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Encyclopedia of Soils in the Environment, Second Edition

The Economics of Soils' Contribution to Human Well-Being

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Abstract
Soils influence human well-being in manifold ways. However, their multifunctionality implies trade-offs. Moreover, soils are a scarce stock of natural capital. Many soil-based ecosystem services are collective goods, whose provision is affected by externalities of soil management. This chapter provides an economic perspective on soils' contributions to human well-being and the associated challenges in terms of public preferences, property rights regimes and policy. It offers an overview of key concepts such as soil-based ecosystem services, property rights and collective goods dilemmas, economic valuation as well as incentive-based policy instruments that help align soil management with public preferences and societal well-being.

Keywords
Collective goods; Economic valuation; Ecosystem services; Environmental policy; Externalities; Incentives; Nonmarket valuation; Offsets; Policy instruments; Property rights; Soil functions; Subsidies; Taxes

Key points/objectives box

- Soils provide multiple benefits to human well-being (soil-based ecosystem services).
- Soil management affects the provision of soil-related collective goods.
- Existing legal property right regimes obscure the public-good nature of soil-based ecosystem services.
- Economic valuation can help demonstrate the contributions of soils to human well-being and the trade-offs involved.

- Incentive-based policy instruments can help align soil management with public preferences.
- The design of effective and efficient incentive-based soil policy instruments is challenging.

Glossary

- Collective good: A good providing benefits that can be enjoyed by anyone and from whose enjoyment no-one can be excluded.
- Externality: Side effect of an economic activity (e.g. soil management) that affects third parties without their consent.
- Incentive-based policy instruments: Policy instruments that rely on shifting relative prices (e.g. taxes, offsets), rather than prohibiting or commanding specific actions (e.g. emission or technology standards).
- Information asymmetry: A situation among at least two interacting agents, in which one of the agents possesses more information relevant to their interaction than the other(s).
- Institutions: Conventions, norms and formally sanctioned rules of a society (e.g. laws, social norms, property rights).
- Marginal value: The value attached by people to an incremental change of one unit (quantity or quality) of a good or service.
- Market failure: A situation in which unregulated market activity leads to societally undesirable outcomes (e.g. due to externalities).
- Opportunity costs: Foregone benefits of alternative uses of a resource (e.g. the profit from agricultural yields foregone in the event of conserving a piece of land).
- Relative scarcity: A good is scarce if its intended uses exceed the available quantity. Scarcity is relative if the good can be substituted with respect to a given use.
- Social dilemma: A situation in which independent rational behavior of individuals leads to an inferior overall outcome as compared with a situation in which individual actions were coordinated.

Introduction

Soils influence human well-being in manifold ways, e.g. by storing carbon, absorbing, storing and filtering water, providing habitat for biodiversity as well as contributing to the production of biomass that can be used as food, feed, energy or materials (Baveye et al., 2016; Dominati et al., 2010). These numerous benefits illustrate soils' multifunctionality. However, soils cannot be managed to maximize all their contributions to human well-being (soil functions or soil-based ecosystem services) simultaneously. Their multifunctionality implies trade-offs. In this sense, they can be considered an essentially scarce resource. Their scarcity is relative, as many of their functions can be substituted or replaced by man-made alternatives, although imperfectly – examples of such substitution are synthetic fertilization, water treatment facilities, flood protection infrastructure, irrigation systems etc. Given the relative scarcity of soils in their multifunctionality and their multiple contributions to human well-being, soils can and should be considered an economic good or, more precisely, a natural capital stock (Dominati et al., 2010). In this view, soil functions and, ultimately, soil-based ecosystem services are benefit streams derived from this stock of natural capital.

Further, while some of the ecosystem services provided by soils benefit predominantly those who own and/or manage the land where they are located, many soil-based ecosystem services provide wider benefits to society. These ecosystem services can be considered public or collective goods. Against this background, a person's private activity, e.g. biomass production, may have negative or positive impacts on a third person not directly involved in the activity, or on society at large. In the case that the person undertaking the action does not consider costs or benefits imposed on others, an uncompensated damage (or spill-over benefit) exists, i.e. a so-called 'externality'. It is the primary role of societal institutions (laws, rules, norms) to internalize them, meaning that measures are undertaken to take into account uncompensated damage or benefits (formally: align private costs/benefits and social costs/benefits). This internalization of externalities can be based on three approaches, depending on context:

- State intervention in the form of corrective taxes (or subsidies in the case of positive externalities).
- Direct negotiations among affected parties, with the aim for contractual internalization (well-defined property rights are required).
- Bottom-up establishment of collective institutions (norms, rules) by those affected (Ostrom, 1990).

The fact that soils exhibit collective good characteristics suggests that there is a need for policy intervention to correct market failure and underprovision of the soil-related collective goods that arise due to soil degradation. This chapter provides an economic perspective on soils' contributions to human well-being and the associated challenges in terms of public preferences, property rights regimes and the design of policy interventions that aim at internalization.

Soil-Based Ecosystem Services

The importance of soils for human well-being can be highlighted and analyzed by means of the ecosystem service concept (Dominati et al., 2010). This concept aims to demonstrate the contributions of ecosystems to human well-being and the associated value humans place on ecosystems (TEEB, 2010). Although scientific interest in the concept has risen substantially since the millennium, so far there has been no clearly defined terminology or a standardized classification of ecosystem services. Ecosystem services are often defined as the indirect and direct contributions of ecosystems to human well-being (TEEB, 2010). The development of the Common International Classification of Ecosystem Services (CICES) is considered an important contribution to a common understanding and standardization (Haines-Young and Potschin, 2018). The CICES differentiates ecosystem services into three overarching categories: provisioning services (e.g. food, timber), regulating and maintenance services (e.g. climate regulation, flow regulation, soil formation) and cultural services (e.g. recreation, aesthetic experiences). Within these three main categories, CICES version 5.1 distinguishes between 83 so-called classes of ecosystem services (Haines-Young and Potschin, 2018).

To illustrate the complex relationship between ecosystems and human well-being in the form of a 'production chain', Haines-Young and Potschin (2010) developed the so-called cascade model (Figure 1). This model assumes a stepwise relationship between the biophysical context, processes and structures created by living organisms and their potential to provide ecosystem services, and the socio-cultural and economic context associated with benefits and value to humans. Final ecosystem services, i.e. all services that contribute directly to human well-being, are the link between the ecosystem functions (including soil functions) on the one hand and benefits and values on the other hand. Thus, there is a need to distinguish between an ecosystem's potential to provide ecosystem services and the actual supply and demand for ecosystem services, which by definition cannot exist in isolation of human needs (Haines-Young and Potschin, 2010). While the standard version of the cascade model is characterized by a unidirectional flow, decision-making may influence the biophysical structure through pressures, e.g. unsustainable management of resources.

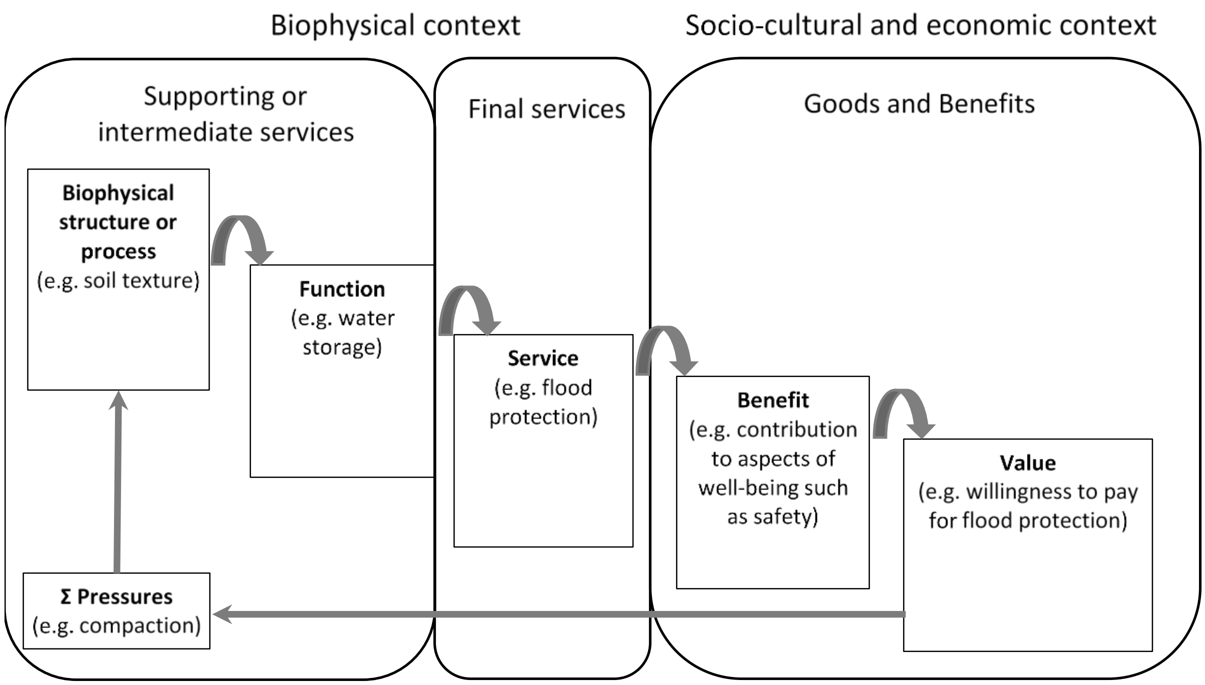

Figure 1: The ecosystem service cascade model

Source: Own illustration adopted from Haines-Young and Potschin (2018; see also, 2010)

As discussed above, soils fulfil multiple functions (production of biomass, water storage and filtration, nutrient cycling, carbon storage and habitat provision), which form the basis for the provision of ecosystem services. While the ecosystem service concept could make the contributions of soils to human well-being and the impacts of soil management on the provision of ecosystem services visible, CICES does not explicitly specify soil-based ecosystem services (Haines-Young and Potschin, 2018). Thus, defining ecosystem services provided by soils remains challenging because ecosystem services are characterized by complex interactions, e.g. between below-ground and (natural and human-driven) above-ground processes. Therefore, identical soils may provide varying levels of ecosystem services under different management regimes; soil-based ecosystem services are the result of an interplay between inherent as well as manageable soil properties (Dominati et al., 2010) and human needs and preferences, which determine for which soil functions there is demand (making them soil-based ecosystem services). For instance, fertilizer input affects the amount of fiber and food production. In this context, Paul et al. (2021) distinguished between i) *soil-related* ecosystem services, i.e. all services affected by soil properties, e.g. soil quality by weathering processes (here called soil-based ecosystem services), and ii) ecosystem services *affected by agricultural soil management*. Out of the 83 ecosystem service classes included in CICES, 29 were identified as soil-related and 40 were classified as affected by soil management, while 23 classes were part of both subsets. Furthermore, reconciling the contributions of soils to human well-being with the CICES classification is hampered by CICES's dualistic conception of biotic ecosystem services, e.g. biomass provision or carbon storage, and abiotic ecosystem services, e.g. groundwater for drinking or control of liquid flows. Soil-related services are often relevant for both categories as they are linked in the interaction zone between pedosphere, hydrosphere, atmosphere and biosphere (Paul et al., 2021). Additionally, the linear relationship between soil functions and soil-based ecosystem services suggested by the cascade model does not necessarily hold. Thus, in the literature definitions of soil-based ecosystem services correspond to some extent to definitions of soil functions (Baveye et al., 2016), but most definitions of soil functions arguably do not have a sufficiently clear link to human well-being. For example, the soil function 'water storage' is highly relevant for the soil-based ecosystem service 'flood protection', but in the absence of further factors (proximity to human settlements, rivers or streams as source of flooding etc.), the function will not become an ecosystem service.

Collective Goods and Property Rights Regimes

Many of the soil-based ecosystem services mentioned in the previous section are public or collective goods. This means that others cannot be excluded from enjoying the benefits of the provision of these ecosystem services. For instance, while increasing the organic carbon content in soils has numerous benefits to the land users themselves (e.g. in terms of soil moisture and productivity), carbon sequestration and storage in soils also removes greenhouse gases from the atmosphere, thus contributing to the provision of a global collective good (a stable climate) enjoyed by every person alive as well as (and especially) future generations. However, while the land user can reap the private benefits of soil management, outweighing the associated costs of management changes, this is not the case for collective goods. Here, the land user as provider of a collective good bears the entire cost of its provision, in particular the opportunity costs resulting from not being able to manage differently, but they cannot reap the benefits, unless some institution has been set up to remunerate them.

The challenge posed by soils in this context is that they are multifunctional, and the private-good and collective-good aspects cannot be easily separated. Building upon Lancaster's consumer theory (Lancaster, 1966), which posits that consumers are interested in the characteristics of a good (e.g. taste, size, color in the case of an apple) rather than in the good as such, soils can be considered a bundle of characteristics (soil functions and soil-based ecosystem services), which contribute to human well-being in different ways (Bartkowski et al., 2018).

This has profound consequences for the conflict between *de facto* and *de jure* property rights towards soils. While in legal terms, soils are part of 'land', which can be owned privately and bought and sold in the market, de facto, many of the ecosystem services provided by them are collective goods that defy private ownership and marketability. Moreover, private and collective goods are not a binary category, but rather a spectrum. To analyze this spectrum and locate various soil-based ecosystem services within it, it is useful to distinguish a set of actions that can be executed towards any economic good (Schlager and Ostrom, 1992). These actions are:

- access, i.e., the physical interaction with land/soils;
- withdrawal, i.e., enjoyment of the 'fruits' provided by land/soils;
- management, i.e., modifying and regulating land/soils and their properties;
- exclusion, i.e., preventing others from access, withdrawal, and/or management;
- alienation, i.e., transferring the land to another person or entity (by selling or giving away).

Different persons or entities can possess different *de facto* and *de jure* rights towards the same good, i.e. control different actions related to this good. For instance, while the tenant may possess the exclusive right to cultivate a piece of land for a contractually defined period (access, withdrawal, management, exclusion), the land owner retains the right to sell the property in question (alienation) (Bartkowski et al., 2018). The same intuition holds for various soil-based ecosystem services, as exemplarily shown in Figure 2. In particular, almost everyone can enjoy the benefits of collective-good ecosystem services (e.g. climate regulation or biodiversity) and no-one can be effectively excluded from enjoying them. In the absence of societal institutions that will address this problem, the land user does not have reasons to bear the cost of managing the soil to provide those soil-based ecosystem services that exhibit collective good properties. The objectives of management will thus be restricted to a subset of ecosystem services that directly affects the interests and well-being of the land user, thus leading to a social dilemma or collective-goods problem.

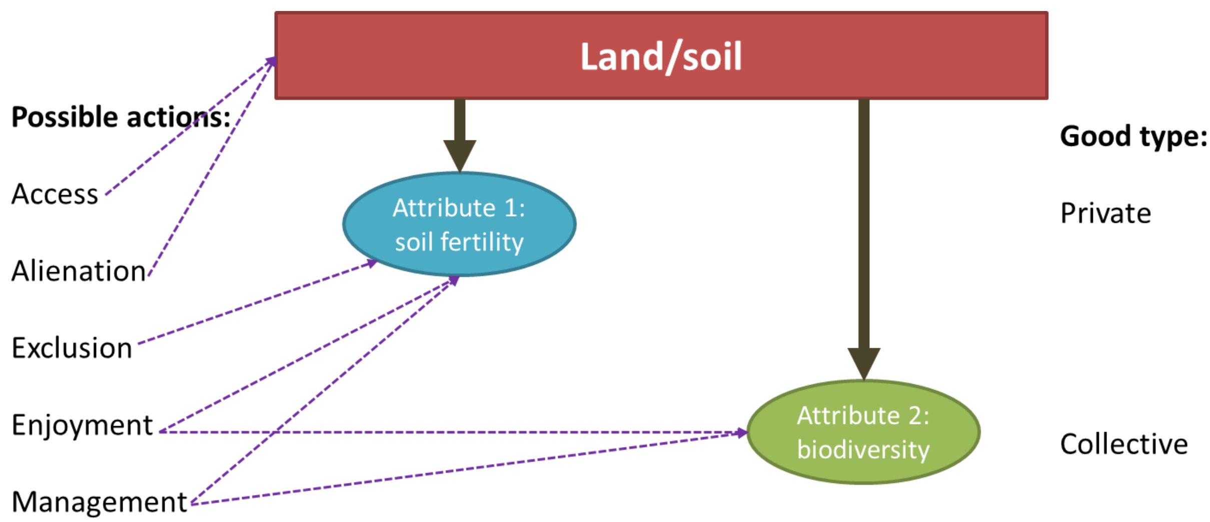

Figure 2: Stylized relationships between different types of attributes of land/soil and various actions covered by *de facto* and *de jure* property rights

Source: Bartkowski et al. (2018); reproduced by permission; licensed CC BY 4.0.

It is impractical to assign distinct legal property rights to each soil-based ecosystem service, and to define the actions permitted for each affected individual, entity or group. However, given how legal property rights are commonly assigned (their object being simply the land), the observation that *de facto* property rights of third parties are also affected creates a rationale for state intervention in the form of institutions (policy instruments) that provide incentives to land users to align their management with the interests of the affected parties. Thus, the social dilemma can potentially be resolved. However, before this can be done, it is first necessary to determine who is affected and how they are affected, i.e. what are the public preferences for various soil-based ecosystem services.

Economic Valuation of Soil-Based Ecosystem Services

The primary motive for economic valuation of the environment, e.g. of soils, is to demonstrate the importance of ecosystem services for human well-being and the value these have for society. The focus is particularly on those ecosystem services that are not traded on markets and therefore do not have prices (nonmarket valuation). Further, economic valuation allows for the expression of trade-offs and assessment of the impact of alternative actions on human welfare (TEEB, 2010). A heuristic to assess the aggregate value of benefits associated with soil-based ecosystem services is the so-called Total Economic Value (TEV) framework. ’Total‘ refers here to the aggregate of different economic, i.e. preference-based value types and categories (see Figure 3) and should not be confused with the absolute value derived by an ecosystem service. Usually, economic valuation of ecosystem services captures marginal values, i.e. the value of a small incremental change in the quantity or quality of the ecosystem service, which depends on the relative scarcity of the ecosystem service and, thus, its current levels of provision. Higher marginal value is associated with increasing scarcity in ecosystem service supply – below a minimal threshold, sometimes called ‘critical natural capital’, when the ecosystem service supply becomes non-substitutable and, thus, essential to human survival, economic valuation ceases to be meaningful (Farley, 2008). Therefore, the aim is not to estimate the absolute value derived from an ecosystem service, but the marginal value associated with a change in the state of the world. For example, a decision on whether to re-wet a peatland area would be informed by the marginal changes in ecosystem service provision with respect to the various value categories of the TEV, described in the following.

The various value categories comprise two overarching types of value: ‘certain-world values’ and ‘uncertain-world values’. Certain-world values are independent of the uncertainty regarding future states of the world, whereas uncertain-world values derive from the inherent uncertainty over future demand and supply of soil-based ecosystem services (Bartkowski et al., 2020). Certain-world values can be divided into ‘use values’ and ‘non-use values’. As suggested by the name, use values refer to values derived from the use of environmental goods which may be ‘direct’ and ‘consumptive’ (e.g. biomass production), direct and ‘non-consumptive’ (e.g. recreational activities such as metal detecting) or ‘indirect’ or ‘passive’ (e.g. climate regulation through carbon storage). Direct use values are often, though not always, reflected in market transactions, whereas indirect use values generally are not. The concept of non-use values captures all values of ecosystems that either relate to altruism towards other humans (‘philanthropic value’) or towards nature (‘existence value’). Philanthropic value may refer to the satisfaction of knowing that future generations will have access to benefits from a given (bundle of) ecosystem services or an ecosystem (‘bequest value’) or that other people currently living have access to such benefits (‘altruistic value’). Satisfaction derived from the knowledge that an ecosystem or species simply exists is referred to as ‘existence value’. Despite the fact that non-use values are associated with other humans or non-human entities, these types of value are usually understood in terms of individual preferences. In other words, individual measures of value are of relevance with respect to individual satisfaction, e.g. of knowing that soils will provide benefits for future generations. Turning to the notion of uncertain-world values, the associated values account for the temporal dimension of soils and the provision of soil-based ecosystem services. The so-called ‘option value’ is associated with the continued ability to respond to future preferences and demand, i.e. it focuses on the preservation of options to use soils in the future and to enjoy the potential benefits of soil-based ecosystem services. ‘Insurance value’ arises from soils’ potential to reduce variance in soil-based ecosystem service supply, in particular with regard to disturbances, and thus to supply uncertainty. Both types of value are strongly linked to biodiversity (Bartkowski et al., 2020; Pascual et al., 2015).

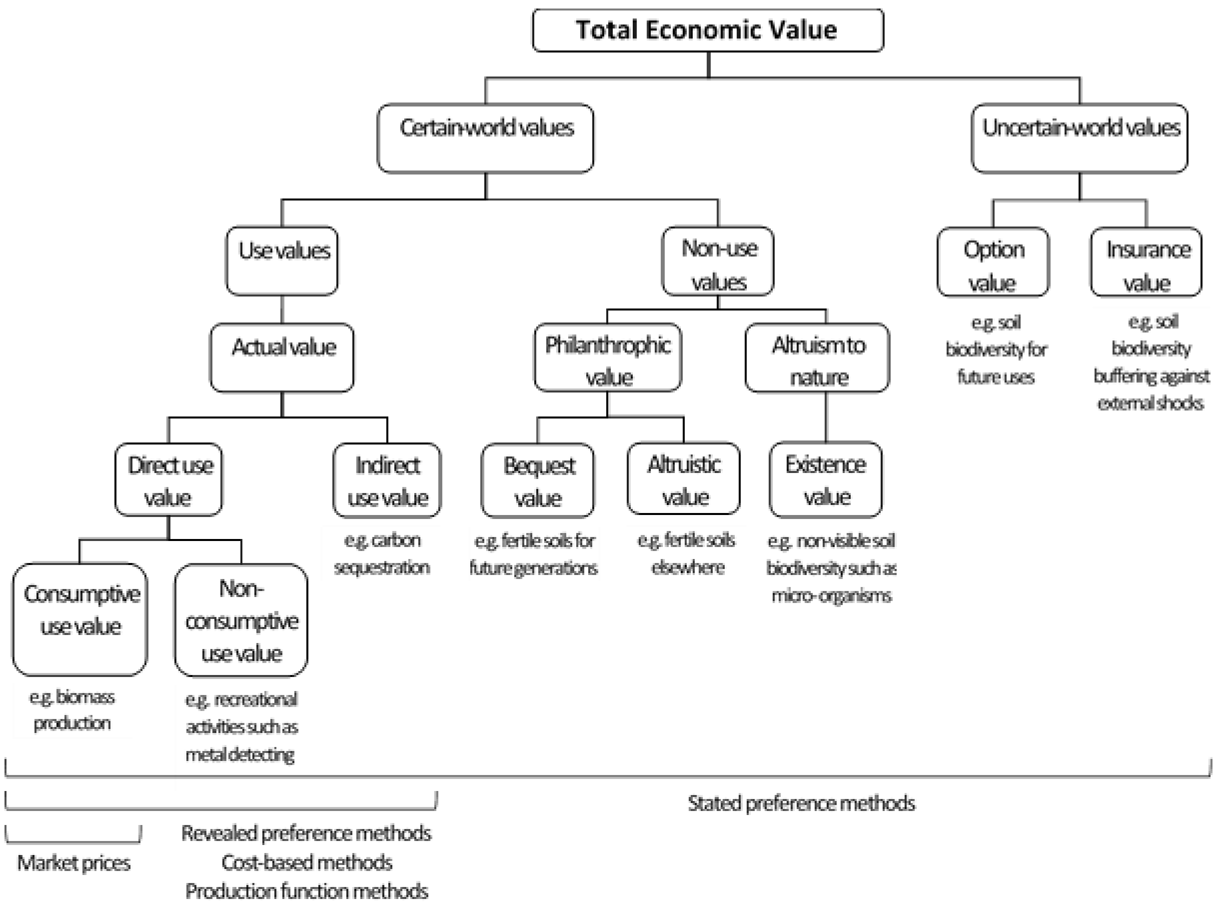

Figure 3: The Total Economic Value framework with soil-relevant examples

Source: Own illustration based on Bartkowski et al. (2020)

A variety of valuation methods can be used to estimate the TEV of ecosystems or ecosystem services. The choice of method is highly context specific, and there are multiple conflicting factors to consider, including the firmness of the theoretical underpinning of a method, the cost of its application, the associated data demands, flexibility and comprehensiveness. The primary goal of each nonmarket valuation method is the inference of preference information from proxies, mostly information about choice behavior. Two common options are the elicitation of preferences for hypothetical scenarios with questionnaires (‘stated preference methods’) and observation of individual market behavior that can be linked to ecosystem services ('revealed preference methods'). Among stated preference methods, one may distinguish contingent valuation, which is based on a direct question about respondents' willingness to pay for a hypothetical change in the provision of an ecosystem service, and discrete choice experiments, which are based on respondents choosing among scenarios that are characterized by variable attributes (e.g. soil-based ecosystem services). Revealed preference methods include the travel cost method (inference of the value of an ecosystem, a landscape etc. from expenditures people incur to visit them) and hedonic pricing (analysis of market data – e.g. real estate or land markets – where price variations can be partly explained by spatially explicit provision of ecosystem services). Stated preference methods are the most comprehensive and flexible, but rather effort- and cost-intensive. Furthermore, they are based on the analysis of hypothetical choices, which may be biased and not reflect how people would behave in the real world. Revealed preference methods reflect actual choice behavior, but they can only be applied to a limited subset of ecosystem services, require substantial amounts of data and assume that people are aware of the benefits they derive from ecosystems. In some cases, the data demands and costs associated with preference-based valuation methods may be prohibitive. In such cases, more crude yet easier to apply methods are sometimes used, such as those based on market prices of comparable goods ('market price-based method'), the costs of replacement, preservation or restoration of the ecosystem service in question ('cost-based methods') or the estimation of production functions that link the production of market goods to ecosystem inputs ('production function method').

In the context of soils, cost-based methods or market price proxies are applied most often to estimate the economic value of soil-based ecosystem services, instead of state-of-the-art preference-based valuation methods (Bartkowski et al., 2020). For instance, in a particularly comprehensive study, Dominati et al. (2014), use replacement costs and market price proxies to calculate the economic values of a range of soil-based ecosystem services (including food provision, flood protection, nutrient cycling and climate regulation). However, cost-based methods are problematic, as they do not provide information about preferences for collective goods, but merely give insights about costs of technical solutions. These costs may be an inadequate proxy for values if public preferences differ significantly. In addition, market prices can only be considered rough proxies because, as discussed above, most environmental goods are non-marketable or rather the associated marketed goods are not equivalent to the soil-based ecosystem services. Furthermore, existing economic valuation studies consider only a minor part of the range of soil-based ecosystem services discussed above. Primarily, economic values of climate regulation (carbon storage), decomposition (nutrient cycling) and (cost of) soil erosion have been investigated in the empirical literature. Thus, the potential of economic valuation to inform decision-making has not yet been fully realized. Hence, there is a need to consider the whole range of soil-based ecosystem services including trade-offs among them and for the application of state-of-the-art methods (Bartkowski et al., 2020).

Incentive-Based Instruments for Soil Protection

As discussed above, soils provide multiple ecosystem services that are valued by the public and exhibit collective good characteristics. The latter implies that their provision is unlikely to be ascertained by markets, given conventional legal property rights regimes. Rather, a corrective intervention by the state is required. However, the spatial heterogeneity of soils suggests that the required corrections in management will vary across locations; also, their effects may manifest at different spatial and temporal scales. Furthermore, the demand for ecosystem services not only depends on the local potential of soils to provide them, but also on the availability of substitutes (e.g. flood protection through infiltration and water storage in soils can be substituted by flood protection walls), the characteristics of the local population (e.g. in terms of income and wealth or attitudes) and the opportunity costs of managing for a given ecosystem service (for instance, in highly productive areas, the opportunity costs of extensification are high). Therefore, in most cases, a mix of different policy instruments will be required to address soil multifunctionality in heterogeneous landscapes (Bartkowski et al., 2021a). Relatively rigid policy instruments such as legal standards or zoning are unlikely to be efficient on their own and should at least be complemented by incentive-based instruments. In some cases, overly rigid policies (e.g. bans of particular practices) may even backfire – e.g., a glyphosate ban has been shown to entail increasing pressure on soils due to a shift to mechanical weed control (Böcker et al., 2020).

The main challenge in crafting effective and efficient policy instrument mixes is that soil protection and the provision of soil-based ecosystem services constitute a so-called principal–agent problem. Land users are the agents who are supposed to manage the land and soil in accordance with the requirements and incentives provided by the principal, i.e. the state or, more broadly speaking, society. However, this principal–agent relationship is hampered by information asymmetry between the state (represented by regulatory agencies) and land users. This asymmetry is especially relevant in cases where the effectiveness of management changes is likely to depend on land users' local, often tacit, knowledge including that about (opportunity) costs. Further, the regulatory agency has only imperfect capability to monitor the land user's compliance with requirements and regulations. Both types of information asymmetry impose two major challenges, which are called 'adverse selection' and 'moral hazard', respectively. In the context of soil protection, adverse selection particularly refers to where soil-friendly management is taking place: where it is most effective (i.e. according to the interest of the principal) or where it is cheapest (i.e. according to the interest of the agent). Properly designed instruments help to avoid adverse selection and to incentivize the implementation of protection measures where they are most effective, e.g. by offering payments for measured improvements in soil condition, rather than simply for the adoption of specified practices (Bartkowski, 2021). In contrast to adverse selection, moral hazard becomes relevant after the contractual agreement (or, analogously, after introduction of binding management standards). The regulatory agency is then unable to monitor perfectly the compliance by the land user, who has an incentive to manage in a way that will maximize their profit, rather than in the agreed/mandated, soil-friendly manner. In this context, digitalization and remote sensing are increasingly important technologies that reduce the costs of monitoring of compliance (Ehlers et al., 2021).

A third major challenge related to information asymmetry is called 'additionality'. Ex ante, the regulatory agency usually does not know what the land user will do in the absence of incentives for soil protection. Given that the provision of incentives is costly for the agency, it is rational to provide them only if the land user would not have changed to soil-friendly management in their absence. Otherwise, the land user receives a windfall profit for an activity they would have undertaken anyway, and the scarce funds used to fund non-additional behavior cannot be used to finance the provision of collective goods elsewhere. However, the land user's future decisions are affected by many factors (Bartkowski and Bartke, 2018), and the counterfactual case of no incentives is difficult to grasp, especially for longer-term problems. In some cases, it may therefore be rational (from the point of view of the regulating agency) to provide incentives for non-additional behavior to prevent a return to the undesirable earlier behavior when circumstances change (e.g. when prices for relevant inputs or outputs change, making opportunity costs of soil protection higher).

These three major challenges should be considered when evaluating the effectiveness and efficiency of policy instruments, including incentive-based instruments. The latter include payments, taxes and (tradable) offsets. Each of these can be found in the context of soil protection: for instance, in agriculture, agri-environmental payments are a common instrument to align soil management with societal preferences (Bartkowski et al., 2021b); taxes have been used and discussed especially as a means to reduce pesticide use (Möhring et al., 2020); tradable offsets have been discussed and implemented intensively with respect to initiatives aiming to increase the soil organic carbon content as a strategy for climate change mitigation (negative emissions) (Thamo and Pannell, 2016).

Agri-environmental payments are the most widespread incentive-based instrument and a specific form of 'payments for ecosystem services'. Here, an important distinction is between action-based and result-based variants. In the case of action-based payments, the payment is not directly linked to the environmental outcome that is supposed to be enhanced or protected. For instance, rather than paying for changes in soil organic carbon, the regulatory agency may offer payments for the adoption of practices that are assumed to be beneficial in terms of carbon sequestration and storage (e.g. non-inversion tillage). In theory, this approach would only be efficient if the regulatory agency had perfect, spatially explicit, ex-ante knowledge about the effects of the regulated activity. In practice, action-based payments are quite common due to the relatively low requirements in terms of measurement and monitoring. Result-based payments are the theoretically preferable alternative in the face of information asymmetries between the regulatory agency and the land users (Burton and Schwarz, 2013). Here, the payments are issued for ex-post measured changes in the environmental good. This approach is more efficient than action-based payments, but it poses high demands in terms of measurement and monitoring. Furthermore, it implies greater risk for land users, as they cannot be certain that their actions will lead to the envisioned results, thus securing them compensation payments (Derissen and Quaas, 2013). Within the European Union's Common Agricultural Policy, one of the largest agricultural and agri-environmental policy frameworks worldwide, none of the few result-based payment schemes is related to soils. An alternative, hybrid approach consists in offering payments on the basis of model predictions regarding the spatially explicit effects of management changes (Bartkowski et al., 2021b). A similar approach has already been tried out in the context of private soil carbon offset schemes (TerraCarbon and Indigo Ag, 2020) as a lower-cost alternative to regular, expensive measurements of changes in soil organic carbon. In the future, further developments in remote sensing technologies could also help address the challenge of prohibitive measurement/monitoring costs (Ehlers et al., 2021).

Taxes are the opposite of payments and have been used less intensively in the context of soil protection, mainly due to the difficulties of monitoring that is required for effective environmental taxes. They are primarily relevant when it comes to making problematic inputs (e.g. synthetic pesticides) more expensive (Möhring et al., 2020). In the context of soils, a slightly more widespread approach has been tradeable offsets. These have been used mainly in the context of nonpoint-source pollution such as nitrate (Stephenson and Shabman, 2017) and in the context of soil carbon (Thamo and Pannell, 2016). However, the former is associated with rather high transaction costs (i.e. costs of setting up schemes, monitoring, organizing a trade market etc.) and its effectiveness has been questioned (Stephenson and Shabman, 2017), while the latter has faced a major obstacle in the need to establish permanence (Thamo and Pannell, 2016), which is required for a real climate effect of soil carbon storage.

Overall, the design of effective and efficient soil protection policy mixes is quite challenging and requires the context-specific consideration of numerous unintended effects such as adverse selection or non-additionality. The increase in understanding of the complexity of land users' decision-making processes (Bartkowski and Bartke, 2018) adds to the challenge by demonstrating the inadequacy of existing instruments. However, effective and efficient policy mixes are essential to align the management of soils with the public preferences for soil-based ecosystem services.

Conclusions

Soils are scarce, both in terms of quantity and, especially, quality. They provide multiple benefits to humans, in the form of soil-based ecosystem services. However, this multifunctionality is characterized by trade-offs. Many of the ecosystem services provided by soils are collective goods, which implies that they will be underprovided in the absence of additional incentives. The extent of underprovision depends on the public preferences for soil-based ecosystem services, which can be estimated by means of economic nonmarket valuation. This can then inform the design of policy instruments required to align soil management with public preferences and to optimize soil management so as to enhance the multifunctionality.

To protect soils effectively and efficiently, it is necessary to understand the relevant economic effects adequately. For instance, soils are heterogeneous; therefore, their potential to provide ecosystem services, the opportunity costs of their protection as well as the most effective management practices vary spatially. Economic valuation can help illuminate the extent of public preferences for non-private soil-based ecosystem services, but not all valuation methods are equally adequate and precise; any number may not be significantly better than no number at all. Furthermore, when designing policy instruments, challenges that arise from information asymmetry in the principal-agent setting need to be properly taken into account to avoid wasting scarce resources that could otherwise be used to finance the provision of other public goods.

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