3.34–6.66; and "High": VCSC = 6.67–10 (left). The absolute average VSCS, ranging from 0 to 10, as well as the relative standard deviation and the number of VSS requirements available in the Standards Map database, are also displayed (right). (Source: ITC (2021b), based on calculations by authors).

Socio-economic spillovers are in general covered less extensively by the Standards Map database. The numbers of VSS requirements relevant to these spillovers range from 5, for regulating worker migration flows or access to services and infrastructure, to 31, for agricultural market spillovers.

Socio-economic spillovers, in general, have much lower coverage than environmental spillovers in terms of both average coverage score and high coverage shares. VSS tend to score more highly for environmental spillovers (13.3% on average) than for socio-economic ones (3.08% on average). The average share of VSS not covering any of the criteria allocated to socio-economic spillovers is 33.0%, while for environmental spillovers it is only 8.3%. In addition, socio-economic spillovers generally have a larger relative standard deviation of VSS coverage scores than environmental spillovers (relative $STDV_{soc\text{-}eco}$ = 119%; relative $STDV_{env}$ = 70%). This indicates that the heterogeneity among individual VSS in term of spillover coverage is much larger for socio-economic spillovers than for environmental spillovers. One could argue that the lower overall score and high heterogeneity is due to the lower number of requirements allocated to socio-economic spillovers. However, that is not necessarily the case, as there are also environmental spillovers with comparably low numbers of requirements and yet higher overall VSCS scores and low heterogeneity (e.g., soil subsidence).

4.2.2. Socio-economic and environmental spillover coverage

Our analysis reveals a positive association between the average coverage scores of socio-economic and environmental spillovers by individual VSS (Fig. 8). This result implies that most VSS have a similar degree of (implicit) ambition to cover environmental and socio-economic spillovers. Examples of standards that deviate from this trend are the standards of the Wine and Agricultural Ethical Trading Association (WIETA), which predominantly covers socio-economic spillovers, or the RedCert EU standards, which have an increased focus on environmental spillovers.

Fig. 9 indicates the environmental spillover coverage scores for each VSS, in relation to their respective overall coverage score for requirements relating to environmental sustainability (i.e., including both spillover-related and non-spillover-related VSS requirements). We can see that the majority of VSS (80%) have a higher score for environmental spillover coverage than for overall environmental requirement coverage (i.e., they are located above the red-shaded area in the graph), with an average relative difference of 1.07. VSS requirements for environmental sustainability thus show a tendency to regulate management practices that potentially (also) have impacts outside the farm (e.g., water management practices affecting downstream water bodies).

Fig. 10 shows the socio-economic spillover coverage scores for each VSS, in relation to their respective overall coverage score for requirements relating to socio-economic sustainability. In contrast to Fig. 9, most VSS (81%) have a higher score for overall socio-economic requirement coverage than for socio-economic spillover coverage (i.e., they are located below the red-shaded area in the graph), with an average relative difference of 0.73. This might indicate that, in general, socio-economic requirements in VSS preferentially tend to target socio-economic outcomes affecting actors within the farm (e.g., labour rights), rather than socio-economic spillovers.

4.2.3. Sensitivity analysis

The sensitivity analysis (Table 3) reveals that the overall spillover coverage scores are affected by the adopted scoring scheme. In particular, when comparing scoring schemes A and B, we observe that average VSCS are systematically lower for all spillover types in scheme B. This is due to the combined effect of distinguishing gradients scores for varying degrees of obligation and criticality, and particularly, assigning a lower score to recommendations and optional compliance requirements. In contrast, when comparing schemes A and C, we observe that average VSCS are systematically higher in scheme C for virtually all spillover types (except for illicit flows and people displacement spillovers). The

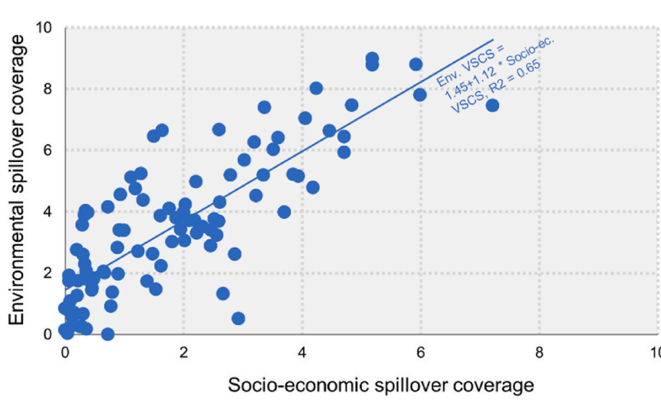


Fig. 8. Average environmental and socioeconomic spillover coverage scores for each VSS. (Source: ITC (2021b), based on calculations by authors).

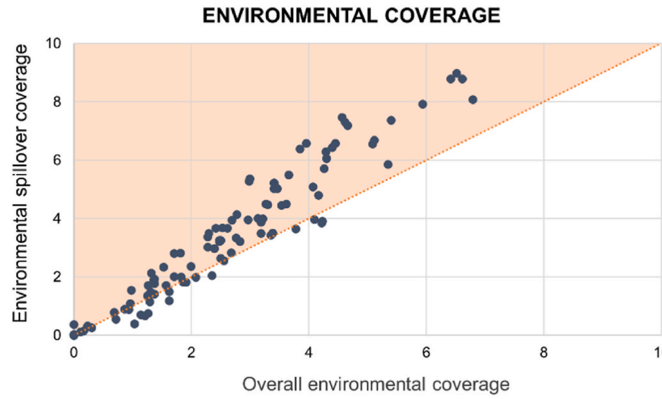


Fig. 9. Environmental spillover coverage score in relation to overall coverage score of environmental sustainability requirements, per VSS. (Source: ITC (2021b), based on calculations by authors).

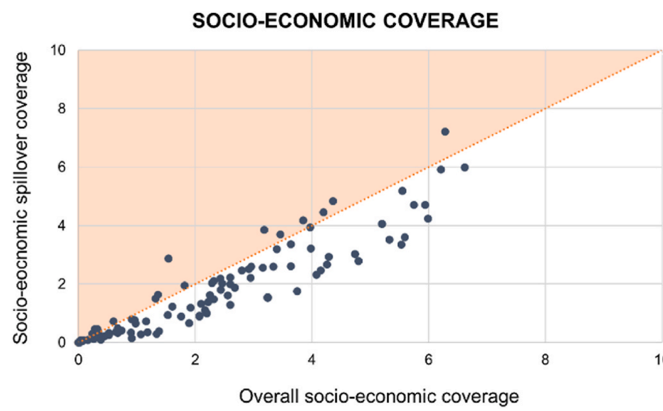


Fig. 10. Socio-economic spillover coverage score in relation to overall coverage score for socio-economic sustainability requirements for each VSS. (Source: ITC (2021b), based on calculations by authors).

absolute magnitude of the relative deviation is, however, much smaller for scheme C (ranging from −3% to 5%) than for scheme B (ranging from −13% to −25%). We can thus conclude that distinguishing varying degrees of obligation and criticality has a larger effect on the overall spillover score than only distinguishing between coverage/no coverage. Despite these results, we also observe that the effect of each scoring scheme on the final scores appears to systematically have roughly the same magnitude and direction across all spillover types. Hence, we conclude that the selection of scoring scheme does not affect our study results in terms of comparing the relative coverage of different types of spillovers among a selection of VSS.

4.3. Linking VSS spillover coverage and VSS characteristics

An explorative comparison of VSCS across different VSS characteristics shows different patterns of VSS spillover coverage (Fig. 11). Different types of standard-setting organizations seem to prioritize certain socio-economic spillovers. Company-based standards (e.g., codes of conduct, n = 10) cover spillovers relating to stakeholder interactions (av. VSCS = 3.27) and institutional development (av. VSCS = 3.18) most extensively. Other private standards (e.g., promoted by multi-stakeholder platforms, industry platforms or NGOs, n = 82)) have a relatively higher coverage of spillovers such as knowledge diffusion (av. VSCS = 2.40) or non-material services (av. VSCS = 1.51). Public standards (n = 8) appear to have a particularly low coverage of socio-economic standards (av. $VSCS_{soc\text{-}eco}$ = 0.26) and they also cover environmental spillovers less extensively than company-based and other

Table 3
Sensitivity analysis results.

Spillover	Scheme A	Scheme B		Scheme C	
	Average VSCS	Average VSCS	Deviation to A (in %)	Average VSCS	Deviation to A (in %)
Water flows	3.96	3.21	−19%	4.06	3%
Chemical pollutants	3.79	3.11	−18%	3.84	1%
Biological pollutants	3.72	3.11	−16%	3.76	1%
Greenhouse gases	2.68	2.17	−19%	2.74	3%
Micro-climate	3.20	2.69	−16%	3.28	2%
Soil dispersion	4.02	3.28	−19%	4.12	2%
Soil subsidence	4.15	3.30	−20%	4.22	2%
Fire spread	3.23	2.59	−20%	3.29	2%
Species movement	3.26	2.71	−17%	3.30	1%
People displacement	2.09	1.81	−13%	2.06	−1%
Worker migration	1.94	1.64	−16%	1.96	1%
Knowledge diffusion	2.21	1.73	−22%	2.24	1%
Resources access	2.20	1.86	−15%	2.20	0%
Services & Infrastructure	1.90	1.43	−25%	1.98	4%
Institutional Development	2.17	1.84	−15%	2.19	1%
Stakeholder interactions	2.03	1.68	−17%	2.05	1%
Non-material services	1.37	1.17	−14%	1.38	1%
Agricultural market	1.85	1.51	−18%	1.87	2%
Disposable income	2.99	2.47	−18%	3.04	1%
Compensation & offsets	0.91	0.68	−25%	0.95	5%
Illicit financial flows	0.70	0.59	−15%	0.68	−3%

private standards. The latter two types of standard setters show similar patterns of environmental spillover coverage, with the exception of spillovers relating to the spread of fire and soil subsidence.

Relating the VSCS to the prevailing VSS verification mechanisms, our study reveals that standards with third-party auditing schemes (n = 85) generally have a higher coverage of spillovers. This pattern is particularly pronounced for environmental spillovers, but also occurs frequently for socio-economic spillovers. Conversely, for illicit financial flows, considerably higher coverage is achieved by VSS with no third-party verification (av. VSCS = 1.53, n = 15) than by those that use independent third-party auditing schemes (av. VSCS = 0.55).

5. Discussion

5.1. Spillovers, sustainable agricultural land use, and spatial scale mismatches in VSS

Growing awareness of interconnectivity between nearby and distant land systems shapes our understandings of current sustainability challenges, as well as attempts to govern them (Challies et al., 2014; Eakin et al., 2017; Munroe et al., 2019; Newig et al., 2020). Therefore, a comprehensive and integrative notion of sustainable agricultural land use requires explicit consideration of the processes that link agricultural practices with impacts beyond the farm in near and distant places, i.e., spillovers of agricultural land use. This study has identified 21 environmental or socio-economic spillovers of agricultural crop production. It builds on and extends previous research on spillovers with specific thematic foci (e.g. land-use spillovers (Meyfroidt et al., 2020, 2018) and deforestation spillovers (Fuller et al., 2019; Heilmayr et al., 2020)) or related concepts (e.g. off-site impacts or externalities (Buchanan and Stubblebine, 1962; Lewis et al., 2008; Van Noordwijk et al., 2004)). It draws on telecoupling research define and conceptualize sustainable agriculture. We hope to contribute to this field by presenting an elaborate, although non-exhaustive, overview of the processes that couple a farm system with other socio-ecological systems, with an explicit focus those that are triggered by agricultural production. This study further also complements recent scientific contributions investigating the presence and distribution of impacts of agricultural production along the supply chain, for example regarding local impacts embedded in international trade flows (e.g., Chaudhary and Kastner, 2016; Dalin et al., 2017; Oita et al., 2016; Qiang et al., 2020; Roux et al., 2021).

The scales of spillovers of agricultural land use can range from neighbourhood to landscape to transcontinental flows and interactions. They can have significant positive and negative impacts on the environment or human wellbeing, even in places far from the site of agricultural production. In the presence of spillovers, the notion of sustainable agricultural land use can thus no longer be confined to the scales of individual production units; it needs to account systematically for spillovers. Spatial scale mismatches arise if the scales of governance arrangements do not fit the scale of the spillover problem (Cumming et al., 2006; Folke et al., 2007; Galaz et al., 2008). This constitutes a key design challenge for VSS that are intended to foster sustainable agriculture and yet are predominantly implemented at the production unit level (Tscharntke et al., 2015). Here, we highlight two main points of reflection regarding this issue:

First, our study shows that VSS can strive to make important contributions to sustainability beyond the farm level, even if they are implemented at the production unit level. For instance, by regulating the use and application of pesticides, the dispersion of chemical pollutants to nearby areas or within the wider landscape (e.g. through pesticide drift or leaching processes) can be addressed (Sagasta et al., 2017), contributing to biodiversity-related and health-related sustainability within the larger region. The explicit consideration of spillover processes in VSS can thus help to reduce challenges related to spatial scale mismatches in VSS design. Our results have shown that the extent to which VSS regulate spillovers, however, varies largely among different types of spillovers. VSS commonly address spillovers relating to environmental flows, but they often have considerable regulatory gaps with regards to socio-economic spillovers. These results are in line with previous arguments suggesting that VSS may not sufficiently account for spillovers (Heilmayr et al., 2020; Meemken et al., 2021; Smith et al., 2019). However, in view of discussing the potential of VSS making sustainability contributions beyond the farm level, it is important to highlight that our analysis of VSS requirements only provides indications of the aspired change by VSS, rather than the actual impact of VSS on the ground. Hence, even if spatial scale mismatches are (partially) addressed through the more systematic integration of VSS perspectives in VSS design, this does not preclude potential challenges relating to the implementation of the respective standards.

Second, even though VSS implemented at the farm level can *contribute* to sustainability beyond the farm, they may not be able to *ensure* sustainability at larger scales (Schneider et al., 2014). VSS can play an important role in regulating spillovers arising from practices at certified farms, but they cannot regulate spillovers that arise from other,

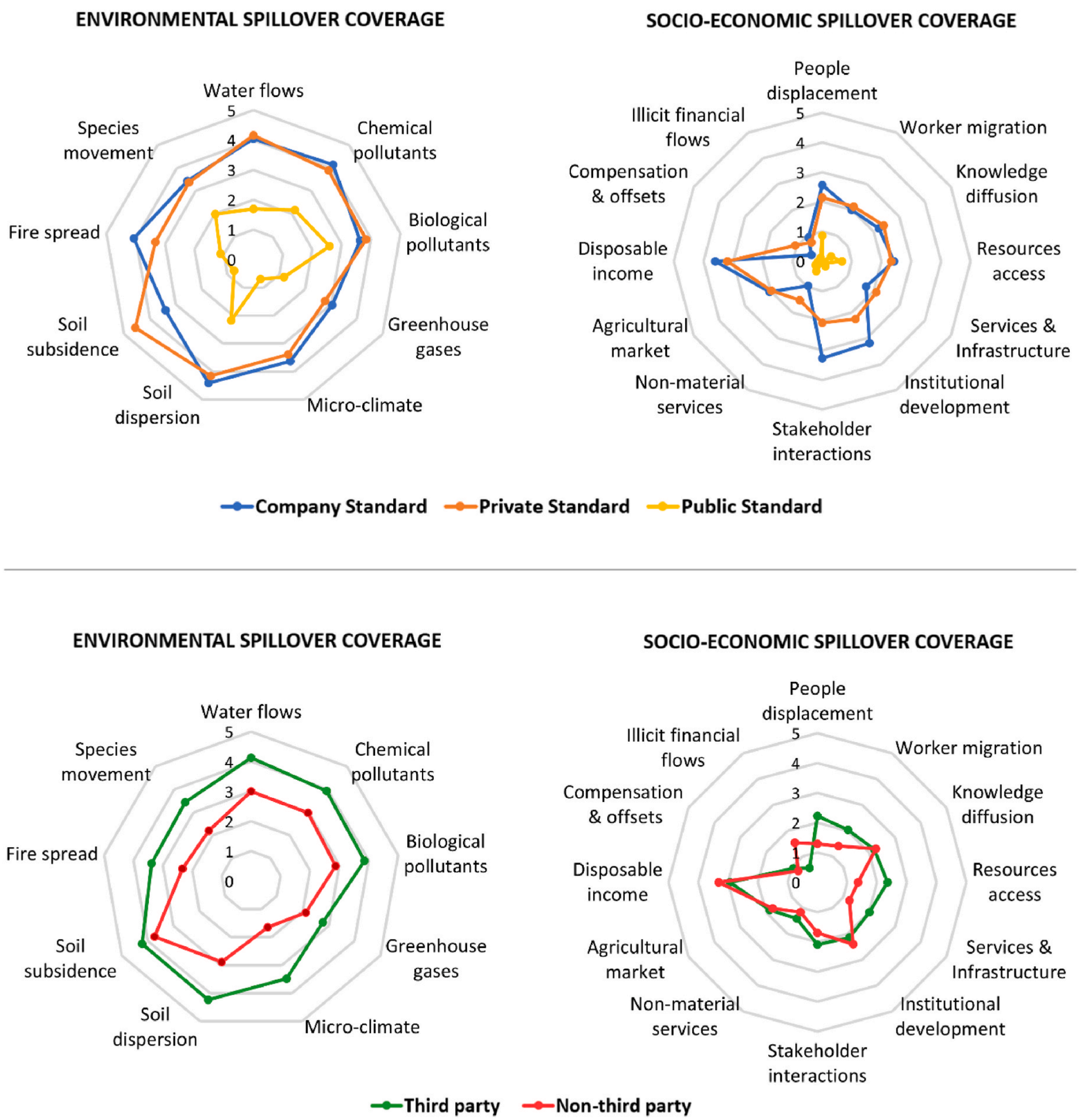


Fig. 11. VSS spillover coverage scores by type of standard-setter (upper panel), VSS verification mechanism (lower panel). (Source: ITC (2021b), based on calculations by authors).

non-certified farms. For instance, VSS aspiring to combat deforestation may be able to prevent farmers from cutting down trees within their certified production unit, but not in surrounding farms (Molenaar, 2021). Aggregated changes in a landscape structure resulting from individual farm-level decisions on the conversion of (semi-) natural habitats can, however, have important effects on biodiversity and provision of ecosystem services within the wider landscape (IPBES, 2019). In this sense, spatial scale mismatches remain an inherent challenge for VSS, as they cannot be fully resolved through farm-level standards. In recent years, the VSS community has increasingly tended to this issue, emphasizing the need to support sustainability at broader scales. Standard-setting organizations have thereby shown a growing interest in linking their activities with multi-stakeholder initiatives at the landscape or jurisdictional levels, moving towards the integration of landscape approaches into their standard systems (ISEAL Alliance, 2017; Mallet et al., 2016). These recent developments could offer promising opportunities for addressing many of the challenges around spatial scale mismatches in VSS and may benefit from the knowledge on spillover processes presented in this study.

5.2. Should VSS cover a broad range of spillovers?

The spillover coverage gaps revealed in this study suggest that VSS standard-setting procedures could lack systematic identification, assessment, and consideration for spillover processes. Should standard-setting organizations therefore work towards filling these gaps, aspiring to address a broad range of spillovers of agricultural land use?

A broad thematic coverage of sustainability standards is often assumed to lead to better VSS performance (Potts et al., 2014). Contrary to this intuitive belief, broad VSS coverage does not necessarily imply good performance, as other factors such as institutional design, market coverage, and implementation and enforcement mechanisms also often play an important role therein (Bissinger et al., 2020; Potts et al., 2014, 2017; Smith et al., 2019). Broader VSS coverage may indeed involve greater risks in designing and implementing VSS. First, more rigorous and extensive standards are likely to lead to higher production costs

(Tscharntke et al., 2015). It is the inherent nature of spillovers that the producers themselves are less likely to benefit directly from the additional efforts needed to mitigate negative or foster positive spillovers. If not compensated sufficiently, the resulting opportunity costs could thus further increase the risk of smallholder exclusion from participation in certification schemes (Fiorini et al., 2019; Grabs, 2020; Starobin, 2020; UNCTAD, 2021). Second, expanding the coverage of standards could further enhance the already frequently high costs for auditing and monitoring, potentially placing additional financial burdens on farmers and nurturing incentives to cheat (Meemken et al., 2021; Schilling-Vacaflor et al., 2020). In addition, the consideration of socio-economic spillovers in particular may require auditors to deal with sensitive and less tangible issues (e.g. land rights or discrimination), which are particularly difficult to monitor and measure (Meemken et al., 2021; Molenaar, 2021). Third, expanding the scope and rigour of sustainability standards could directly contrast efforts to scale up VSS certification. There is a risk that supply chain actors will replace more ambitious VSS with weaker ones or adopt less ambitious standards (Tscharntke et al., 2015). Becoming more ambitious in terms of covering spillovers more comprehensively in VSS might thus contribute to a "race to the bottom" and thereby even negatively affect the overall impacts of VSS (Dietz et al., 2018).

An extensive coverage of spillovers may also lie beyond the scope or possibilities of individual standards. VSS differ in terms of the scope of their objectives as well as their foci on commodities, sectors, and sustainability issues (McDermott, 2013; Tröster and Hiete, 2018). Hence, certain topic areas and their related spillovers may not be of equal relevance. In addition, while this study has focused on the requirements postulated in the standard documents, standard-setting organizations might also employ other tools to address spillovers (e.g., complaint mechanisms). Our study thus does not point to the performance of individual standards, but rather presents a sector-wide overview of priorities and potential gaps in the coverage of spillovers in VSS. However, our results regarding the linkages between VSS spillover coverage and VSS characteristics (Section 4.3) suggest that differences exist among different types of VSS systems and their coverage of individual spillovers. Exploring the reasons and dynamics behind these results offer interesting avenues for further research. To understand better the limitations and opportunities for governing spillovers through VSS, the following questions could be explored further: What are the successful strategies through which VSS currently govern spillovers? Which types of spillovers are best suited to be regulated by (which types of) VSS? What are limitations of VSS to address sustainability beyond farm level?

Furthermore, standard systems do not operate in isolation and interact with other governance instruments (e.g. public policies or international trade regulations) that might be better equipped to address (certain) spillovers (Lambin and Thorlakson, 2018). Literature on VSS effectiveness points to a number of challenges related to the design and implementation of sustainability standards. For instance, VSS have been criticized for ineffective monitoring and enforcement procedures (Schilling-Vacaflor et al., 2020), a selection bias in the uptake of VSS (Lambin et al., 2018; Meemken et al., 2021) or lacking inclusion of smallholders in the governance of VSS (Bennett, 2017; Renckens and Auld, 2019; Schleifer et al., 2019). As indicated in the previous section, some implementation challenges could even further exacerbate through an extensive spillover coverage in VSS. However, as new governance mechanisms are emerging to address sustainability challenges in global supply chains (e.g., due diligence laws (Schilling-Vacaflor and Lenschow, 2021)), this calls for more research about the complementary roles that different governance mechanisms (can) play in regulating spillovers of agricultural production.

In sum, spillovers can be highly important in terms of achieving sustainable agricultural land use. However, as we have shown in this section, simply broadening the coverage of standards to address a multitude of spillovers can exacerbate existing challenges of VSS and may fall beyond the scope of the objectives of certain VSS. In today's interconnected world, positive and negative spillovers will always exist. Efforts should thus be placed not only on identifying potential spillover processes *per se*, but more importantly, on identifying the most relevant processes in terms of their sustainability impacts and existing possibilities for regulating them (TEEB, 2018). In order to foster sustainability beyond scale, standard-setting organizations should thus identify and select carefully those spillover processes with strong potential for supporting or undermining their sustainability targets, and then consolidate efforts towards fostering practicable solutions for governing them effectively, within and beyond the immediate realm of the standard.

5.3. *Moving forward: the role of scientific knowledge*

Good practice guidelines on standard-setting postulate that VSS should "reflect best scientific understanding" (ISEAL Alliance, 2014, p. 8). There are, however, a number of critical challenges for the uptake of scientific knowledge on spillovers in the operationalization of VSS. Spillover processes and the causal mechanisms leading to sustainability impacts are conceptually complex and difficult to assess, as they evolve dynamically and potentially across scales and large distances. This is to some extent reflected in the current lack of agreed-upon definitions and guidelines for defining spillover processes. Research on spillovers is largely scattered across different scientific disciplines, each of them using specialized concepts, methods, and jargon. The absence of a harmonized understanding of spillovers in the scientific domain constitutes on itself a major barrier for developing standardized sets of rules through which spillovers could be taken up in existing VSS.

With regards to individual types of spillovers, our study suggests that spillovers that are less studied and/or more difficult to measure may be particularly challenging to be regulated through standards. In general, we found that environmental spillovers tend to be covered more extensively than socio-economic ones. Many of the environmental spillovers commonly addressed by VSS, such as those relating to dispersion of soil or chemical pollutants, have been subject to scientific research for a long time (Kristiansson et al., 2021). Consequently, more well-defined approaches to observe, quantify and mitigate them exist. Social sustainability in agriculture, contrarily, has received relatively little scholarly attention (Janker and Mann, 2020). As also indicated by Alexander et al. (2020), it is particularly difficult to be operationalized and has received less attention in many VSS.

This study presents a first attempt to contribute to a more comprehensive understanding of spillovers of agricultural production. Yet, in order to facilitate the integration of spillovers into VSS, more efforts are needed to foster transformative sustainability research about a broad range of spillovers (Liu et al., 2018) and to develop approaches for communicating the resulting knowledge in an accessible way to different types of stakeholders (e.g., through visuals, see Sonderegger et al., 2020). Inter- and transdisciplinary co-creation of knowledge and knowledge platforms navigating the related science-policy-society interface (e.g. the Evidensia platform (https://www.evidensia.eco/)) may thereby offer valuable opportunities to foster dialogues about sustainable agriculture in an interconnected world (Burch et al., 2019; Jacobi et al., 2022; Wibeck et al., 2022).

6. Conclusions

VSS are widely used tools for promoting and fostering sustainable agricultural production at farm or supply chain level, with a tendency to grow further in relation to public and private actors. In recent times, standard-setting organizations have increasingly striven to achieve impact beyond the scale of farms or other production units, aiming to address potential scale mismatches in their VSS design. These developments call for a better understanding of spillovers of agricultural production. A spillover lens can help to identify and reflect on the standards' current and potential contributions to sustainable agriculture beyond scale. In this study, we have identified 21 socio-economic and environmental spillovers of agricultural production and analysed their coverage in 100 agricultural standards. We found that many spillover processes are – at least implicitly – already present in the standards' requirements. However, our study has also revealed considerable gaps of spillover coverage in the VSS landscape. In particular, socio-economic spillovers are often not regulated through existing VSS, or only to a limited extent. To explore our full potential for achieving sustainable agriculture beyond the farm level, it is thus important to integrate spillover perspectives into standard-setting procedures.

Spillovers are omni-present in our interconnected world. Hence, effective spillover governance requires a systematic identification of a range of spillovers and a thorough assessment of the feasibility and purposefulness of governing them, followed by a careful selection of the most relevant ones. This study may serve as a starting point for identifying potentially relevant spillovers. However, a more detailed suite of tools to support and guide the VSS community throughout the overall process of integrating spillovers into VSS governance, and potentially also other governance instruments, is currently lacking. To achieve effective development of the tools needed to support decision-makers, an engaged science-policy-society dialogue is essential. Fruitful dialogues between researchers, standard-setting organizations, and other key players (e.g., policymakers and civil society organizations) about the possibilities, needs, and responsibilities relating to the governance of spillovers is needed to move conjointly towards sustainable agriculture beyond scale.

CRediT authorship contribution statement

Gabi Sonderegger: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft, Visualization. **Andreas Heinimann:** Writing – review & editing, Supervision. **Vasco Diogo:** Data curation, Software, Writing – review & editing. **Christoph Oberlack:** Conceptualization, Writing – review & editing, Supervision.

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

The authors do not have permission to share data.

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Appendix A. Supplementary data

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