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Can agricultural policy achieve environmental goals through an indicator-based direct payment system?

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Abstract

Indicator-based frameworks for assessing farms' environmental performance have become a resource for environmental knowledge regarding the impacts of agricultural practices. The present study explores whether a novel indicator-based direct payment system, which focuses on the farms' environmental impact, could better target Swiss agricultural policy and help achieve its environmental goals. The system covers the environmental topics of biodiversity, nutrients and climate, plant protection products, and soil. Despite high direct payments, simulations with an agent-based agricultural sector model show that such indicator-based payments have a limited impact. For example, the decrease in the animal population is only moderate. Though direct payments alone can hardly lead to the desired reduction in Switzerland's environmental pollution, they could help make important contributions to a more targeted distribution of environmentally oriented direct payments and steer agricultural production in a more environmentally friendly way.

Keywords: Agri-environmental policy, Agricultural direct payments, Agri-environmental indicators
JEL codes: Q1, Q5

Highlights

- An alternative to the current Swiss agri-environmental direct payment system was conceptually developed.
- The proposed indicator-based direct payment system was designed to consider the approximated environmental impact of a farm.
- Some environmental improvements are achieved; however, the novel system does not lead to the achievement of agri-environmental policy objectives.
- We recommend implementing further measures on the production and consumption side in addition to direct payments to achieve agri-environmental policy goals.

1. Introduction

In recent decades, it has become increasingly evident that the main purpose of agricultural policy in developed countries is the internalisation of environmental externalities caused by agricultural production (Stobbelaar et al. 2009; Erjavec and Erjavec 2015; Renner et al. 2020). Within the framework of multifunctionality (Dufour et al. 2007), agricultural policy has been transformed from incentivising and administering huge milk, grain, and beef surpluses to supporting farmers in a production-neutral way by offering increased incentives for the 'greening' of agriculture (Francis et al. 2007). However, the environmental improvements resulting from attempts to internalise the negative externalities of agricultural production have been modest at best (Gocht et al. 2017; Louhichi et al. 2018).

At the same time—but largely independent of agricultural policies—sustainability assessment frameworks have attained a major role as a normative approach for evaluating agri-food systems, even though only around 1.1 per cent of global cropland is currently certified under one or more sustainability schemes (Tayleur et al. 2017). These frameworks often employ indicators with different complexity levels to assess topics such as ammonia emissions, farmers' working hours, or profitability. Indicators simplify and summarise huge information flows and reduce the number of complex relationships by transforming them into simple expressions (Ciegis et al. 2009). Although some aspects of the current Swiss direct payment system, such as land under organic farming, can be understood as indicators, the system is not a classical indicator-based sustainability framework because the summarising characteristic is largely missing and a comprehensive assessment of sustainability is not its main focus.

The multiplicity of indicator frameworks has been described as a 'market' (Reinecke et al. 2012) or even as 'tribal' (Mann 2018) to illustrate how different groups of scholars develop their own methods. However, the abundance of intellectual inputs from the Food and Agricultural Organisation of the United Nations (FAO; Jawtusch et al. 2013), science (Schader et al. 2019), business (Atzori et al. 2018), and non-governmental organisations (NGOs; Linton 2005) on how to define agricultural sustainability can also be considered an asset. While the social and economic dimensions of sustainability have rather been neglected (Roesch et al. 2016; Janker et al. 2018), sustainability frameworks and standards have become a resource for knowledge on the environmental impacts of different agricultural practices, even if their application is often unsatisfactory (Silvestre et al. 2020). In addition, other indicator-based frameworks exist that deliberately limit themselves to the ecological pillar of sustainability. Examples include the Swiss Agricultural Life Cycle Assessment (SALCA; Gaillard and Nemecek 2009) or the Swiss Agri-Environmental Data Network (SAEDN; Gilgen et al. 2022b). If agricultural policy aims to internalise environmental externalities, the wealth of indicators from such frameworks could be used to design a well-informed toolkit.

In the present study, we aim to explore the degree to which indicator-based frameworks can offer added value to agricultural policy design. This topic has been neglected in the agricultural policy design literature (e.g. Wunder et al. 2018, Graskemper et al. 2021; Saint-Cyr 2022). So far, agri-environmental policy programmes have largely evolved independently from sustainability standards (Batary et al. 2015). Tapping into the knowledge of existing indicator-based frameworks could lead to improvements in the quality of direct payment systems. Moreover, such payments could help Switzerland—the focus of this study—achieve its agri-environmental policy goals.

The main goal of this study is to develop and evaluate a new direct payment system, the so-called indicator-based direct payment system (IBDPS). The IBDPS was designed in a way that the indicators for individual environmental issues approximate the environmental impact of a farm. The payments are linked to the indicator values, and thus to the approximated environmental impact.

We conceptually developed three variants of the IBDPS for the agri-environmental sector called ‘simple’, ‘medium’, and ‘detailed’ (Roesch et al. 2022, submitted; Gilgen et al. 2022a). Here, we focus only on the simple variant, the effect of which was investigated using the agent-based agricultural sector model SWISSland. The IBDPS aims to improve farms’ environmental performance while simultaneously reducing transaction costs. The changes only concern environmental payments; economic and social payments are outside of the objective of the IBDPS. However, the economic and social *consequences* of the new environmental payments are analysed because they are important for the holistic assessment of the system and the identification of trade-offs. The main research question is as follows: How do key figures of the agricultural sector change under a novel, simple IBDPS that primarily attempts to internalise approximate environmental damage?

The rest of the paper is organised as follows. Section 2 describes key figures of Swiss agriculture, the IBDPS structure, the SWISSland model (including the simulations conducted), and the developed indicators. Section 3 presents the SWISSland model results. Section 4 discusses the transferability of indicator-based frameworks to direct payment systems, compares the IBDPS with the direct payment system currently used in Switzerland, addresses uncertainties in the calculations, suggests possible improvements for the indicators, and details which measures outside the direct payment system could lead to environmental improvements in Swiss agriculture. Section 5 summarises the findings and highlights the potential benefits of an IBDPS.

2. Data and methodology

2.1 Key figures of the Swiss agricultural sector

To provide context for the agri-environmental indicators derived for the present study and the model results, this section provides general information about the Swiss agricultural sector (see Table 1; Federal Office for Agriculture (FOAG) 2020, 2021; Jan et al. 2021).

The average Swiss farm size is 21 ha. Most of the utilised agricultural area in Switzerland consists of permanent (58 per cent) and temporary (12 per cent) grassland, the rest is mostly arable land. The utilised agricultural area does not include alpine summer pastures; otherwise, the share of grassland would be even larger. Cereals are the most important arable crops in terms of area, and they are used both for human nutrition (especially wheat) and as animal feed (especially barley). Biodiversity promotion areas[1] (BPAs) are found in 16 per cent of utilised agricultural areas (excluding trees), with extensive meadows and pastures accounting for the majority. Cattle are the most important category of animal, both in terms of number of farms keeping cattle and livestock units (LU). The mean livestock density per farm is 1.2 LU/ha. Direct payments are an important component of the income of many farmers, and they account for 23 per cent of agricultural revenue on average.

2.2 Conceptual development of the IBDPS

To utilise insights from indicator-based frameworks to improve agricultural policies, we first needed to engage in pragmatic operationalisation. Due to the plethora of environmental topics and frameworks, we introduced several limitations to the IBDPS development process. Since they had to be suitable for Swiss circumstances, we focused on the following indicator-based frameworks developed in Europe: IDEA (Zahm et al. 2008), KSNL (Zapf et al. 2009), REPRO (Ehrmann and Kleinhanß 2008), RISE (Grenz et al. 2009), SALCA (Gaillard and Nemecek 2009), SMART (Schader et al. 2019), and SAEDN (Jan et al. 2012; Gilgen et al. 2022b). These frameworks have highly different levels of complexity in terms of indicators and pursue different objectives (e.g. research, monitoring, and advisory).

Table 1. Key figures in Swiss agriculture in 2019 (FOAG 2020, 2021; Jan et al. 2021). In Switzerland, the utilised agricultural area does not include alpine summer pastures.

Category	Number
Total number of farms	50,038
Income	
Average farm net income	CHF 74,195
Average share of direct payments in agricultural revenue	23%
Areas (whole Switzerland)	
Utilised agricultural area	1,043,663 ha
Natural meadows and pastures	601,850 ha
Ley[4]	126,248 ha
Bread cereals	81,684 ha
Feed grain	59,556 ha
Silage and green maize	46,692 ha
Oilseeds	30,404 ha
Sugar beets	17,555 ha
Potatoes	10,981 ha
BPAs (whole Switzerland)	
QI BPAs (excluding trees and alpine summer pastures)	168,388 ha
QII BPAs (excluding trees and alpine summer pastures)	71,403 ha
BPAs on arable land	3,579 ha
Animals (whole Switzerland)	
Number of livestock farmers	42,404
Number of cattle farmers	34,251
Number of pig farmers	5,821
Number of chicken farmers	13,324
Number of cattle	945,103 LU
Number of pigs	175,461 LU
Number of chickens	69,643 LU

BPAs stand for biodiversity promotion areas. QI are action-oriented payment schemes that reward farmers for implementing specific land management practices; QII are outcome-oriented payment schemes that reward farmers for achieving specific outcomes, such as the number of targeted species per square metre. The numbers were taken from agricultural reports (FOAG 2020, 2021) and Jan et al. (2021).

Regarding environmental topics, we did not consider landscape (the beauty of scenery) and animal welfare for the IBDPS because we viewed them as social concepts, not environmental ones. In the literature, some sources have considered these topics as environmental, while others have categorised them as social (Buijs et al. 2006; FOAG and Federal Office for the Environment (FOEN) 2008; Zapf et al. 2009; Cassatella 2011; Averos et al. 2013; FAO 2014; Prager 2015). We considered biodiversity, greenhouse gas emissions, ammonia emissions, nutrient leaching, plant protection products (PPPs), erosion, and soil organic carbon because these topics are represented prominently in the indicator-based frameworks we used as well as in Swiss agricultural policy.

Initially, we aimed to incorporate existing indicators into the IBDPS on a one-to-one basis. However, in most cases, those indicators were not applicable to a direct payment system for various reasons (see Section 4.1). Therefore, we developed new indicators inspired by existing indicator-based frameworks.

In the agricultural policy literature, there exists a well-known trade-off between the level of transaction costs due to a system's complexity and the level of precision due to targeted policy instruments (Rørstad et al. 2007). The greater the number of instruments, the more expensive it is to implement the system and the more complex it is to use; however, its effectiveness in terms of policy objective attainment can be assumed to rise. As no scientific method exists to identify an optimum in this trade-off, we designed three IBDPS variants that mainly differ in terms of their degree of complexity. In the present study, we focus on the simple variant because the other variants could not be implemented in the SWISSland model due to spatial model resolution and data availability. The selected variant is characterised by very simple indicators (see Section 2.3). In addition, the previously mentioned environmental topics were aggregated into four categories: biodiversity, nutrients and climate, PPPs, and soil. Please see Roesch et al. (2022) submitted for a description of the indicators for the other variants.

The IBDPS is based on the idea that farmers are remunerated according to their environmental impact, which is estimated by using indicators. The amount of direct payments depends on the indicator values (and thus on the estimated environmental impact). To link the indicator values with direct payments, we use external costs (true-cost pricing); the reasons for not choosing compliance costs can be found in Mann (2006). To assess the environmental footprint of a farm, we treat different farm types equally. The IBDPS should reflect when a certain farm type performs better for a specific environmental topic, such as a grassland farm for PPP performance or an arable farm for nutrients and climate performance. Since agricultural structure—e.g. cultivated crops, number of animals—is key to many environmental issues (e.g. Hersener et al. 2011; Bretscher et al. 2018), it should not be neglected in an IBDPS. In the long-term, such an IBDPS could create incentives to steer agricultural structures in a more environmentally friendly direction than is the case today.

The suggested design of the system implies that most farms receive a certain amount of indicator-based direct payments without changing their structure or behaviour because they already perform well in at least one environmental area. This circumstance could lead to (1) a much higher direct payment budget than today and (2) a reduced incentive for farmers to engage in the environmental areas in which they perform badly (due to deadweight effects). To mitigate this problem, we undertook two measures. First, in addition to the current environmentally relevant direct payments, the majority of the food supply and cultivation and single crop payments were omitted from the IBDPS. The current Swiss direct payment system and IBDPS budget shifts are described in Sections 1 and 2 of the Supplementary Material. Since the omitted payment types are not linked to any specific performance (such as landscape quality), the released budget can be used in a more environmentally targeted way (Möhring and Mann 2020). This omission prevents a substantial increase in the total direct payment budget. Second, in SWISSland scenarios (see Section 2.5), we tested the effect of negative payments (i.e. a penalty) if a farm performs poorly in one or more environmental areas. These negative payments reduce the remaining direct payments by the corresponding amount. The sum of all direct payments cannot become negative.

The removal of the aforementioned payment types allows all direct payments that are not used for specific purposes to flow into the IBDPS, maximising the budget available for the new indicator-based environmental payments. Accordingly, we simulated the budget variant with the highest expected effect of payments on the environment. This approach seemed appropriate for an initial analysis of the potential impact of the proposed IBDPS.

Table 2 compares the design principles of the environmentally related direct payments of the current system and the IBDPS.

2.3 The developed indicators

The developed indicators refer to the utilised agricultural area. Other possible denominators are discussed in Section 4.6. The system boundary represents the farm gate, excluding upstream phases (e.g. greenhouse gas emissions related to the production of mineral fertiliser) and downstream phases (e.g. greenhouse gas emissions related to the processing of agricultural products).

Table 2. Comparison of environmental-based payments of the current system with the indicator-based system (IBDPS).

	Current direct payment system	Indicator-based system
Reference for criteria	Administration, supported by scientists	Indicator-based frameworks (e.g. sustainability tools) supplemented by scientific input
Environmental design principle	Political consensus	Direct relationship to externality
Environmental categorisation	(i) Biodiversity payments, (ii) resource efficiency payments, and (iii) production system payments (excluding animal welfare)	(i) Biodiversity, (ii) nutrients and climate, (iii) PPPs, and (iv) soil
Financial design principle	Lump sum payment (if criteria are fulfilled)	Lump sum payment (if criteria are fulfilled) or payment based on linear function between minimum and maximum values
Level of payment	Political consensus	Related to social cost
Level of complexity	Medium	Simple

2.3.1 Biodiversity

Biodiversity-related direct payments are well established in Switzerland (Mack et al. 2020). Farmers receive payments for BPAs such as extensive meadows, hedges, or wildflower strips. These payments are grouped into three categories. First, quality level 1 (QI) areas fulfil certain basic use and maintenance requirements, such as fertilisation or cutting time. Second, BPAs with certain plant species and/or structures, such as stonewall, additionally fulfil quality level 2 (QII) requirements and receive additional payments. QI- and QII-related payments are cumulative, and they differ depending on the BPA type and the agricultural zone (valley, hill, and mountain I–IV). However, QII requirements do *not* exist for all BPAs. For example, BPAs on arable land are exclusively assigned to the QI category. Third, farms can participate in networking projects and receive networking payments for BPAs. According to cross-compliance standards, a farm that receives direct payments must have BPAs on at least 7 per cent of its utilised agricultural area (3.5 per cent for specialised culture farms).

Since BPAs are already established and have greater species diversity than other agricultural areas (Meier et al. 2021), we decided that the biodiversity-related payments in the IBDPS build on the existing direct payment system. As such, we simplified the existing system by only including QII payments in the novel IBDPS; QI payments for BPAs on arable land, for which no QII payments exist, are the exception. Meier et al. (2021) showed that QII areas generally have more biodiversity than QI areas. Keeping QII payments in the IBDPS is a further step toward an outcome-oriented policy (Mann 2010; Rudin et al. 2015).

2.3.2 Nutrients and climate

According to the guidelines and system boundaries of the Intergovernmental Panel on Climate Change (IPCC), the most important greenhouse gas emissions from Swiss agriculture are methane emissions from digestion (55 per cent), nitrous oxide emissions from agricultural soils (26 per cent), and methane and nitrous oxide emissions from manure storage (18 per cent; FOEN 2021)[2]. Swiss agricultural ammonia emissions mainly originate from manure application (40 per cent); emissions from barns, including exercise yards (34 per cent); and manure storage (17 per cent; Kupper et al. 2018). Nitrate leaching is influenced by not only factors such as soil cover and plant nutrient uptake, but also by the amount and type of fertiliser applied. To a large extent, these environmental issues are influenced by the number of animals and the amount of nitrogen applied in the field. Therefore, the nutrients and climate indicator (X_1) is calculated using the following formula:

$$X_1 = 1 - \left(\frac{\text{TAL}}{\text{UAA}} \times 0.33 + \frac{\text{N}_{\text{app}}}{\text{UAA}} \times 0.0025\right).$$
$$|X_1 \in [0, 1].$$

The related payments per farm (P_1) are calculated as follows:

$$P_1 = X_1 \times \text{UAA} \times \text{PL}_{\text{nucl}}.$$

where *TAL* is the total agricultural livestock (in LU); *UAA* is the farm's utilised agricultural area (in ha); N_{app} is the amount of (mineral and organic) nitrogen applied (in kg); and PL_{nucl} is the payment level for nutrients and climate (i.e. CHF 3,100/ha; see Section 2.4). The indicator values range between 0 and 1, where 0 means that a farm receives the minimum payment (CHF 0/ha) and 1 means that it receives the maximum payment (CHF 3,100/ha). For the indicator-based (IB) mandatory scenarios (see Section 2.5), X_1 and P_1 can take negative values, which are associated with a reduction of other direct payments.

TAL represents a proxy for ammonia and greenhouse gas emissions that occur before manure application, including methane emissions from digestion and storage, nitrous oxide emissions from storage, and ammonia emissions from the barn and storage. The larger the animal population, the higher these emissions to a first approximation. N_{app} represents a proxy for ammonia and nitrous oxide emissions in the field and for nitrate leaching. Again, higher applications are associated with higher emissions.

The values 0.33 and 0.0025 represent the threshold values that determine how many animals a farmer may keep and how much fertiliser he/she may apply to receive direct payments. These values can be adjusted, thereby steering direct payments. The initially chosen threshold values allow for an animal density of 1.5 LU/ha and an application of 200 kgN/ha (or combinations resulting in the same indicator value). The threshold values (thr) were changed in the *IB basic thr* and *IB mandatory thr* sensitivity scenarios (see Section 2.5).

2.3.3 Plant protection products

Some existing indicator-based frameworks contain simple PPP indicators, such as the number of inventions, the amount of active ingredients applied, or the treatment index (e.g. Zapf et al. 2009; Gilgen et al. 2022b). However, the active ingredients of PPPs differ greatly in terms of their environmental impact (Korkaric et al. 2020), and this cannot be represented by the indicators mentioned. Thus, we opted for a binary indicator that differentiates between high-risk active ingredients and other active ingredients. Farmers who use one or more high-risk active ingredients (from what we call 'risky PPPs' = RPPPs) cannot receive PPP-related direct payments. Farmers who do not use any RPPPs receive CHF 300/ha for their (whole) utilised agricultural area. PPP payments per farm (P_2) are thus calculated as follows:

$$P_2 = X_2 \times UAA \times PL_{nucl},$$

where $X_2 = 0$ if the farm uses high-risk active ingredients and $X_2 = 1$ if the farm does not use such ingredients. PL_{nucl} is the PPP-related payment level (CHF 300/ha; see Section 2.4).

Korkaric et al.'s (2020) method serves as the basis for making the distinction between RPPPs and other PPPs. The authors calculated risk scores for each (important) active ingredient and various environmental compartments (e.g. groundwater). The active substances listed in Table 1 of Korkaric et al.'s (2020) study were used in the present study; these substances are considered particularly harmful to the environment. However, such a list of high-risk PPPs must be revised regularly, as new active substances are constantly introduced to the market, and others are banned.

2.3.4 Soil

Soil problems, such as erosion, soil organic carbon loss, and compaction, mainly occur in arable farming. In light of this, permanent grassland areas receive the maximum amount of soil payment without further conditions. Since these areas typically have fewer soil problems, it is not surprising that a high proportion of ley in a crop rotation leads to less erosion (Mosimann and Rüttimann 2006; Prasuhn and Blaser 2018; Prasuhn 2022) and higher soil organic carbon content (Neyroud et al. 1997). Catch crops are also beneficial because they cover the soil for longer, protecting it from erosion while also providing more input of organic matter (Mosimann and Rüttimann 2006; Flessa et al. 2019). In contrast, having a high proportion of root crops (maize, potatoes, and sugar beets) in a crop rotation has a negative effect on erosion risk and soil organic carbon build-up because root crops are usually associated with intensive tillage (Neyroud et al. 1997; Prasuhn 2022). The soil indicator (X_3) is determined using the following equation:

$$X_3 = \frac{G_p + G_t + \mathrm{CC} - \mathrm{RC}}{\mathrm{UAA}}.$$

The related payments per farm (P_3) are calculated as follows:

$$P_3 = X_3 \ \times \mathrm{UAA} \times \ \mathrm{PL_{soil}},$$

where G_p is the area of permanent grassland, G_t is the area of temporary grassland/ley, CC is the area of catch crops, and RC is the area of root crops grown on the farm (all in ha). PL_{soil} is the soil-related payment level (400 CHF/ha; see Section 2.4). In the IB mandatory scenarios, X_3 and P_3 can take negative values.

2.4 Payment levels

The payment levels are mainly based on damage costs to internalise environmental damage. For each environmental topic, we identified plausible payment levels, as described below.

2.4.1 Biodiversity

For biodiversity, the *payment levels of the current direct payment system*, which refer to BPAs, were used as a basis (see Supplementary Material). Since some current payments were not considered in the IBDPS (see Section 2.3.1), the remaining payments were increased by 50 per cent to partially counteract this omission. According to Braat and ten Brink (2008), by 2050, the global annual loss of biodiversity on land will increase to a loss of ecosystem services equivalent to 14,000 billion Euros, corresponding to 7 per cent of projected GDP for 2050. This percentage would amount to approximately CHF 45,000 million for Switzerland. However, it is not appropriate to apply this global projection to current Swiss conditions, and it is unclear what proportion of these damage costs would stem from the agricultural sector. Therefore, no biodiversity-related damage costs could be considered in the IBDPS.

2.4.2 Nutrients and climate

Regarding nutrients and climate, we considered damage costs from greenhouse gas emissions (UBA 2019), ammonia emissions (CE Delft 2018; UBA 2019), and nitrate and phosphorus pollution (based on Schaller et al. 2006; FOEN and FOAG 2016; Preschl et al. 2017; FOAG 2019; Schläpfer 2020; SCNAT 2020; FSO 2021). For Switzerland, these damage costs amount to approximately CHF 1,100 million for greenhouse gas emissions (assuming ~6 million tonnes of CO_{2eq} emitted per year), CHF 1,400 million for ammonia emissions (assuming ~40 kt of ammonia-N emitted per year), and CHF 600 million for nitrate and phosphorus pollution. The combined total corresponds to *CHF 3,100/ha* of utilised agricultural area.

2.4.3 Plant protection products

According to the literature, PPP damage costs in the Swiss agricultural sector range from CHF 100 million to CHF 500 million (based on Zandonella et al. 2014; de Baan et al. 2015; FOAG 2019; FSO 2020). The values thus range from approximately CHF 100/ha to CHF 500/ha of utilised agricultural area. In the present study, we assumed a value of *CHF 300/ha*. This value is similar to the current direct payments associated with the partial renunciation of PPPs, which range from CHF 200/ha to CHF 800/ha but only refer to areas on which PPPs were waived.

2.4.4 Soil

Based on available data on erosion, organic matter decline, salinisation, landslides, and contamination, total soil degradation costs for the EU 25 were estimated at up to €38 billion per year (Montarella 2007) or about CHF 350/ha of utilised agricultural area at that time. Therefore, we assumed a value of *CHF 400/ha*. In the current direct payment system, between CHF 150/ha and CHF 250/ha are paid for areas with conservation tillage, which has a strong influence, particularly on erosion (Prasuhn 2012). Soil organic carbon enhancing measures—such as the cultivation of undersown crops, green manure, or ley—were investigated in a resource project in the canton of Solothurn (Canton Solothurn 2020) and rewarded with payments between CHF 110/ha and CHF 420/ha, with an average value of approximately CHF 250/ha. These values, which are lower than the damage costs, only consider some aspects of soil protection.

2.5 SWISSland simulations

The effects of a policy shift to an IBDPS were evaluated using the SWISSland model (Möhring et al. 2016). This model provides future trends in agricultural production and income at the farm and sectoral levels as well as associated structural changes in land use, livestock population, and product prices over a 10–15-year time period. Developed to support policy decisions by assessing the impact of new agricultural policies, this model combines an agent-based approach with a microeconomic model at the farm scale (Möhring et al. 2016).

SWISSland agents, represented by 3,077 farms from the Swiss farm accountancy data network (FADN; Renner et al. 2019), are assumed to maximise farm income in the forecast year, considering various constraints. The production decisions of individual agents are determined based on single-farm optimisation models. Crop and animal production activities are calibrated to observed base-year levels using Positive Mathematical Programming (PMP; Mack et al. 2019). In addition, SWISSland models individual agents' farm exit and takeover decisions and assesses corresponding structural changes in agriculture. It also aggregates the model results of the agents to the national scale using upscaling factors (Zimmermann et al. 2015).

We chose SWISSland for the present study because it allowed us to test how many farmers might participate in the IBDPS and how large the effect on the agricultural sector would be, thus making it possible to not only illustrate some trends in terms of environmental impact (e.g. through nitrogen balances), but also show how agricultural income develops and the degree of self-sufficiency changes. Such consequences are important, for example, for highlighting potential conflicts in agricultural policy objectives and achieving acceptance of the IBDPS. Regarding disadvantages, since SWISSland is not an environmental model, environmental impacts are only partially modelled.

The concept of the IBDPS allows for various design options. For example, the damage costs for nutrients and climate are estimated at CHF 3,100/ha, but it is an open question how damage costs are exactly implemented in the IBDPS. Should farms receive additional direct payments for emissions that they do not emit compared to other farms, i.e. 'save' on average? Or should farms have to pay indirectly for their emissions by subtracting the damage-related

Table 3. Ovverview of the SWISSland scenarios.

Scenario name	Voluntary degree	Payment levels	Nutrient and climate indicator thresholds
Reference scenario	Continuation of the existing agricultural policy		
IB basic	Full	Standard	1.5 LU/ha, 200 kgN/ha
IB mandatory	None	Standard	1.5 LU/ha, 200 kgN/ha
IB basic 0.8	Full	0.8 × standard	1.5 LU/ha, 200 kgN/ha
IB mandatory 0.8	None	0.8 × standard	1.5 LU/ha, 200 kgN/ha
IB basic thr	Full	Standard	1 LU/ha, 150 kgN/ha
IB mandatory thr	None	Standard	1 LU/ha, 150 kgN/ha

The payment levels and the nutrient and climate indicator are described in Sections 2.4 and 2.3.2, respectively.

costs from their (other) direct payments? And, related to that: when environmental direct 'payments' can become negative and thus reduce other direct payments, such farms will simply not participate in environmental direct payment unless they are forced to do so. For this reason, we also conducted simulations in which the IB payments—in contrast to other direct payments—are a prerequisite to receive any direct payments (like cross-compliance).

Such design decisions have an impact on the simulated results. Therefore, various IB simulations were carried out. The IB simulations were compared with a projected continuation of the current agricultural policy in Switzerland, i.e. the reference scenario. Specifically, the following simulations were conducted:

- *Reference scenario*: The existing agricultural policy is maintained.
- *IB basic scenarios*: Participation in indicator-based payments is voluntary for each environmental topic.
- *IB mandatory scenarios:* Participation in indicator-based payments is a mandatory prerequisite for receiving any direct payments (also those not related to the environment). For farmers, the monetary values related to some indicators can become negative and reduce the total amount of direct payments.

As new direct payments were introduced in the IBDPS, others were removed (see Section 2.2). An overview of direct payments in the reference and IB scenarios can be found in Section 2 of the Supplementary Material. Indicator-based direct payments are paid per area and year, in line with other direct payments. In Switzerland, every farm receiving direct payments must fulfil cross-compliance standards, which were included in all scenarios.

The two types of IB scenarios were also each subjected to two sensitivity analyses. The payment levels for all indicators (IB basic 0.8, IB mandatory 0.8) and the nutrient and climate indicator thresholds (IB basic thr, IB mandatory thr; see Section 2.3.2) were adapted. All the scenarios are listed in Table 3. They spanned from 2019 to 2029, and the 3-year average of 2016–2018 was used as a statistical year based on observed data. This time span was chosen because the SWISSland model allows simulations to be conducted from 2019 to 2029. The indicator-based payments in the IB scenarios were introduced as of 2023. In the results section, we refer to the final simulation year (2029).

To model the IBDPS, it was necessary to implement the indicators described in Section 2.3 in SWISSland. We describe this procedure in Section 3 of the Supplementary Material.

3. Results

3.1 Simulated effects of indicator-based payments

This section reports the IBDPS simulation results on a national scale. To this end, we compare the results of the reference scenario with the results of the IB scenarios for 2029. Table 4 shows how the most important variables change.

Table 4. Relative changes for key variables between the IB basic/IB mandatory scenarios and the reference scenario for 2029.

Key variable	Unit	IB basic (per cent)	IB mandatory (per cent)
Utilised agricultural area	Ha	−0.7	−0.3
Open arable land	Ha	−3.2	−2.2
Ley	Ha	−0.9	−0.8
Natural meadows	Ha	0.0	0.3
QII BPAs (excluding trees and alpine summer pastures)	Ha	3.6	3.3
BPAs on arable land	Ha	60.3	60.9
Roughage eaters	LU	−3.7	−3.2
Pigs and poultry	LU	−8.0	−10.1
Total livestock	LU	−4.6	−4.6
Nitrogen surplus	kg N/ha	−3.8	−4.0
Average farm net income	CHF	16.1	11.1
Direct payments	CHF	21.8	13.8
Operating surplus/mixed income according to EAA	CHF	11.7	8.0
Gross self-sufficiency	Per cent	−5.8	−5.9
Number of farms	#	0.2	0.0

Note: The column 'unit' indicates the unit of the key variables; as an example, the relative changes in total livestock are calculated in LU. EAA stands for Economic Accounts for Agriculture.

3.1.1 Agricultural Structure

The utilised agricultural area shows a small decrease due to changes in (mainly open) arable land. While cereal areas are slightly increasing, the silage maize, oilseeds, sugar beet, and protein crop areas are decreasing (not shown).

The livestock declines in the IB scenarios by 4.6 per cent. The roughage eater stocks decline by between 3 and 4 per cent, while the pig and poultry decline is between 8 and 10 per cent (Table 4). The relative changes for pigs and laying hens are significantly higher (8–12 per cent) than the change for fattening chickens (4 per cent; not shown).

A detailed examination at the farm level revealed that declining animal numbers are primarily driven by farm closures. In both IB scenarios, increased farm closures contribute to 70–90 per cent of the total livestock reduction. Thus, herd reductions contribute only 10–30 per cent of the decline. In addition, considerable restocking on other farms occurs.

3.1.2 Agricultural production and degree of self-sufficiency

The changes in the agricultural structure are reflected in production volume decreases for animal products and most plant products (Fig. 1). The most pronounced declines are in oilseeds, sugar, pork, and eggs. Feed grain is the only product that increases in both IB scenarios (2.1–4.5 per cent).

The agricultural production changes are transferred to calorie production of Swiss agriculture. Consequently, the number of calories produced decreases in the plant and animal sectors, and the gross self-sufficiency rate drops from 57.1 per cent in the reference scenario to 53.7 and 53.8 per cent in the IB basic and mandatory scenarios, respectively.

3.1.3 Direct payment budget and farmers' income

In the IB scenarios, some of the current direct payments were omitted and replaced by new IB payments. As a result, food supply payments decrease considerably (Fig. 2). However, even direct payments with unmodified payment levels can change at the sector level. For example, animal welfare payments decrease between 2 and 4 per cent due to the reduction in livestock induced by the IB direct payments.

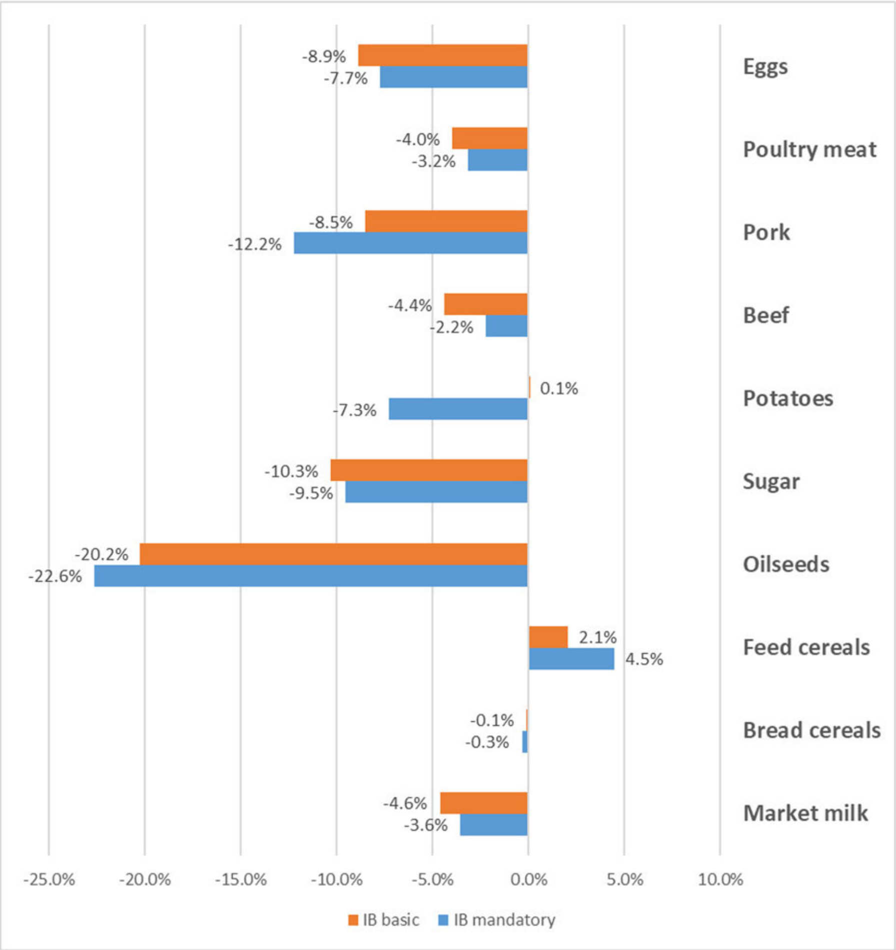

Figure 1. Relative changes in the quantity of goods produced in the IB basic/IB mandatory scenarios compared with the reference scenario.

In the IB basic and mandatory scenarios, the total direct payment budget increases by 18.8 and 13.8 per cent, respectively, due to the high IB payments. The increase is smaller in the IB mandatory scenario due to the compulsory participation requirement and the possibility of negative IB direct payments. In both scenarios, IB direct payments account for more than 60 per cent of the total direct payments and are thus significantly higher than the environmentally relevant direct payments in the reference scenario (22 per cent).

The average farm net income increases in both IB scenarios due to the larger direct payment budget. Income is CHF 104,127 in the IB basic scenario and CHF 100,723 in the IB mandatory scenario; in the reference scenario, it is only CHF 93,258. Mountain farms benefit from the conversion in both IB scenarios and receive significantly more direct payments. Regarding farm type, cattle and suckler cow farms and arable farms benefit in particular (Fig. 3). In contrast, pig and poultry farms in the valley and hill zone are the only farm types to suffer significant income losses at the sector level.

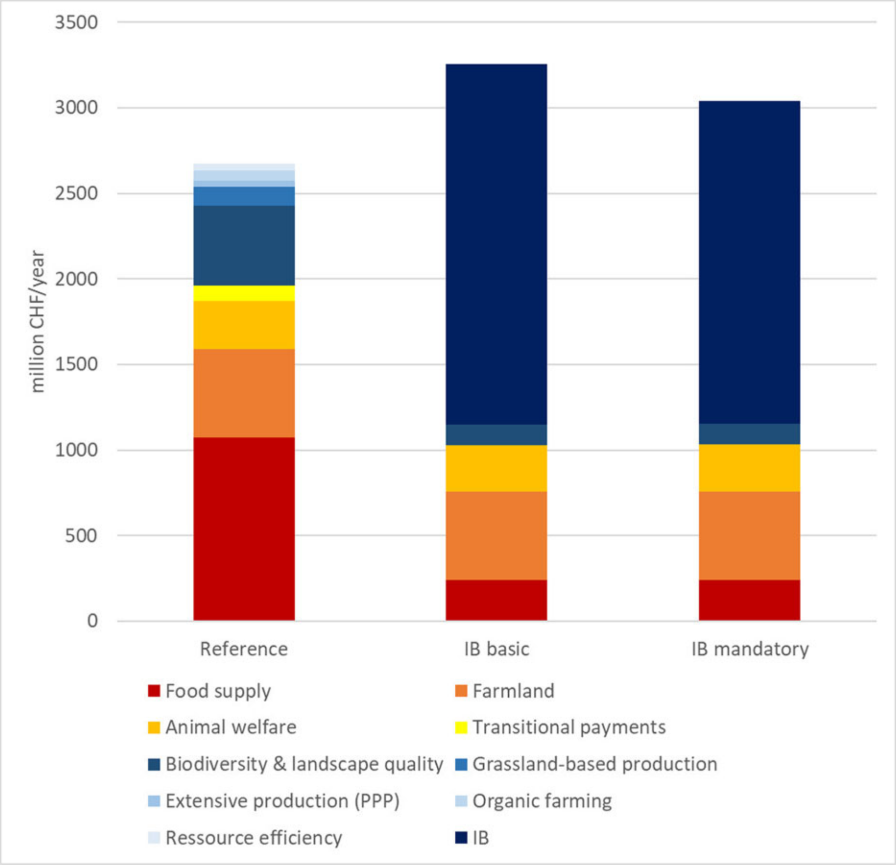

Figure 2. Allocation of total Swiss direct payments for the reference, IB basic, and IB mandatory scenarios. For the IB basic and mandatory scenarios, biodiversity-related payments are included in the IB direct payments, i.e. only landscape payments are included in the biodiversity and landscape quality category.

3.1.4 Environmentally related developments

While SWISSland is the only agent-based sector model for Swiss agriculture, it cannot represent detailed environmental processes. Nevertheless, we were able to draw some conclusions about the expected environmental impacts from the SWISSland results.

The livestock developments, which are particularly relevant for greenhouse gas and ammonia emissions, have already been described. In the case of nitrogen balancing, a slight improvement occurs under the IB scenarios compared to the reference scenario. Overall, reductions of around 4 per cent are achieved in the nitrogen surplus.

Regarding BPA development, there is a pronounced difference between the grassland and arable BPA results in the IB scenarios. While an increase of only 3 per cent can be observed in grassland BPAs compared to the reference scenario, the BPAs on arable land increase considerably (approximately +60 per cent), mainly due to a 50 per cent increase in those payments.

Regarding PPPs, about three-quarters of RPPP users stop using high-risk PPPs in exchange for direct payments. All farms receive soil payments for cultivating some form of grassland and/or green manure.

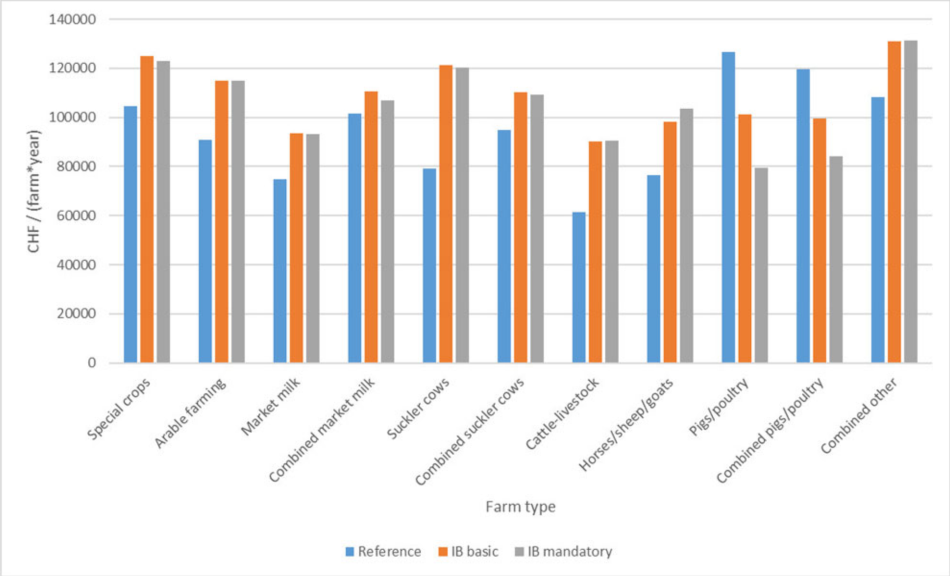

Figure 3. Average farm net income for different farm types for the reference, IB basic, and IB mandatory scenarios.

3.2 Sensitivity of indicator-based payments

3.2.1 Changing the payment levels

This section reports the results from sensitivity scenarios in which the payment levels were reduced by 20 per cent. For example, the IB payment level for soil-related payments was reduced from CHF 400/ha to CHF 320/ha.

The smaller payment levels directly influence the direct payment budget. The total direct payments are now similar to those in the reference scenario: +5.3 per cent for IB basic 0.8 and −1.2 per cent for IB mandatory 0.8, respectively (Tables 5 and 6). Similarly, farmers' income is now, on average, also close to the reference scenario (+2.5 and −1.2 per cent, respectively).

The changes in the agricultural structure are similar to those in the IB basic and mandatory scenarios. In most cases, the changes to the reference are somewhat less pronounced, which would be expected due to the lower payment levels. Arable BPAs are an exception; in many cases, the 20 per cent reduction in payment levels makes cultivation no longer worthwhile. While an increase of about 60 per cent was recorded in the IB basic and mandatory scenarios, the increase in the IB basic 0.8 and IB mandatory 0.8 scenarios is a much more modest 25 per cent.

3.2.2 Changing the indicator thresholds

This section reports the results of the sensitivity scenarios in which the nutrient and climate indicator thresholds were changed. In these scenarios, farmers must fulfil stricter conditions (e.g. lower livestock density) to receive direct payments.

The threshold shift leads to lower federal direct payments and a lower average agricultural income than in the IB basic and mandatory scenarios, as for the other sensitivity scenarios (Section 3.2.1). For IB mandatory thr, direct payments and average income are now even significantly below the reference scenario (−25.3 and −17.6 per cent; Tables 5 and 6) because a large percentage of farms keep most or all of their animals, which leads to high losses in direct payments.

Table 5. Relative changes for key variables between the different IB basic (sensitivity) scenarios and the reference scenario for 2029.

Key variable	Unit	IB basic (per cent)	IB basic 0.8 (per cent)	IB basic thr (per cent)
Utilised agricultural area	Ha	−0.7	−0.9	−3.1
Open arable land	Ha	−3.2	−2.6	−6.9
Ley	Ha	−0.9	−1.6	−4.3
Natural meadows	Ha	0.0	−0.2	−1.8
QII BPAs (excluding trees and alpine summer pastures)	Ha	3.6	1.4	3.9
BPAs on arable land	Ha	60.3	24.2	71.5
Roughage eaters	LU	−3.7	−3.5	−7.9
Pigs and poultry	LU	−8.0	−6.6	−9.1
Total livestock	LU	−4.6	−4.1	−8.2
Nitrogen surplus	Kg N/ha	−3.8	−3.3	−6.2
Average farm net income	CHF	16.1	2.5	−3.4
Direct payments	CHF	21.8	5.3	−0.9
Operating surplus/mixed income according to EAA	CHF	11.7	0.8	−5.9
Gross self-sufficiency	Per cent	−5.8	−5.0	−8.0
Number of farms	#	0.2	0.0	−0.3

Note: The column 'unit' indicates the unit of the key variables; for example, the relative changes in total livestock are calculated in LU.

Compared to the other scenarios, the utilised agricultural areas decrease somewhat (more). For example, the open arable area declines by 4 –7 per cent instead of 2–3 per cent. The livestock and nitrogen surplus changes are also more pronounced. The total livestock numbers decrease by 8 per cent instead of 4–5 per cent. The reductions in agricultural land and livestock lead to more pronounced reductions in the degree of self-sufficiency compared to the other scenarios.

4. Discussion

4.1 Transferability of indicator-based frameworks in direct payment systems

In most cases, indicators could not be transferred directly from the indicator-based frameworks (see also Roesch et al. 2022, submitted; Gilgen et al. 2022a). Most of the analysed indicators were too complex to be suitable for direct payment purposes. The indicators are often calculated with models that depend on many variables; this is problematic because a direct payment system must be controllable and administratively implementable. Furthermore, acceptance of the system is likely to be lower if farmers do not understand it and direct payments become a black box for them.

In individual cases, indicator-based frameworks included simple indicators such as 'field size median' as a biodiversity indicator or 'number of PPP applications'. However, according to consulted experts, these indicators are not environmentally relevant enough: The field size median in Switzerland is small compared to that of other countries, and no major effect is expected from reducing it. The number of PPP applications says too little about their environmental impact, as active ingredients have a wide range of risks.

4.2 Comparison of the current with the indicator-based direct payments

Compared to the current system, the IBDPS uses a much higher proportion of direct payments to reduce environmental impacts. Furthermore, the omission of unspecific payments

Table 6. Relative changes for key variables between the different IB mandatory (sensitivity) scenarios and the reference scenario for 2029.

Key variable	Unit	IB mandatory (per cent)	IB mandatory 0.8 (per cent)	IB mandatory thr (per cent)
Utilised agricultural area	Ha	−0.3	−0.4	−2.2
Open arable land	Ha	−2.2	−1.8	−4.2
Ley	Ha	−0.8	−0.6	−1.9
Natural meadows	Ha	0.3	0.0	−1.9
QII BPAs (excluding trees and alpine summer pastures)	Ha	3.3	1.1	3.7
BPAs on arable land	Ha	60.9	26.5	68.1
Roughage eaters	LU	−3.2	−2.5	−6.5
Pigs and poultry	LU	−10.1	−8.8	−13.4
Total livestock	LU	−4.6	−3.8	−7.9
Nitrogen surplus	Kg N/ha	−4.0	−3.5	−6.6
Average farm net income	CHF	11.1	−1.2	−17.4
Direct payments	CHF	13.8	−1.2	−25.3
Operating surplus/mixed income according to EAA	CHF	8.0	−1.7	−17.6
Gross self-sufficiency	Per cent	−5.9	−5.7	−7.9
Number of farms	#	0.0	−0.3	−0.9

Note: The column 'unit' indicates the unit of the key variables; for example, the relative changes in total livestock are calculated in LU.

(see Section 2.2) allows high environmentally targeted payments without massively exceeding the total direct payment budget. As shown in the sensitivity scenarios, the IBDPS budget can be controlled by adjusting payment levels and indicator thresholds.

Moreover, the IBDPS places a higher weight on environmentally relevant farm structures and production (e.g. livestock per area) than the current environmental payments because they often significantly influence environmental impacts. In fact, Bretscher et al. (2018) concluded that technical measures alone are insufficient to realise substantial reductions in agricultural greenhouse gas emissions and achieve set targets. Consequently, there is a clear redistribution of direct payments in the IBPDS. Pigs and poultry farms lose income due to their high animal densities and high payment levels for the climate and nutrient indicator. In contrast, farms with lower animal densities, such as farms from mountain areas and arable farms, can benefit overall.

The IBDPS presented in the present study is considerably simpler than the current environmental direct payments. A good example is PPPs: In current production system payments, there is a reimbursement for organic farming that, among other things, involves stricter rules regarding PPP use. Production system payments also include a payment for extensive production that rewards the cultivation of cereals, sunflowers, protein peas, field beans, and canola without the use of fungicides, insecticides, growth regulators, and synthetic chemical stimulators of natural defences. In addition, resource efficiency payments include payments for the use of precise application techniques, a payment for internal sprayer cleaning, and various payments for PPP reductions in fruit growing (partial waiver of herbicides, complete waiver of herbicides, and waiver of fungicides with special risk potential[3]), viticulture (partial waiver of herbicides, complete waiver of herbicides, waiver of fungicides with special risk potential, waiver of fungicides with special risk potential, and copper), sugar beet cultivation (mechanical weed control from the four-leaf stage, mechanical weed control from sowing, waiver of herbicides, and waiver of fungicides and insecticides), and open arable land (complete/partial herbicide avoidance). In contrast, the IBDPS only considers whether any RPPPs are used at the farm level. This makes the IBDPS much clearer, easier to control, and more appropriate from an ecological point of view, as it hardly matters on which crop a harmful active ingredient is applied.

4.3 Uncertainties concerning payment levels

We mainly used damage costs to quantify the payments per hectare. These costs originate from various sources, some of which had different methods and system boundaries. Furthermore, making a clear distinction between the damage costs of different environmental issues is challenging because they are partly interrelated. For example, ammonia emissions and PPPs lead to biodiversity losses. For this reason, the chosen values are subject to a certain degree of uncertainty. Nevertheless, it can be stated that the damage costs for nutrients and climate are significantly higher than those for PPPs and soil (see Section 2.4). This is reflected in the IBDPS. The overall damage costs for biodiversity are likely also high; however, we could not specifically assign them to the Swiss agricultural sector. Therefore, we used existing direct payments, which probably lie at the lower end of the damage costs, as a basis. This decision is legitimated by the fact that biodiversity losses are partly already included in other damage costs (e.g. ammonia emissions).

In the present study, the payment levels are spatially constant, except for the biodiversity payments, which are based on current regionalised payment levels. Regionalised payment levels might also be suitable for ammonia emissions and nutrient leaching, for example, because their environmental impact varies regionally. However, the regionalisation of damage costs is not straightforward, as the data availability in Switzerland is still insufficient in some cases (e.g. complete mapping of inflow areas; Gilgen et al. 2022a). Furthermore, under a regionalised payment system, regions that have performed very badly in the past could receive very high environmental payments, which can be considered unfair. In light of this, we used spatially uniform damage costs in this study as the first step. However, the payment levels are not set in stone; they can be adjusted to control direct payment flows, as shown in the IB basic 0.8 and IB mandatory 0.8 sensitivity scenarios.

4.4 Limitations of the SWISSland model

The SWISSland model is designed to optimise the incomes of around 3,000 FADN farms. In reality, non-economic and non-structural factors, such as the morals and values of farm managers and the behaviours of neighbouring farmers, might also influence decisions. These factors can only be partially accounted for in the model. For example, in the case of BPA on arable land, a low acceptance rate is considered in the non-linear optimisation approach.

An additional uncertainty is that SWISSland farms cannot completely change their current production portfolio; conversions from one farm type to another are not simulated. This is realistic insofar as farmers cannot convert their farms in the short term. In the longer term, however, such conversions could take place. We consider smooth conversions of the current production portfolio in the non-linear optimisation models using a PMP approach (Mack et al. 2019). The main advantages of PMP models over conventional linear optimisation models are that they guarantee exact calibration to the base year and avoid predicting overspecialisation of land use and livestock without adding weakly justified constraints to the model formulation (Kanellopoulos et al. 2010).

The occurrence of rare plant species cannot be considered when modelling BPAs, although this is, in reality, important for distinguishing between QI and QII areas. Instead, it is assumed that the ratio between the QI and QII areas per farm remains constant. In SWISSland, a farm must therefore increase a QI area (even if it no longer receives QI payments) so that the corresponding QII area can increase. Furthermore, SWISSland does not consider a certain time lag for the indicator species needed to colonise the new QII areas. The biodiversity results for the QII areas should therefore be treated with caution.

In addition, the simplified implementation of the abandonment of RPPPs in SWISSland causes further uncertainties. Since there is a lack of area-wide data on PPP use on SWISSland farms, a predefined number of farms were forced to decide between ‘continue as before with the same natural yields and no indicator-based direct payment’ or ‘reduced natural yields and indicator-based direct payment’. This is a valid approach, as the predefined number is based on the percentages derived from real PPP use data. However, the determination of PPP farms is a source of uncertainty. Due to resource constraints, only one random selection of farms was simulated.

4.5 Potential improvements in indicators

Indicators at the simple end of the spectrum were developed in the present study so that the IBDPS would be controllable and implementable with little effort by farmers and minimal enforcement. Furthermore, an important prerequisite for the developed indicators was that they could be implemented in the SWISSland model, which has also limited the indicator complexity. It is therefore clear that the indicators by no means take all environmentally relevant aspects into account. Please see Roesch et al. (2022, submitted) for more complex indicators that can account for more environmentally relevant processes and management measures (e.g. the number of lactations).

Regarding biodiversity, with the exception of arable land, only QII payments remain. Therefore, money is only paid if certain plant species or small structures (e.g. stonewall) occur on the area. In practice, however, this approach could lead to a decline in total BPA because it may not be possible to achieve QII at all sites. This could be detrimental to biodiversity. At a minimum, all farms must continue to have at least 7 per cent BPAs due to cross-compliance standards, even if they only have QI areas and thus no longer receive biodiversity payments.

The nutrients and climate indicator includes the variables animal density and nitrogen application in a linear fashion. This approach was inspired by frameworks, such as RISE (Grenz et al. 2009), in which indicators are usually in the form of scores, and full and zero points are given for optimal and minimal levels, respectively. Between these levels, many frameworks assume a linear relationship between rating and scoring. However, some environmental relationships are not linear, and the proposed formula could be refined.

The PPP indicator divides all PPPs into two groups: those that may be used and those that may not. To further differentiate between the various active substances, PPPs could be divided into more groups based on their risk scores.

The soil indicator is defined exclusively by the crops grown. In the indicator, all the considered areas (e.g. ley and root crops) are weighted equally. In reality, different weightings could better describe the actual environmental processes. In principle, many important influences on soil quality—e.g. crop rotation, use of ploughs, and application of organic fertilisers—could not be taken into account in the soil indicator or could only be considered indirectly because the processes affecting the soil often occur at the field level or in even smaller spatial units. However, a field-level approach would contradict the goals of the indicator, namely, to be as easy to control and implement as possible. In addition, since it is not a spatially explicit model, field-level implementation in SWISSland would not have been possible.

4.6 Choice of denominator

The denominator of the indicators is the utilised agricultural area. The derived indicators thus attempt to approximately quantify the ecological footprint of the farms per utilised agricultural area. They do not focus on increasing the environmental efficiency of farms, i.e. achieving low environmental impacts per kilogram of unit produced (e.g. in kilocalories).

We use the utilised agricultural area as the denominator because the agri-environmental policy goals relate to Switzerland, which is defined by its land area rather than its agricultural production. Furthermore, farmers already have an economic self-interest in achieving the highest possible yields with a given level of production input.

However, there are also advantages to the use of a production-based denominator. Such a denominator would lead to a smaller trade-off between improved environmental impact and reduced agricultural production. For resource reasons, however, it was not possible to conduct SWISSland simulations with a different denominator.

4.7 Achievement of agri-environmental policy goals

This section describes a few conclusions about the expected environmental impacts of the IBDPS in terms of agri-environmental policy goals. SWISSland only partially reflects the environmental impacts of current environmentally targeted direct payments. For example, environmental improvements resulting from the use of a drag hose are not explicitly simulated. Omitting these payments could therefore lead to higher ammonia emissions, which we cannot model in the present study. However, it must be taken into account that resource efficiency payments are limited in time; therefore, long-term behavioural changes are not guaranteed.

BPAs on arable land increase significantly (by about 60 per cent) in the baseline IB scenarios. Although this increase is positive in terms of the biodiversity deficit in those areas, it is not sufficient to achieve agri-environmental policy goals: The FOAG (2022) proposed a minimum proportion of 3.5 per cent BPAs on arable land for cross-compliance standards. Based on the increase in the present study, just under 1.2 per cent of the arable land (including ley) would be BPAs. The area and quality of the other BPAs hardly change in the IBDPS.

The climate and nutrients payment leads to a reduction in livestock of about 5 per cent and a reduction in the nitrogen surplus of 3–4 per cent. The stricter indicator thresholds in the sensitivity scenarios lead to reductions of up to 7–8 per cent. Nutrient and climate improvements can be expected in the same order of magnitude, since the number of animals and the nitrogen applied are the main drivers of these emissions. The significantly more ambitious policy targets (FOEN & FOAG 2016; FOAG 2022) cannot be achieved with these reductions: The agri-environmental targets assume a reduction of ammonia emissions by more than 50 per cent, a reduction of greenhouse gas emissions by one-third between 1990 and 2050 (only 12 per cent has been achieved so far), and a 20 per cent reduction of nitrogen and phosphorus surpluses by 2030 (reference years: 2014–2016).

According to the SWISSland simulations, the IBDPS would lead to a large proportion of farms dispensing with RPPPs. These active substances clearly dominate the risks to surface waters, groundwater, and bees (Korkaric et al. 2020). Thus, the goal of halving PPP-related risk between 2012–2015 and 2027 (FOAG 2022) could be achieved through a significant reduction in their usage. However, it is likely that farms with low use of irreplaceable RPPPs will waive their use, while farms with a high level of use will proceed as before and forego direct payments. Therefore, the proportion of farms dispensing RPPPs might be higher than the proportion of the area in which RPPPs are no longer applied.

Concerning soil protection, no statement can be made about the environmental impact from the SWISSland results. A comparison with political targets is anyway hardly possible because the target gaps regarding erosion and soil fertility are not precisely known (FOEN and FOAG 2016).

Overall, although the IBDPS was designed to create significant environmental improvements, it clearly did not achieve the agri-environmental policy goals. We attribute this to the fact that it only changes one component of the agricultural policy system. We suspect that more environmental improvements would be achieved using a holistic approach.

4.8 Further possibilities for achieving agri-environmental policy goals

According to our simulations, although the IBDPS strongly rewards more environmentally friendly structures and management, it does not lead to a strong change in agricultural structures. Besides SWISSland's inability to simulate farm-type conversions, the main reason for this is the framework conditions outside the environmental direct payments. Market prices as well as other direct payments play a decisive role. For example, it is still worthwhile for many specialised livestock farms to keep their animals because the market performance of Swiss animal products is high. In addition, some current direct payments, such as animal welfare payments, are linked to the number of animals, and thus contradict the IB payments.

A change in the direct payment system alone does not seem to be effective. However, other (additional) possibilities are open to policymakers. One important influencing factor is consumption, as production reflects demand. If fewer environmentally harmful products were consumed, then their production would decrease. Therefore, at best, production and consumption levers should be applied simultaneously. Furthermore, there are other options besides direct payments for encouraging producers to act in a more environmentally friendly way, including legal requirements, some of which already exist today (e.g. the Water Protection Act).

4.9 Critical appraisal of the ex-ante policy impact assessment

We have already discussed the limitations of the developed indicators and SWISSland model in previous sections (Sections 4.4 and 4.5). Here we evaluate at a higher level which limitations are associated with the basic concept of the research study, i.e. the development and evaluation of new environmental direct payments using a sector model.

Every model only depicts a part of reality. Model results are therefore always an amalgamation of model-specific effects and the conducted simulations. Thus, it is difficult to determine to which degree model simplifications affect the simulated results. The evaluation of models is one way to better understand model uncertainties and to improve the models (e.g. Mack et al. 2019). However, such evaluation studies for direct payment systems can usually only be carried out after the new system has been implemented. Alternatively, it would be possible to test a new direct payment system in a farm network before its implementation, which requires a lot of resources. However, modelling studies can also be considered as the first step in a chain of action: First, to model the expected effects on the agricultural sector. Second, to launch a pilot project if the simulated changes in the direct payment system are promising. Third, to introduce the new direct payments throughout Switzerland if the pilot project is successful.

A further possibility to deal with model uncertainties is to use different models to answer a certain research question. The idea behind this is that different model errors balance each other out on average. Such approaches are used for future climate projections (Eyring et al. 2016). However, these projections are very expensive because each (complex) model requires a high level of expert knowledge and simulations need computing power. In our study, we are also limited by the fact that no comparable model to SWISSland exists for the Swiss agricultural sector. This could remain the case in the future, as such models have to be specific to the Swiss agricultural sector—unlike climate models, which make global projections and are thus developed in different countries.

In this study, we introduced several new environmental direct payments and skipped several existing payments. All changes in the direct payments were simulated simultaneously. With this approach, it is not possible to fully disentangle the effects of the individual changes in the new direct payment system. Stepwise simulations are an approach to better understand which changes in model results stem from which changes in direct payments. However, such step-by-step simulations are very time-consuming. Furthermore, the combinations of the individual payments in the simulations affect the model results: because of non-linear effects, the model result is different when running a simulation with two additional payments A and B than when running a simulation with payment A and a simulation with payment B and adding these changes.

For this reason, stepwise simulations should only be carried out if the gain in knowledge outweighs the costs. In our case, this was rather not the case, as our focus was on evaluating the new direct payment system as a whole. Also, in our case, stepwise simulations would have led to very large changes in the total direct payment budget, which would in some cases have caused many farmers to drop out of production (e.g. omission of food supply payments). Such 'findings' provide limited implication.

A clear limitation of the study is that environmental impacts are only modelled in a reduced manner with SWISSland. To improve this, it would be useful to further develop existing models or to couple existing models with different foci. However, it is worth mentioning that many environmentally relevant management data are currently only available for a very small proportion of Swiss farms (Gilgen et al. 2022b). Such data would be important to adequately describe the current environmental state for the reference simulation in an improved model.

5. Summary and conclusion

In the present study, we developed a concept for a new, environmentally oriented direct payment system for Switzerland with the goal of substantially reducing the environmental impact of agriculture. We drew inspiration from existing indicator-based frameworks, such as RISE or the SAEDN. Simple indicators for four environmentally relevant topics—biodiversity, nutrients and climate, PPPs, and soil—were derived and linked with specific payment levels. We primarily evaluated damage costs to determine the payment levels. In this way, we approximated the actual environmental damage in the indicator-based system. Nutrients and climate was found to have the highest damage costs and thus the highest payment level in CHF per utilised agricultural area.

Current environmentally oriented direct payments include measures such as the renunciation of fungicides and insecticides in cereal production or the use of drag hoses for spreading manure. Meanwhile, structural variables that influence the environment, such as the penalisation of PPP-intense crops and the number of livestock, are of limited importance. In contrast, we try to introduce the environmental damage of farms into the direct payment system. Consequently, the newly developed indicator-based payments give higher weight to environmentally relevant farm structures and the overall use of production inputs because these often exert a larger influence on environmental impact than single technical or management measures. For example, in the indicator-based system, it only matters which PPPs are used on a farm; it does not matter whether the farmer cultivates grassland, winter wheat, sugar beets, and/or apples. Thus, the indicator-based payments aim to steer agricultural structures in a more environmentally friendly direction.

The SWISSland model simulations show that, despite high incentives, the indicator-based payments only achieve modest environmental progress. One main reason for this result is the relatively high market prices for livestock products, which limit the incentive to reduce the number of animals. Moreover, the achieved environmental improvements are the result of extensified production, which represents a conflict of objectives for agricultural policy. These results only refer to Switzerland, and their applicability to other agricultural policy systems is unknown. However, our concept of developing indicator-based direct payments is transferable to other countries.

A clear weakness of our study is that the sector model only depicts environmental impacts to a limited extent. Such shortcomings could be remedied in the future through further development of models and greater availability of environmental data. Moreover, our study is purely conceptual and model-based. In order to test whether the new direct payments would actually have the simulated effect, further studies could be conducted on pilot farms.

We conclude that indicator-based direct payments are worth pursuing despite their modest environmental improvements. The presented system impresses with its simplicity, and it should penalise the actual environmental pollution of farms more realistically than the current direct payment system. Since it can be designed in many ways with different variants—e.g. with/without negative payments, with indicator threshold adjustments—it offers several possibilities for direct payment budget control.

Supplementary material

Supplementary data are available at *Q Open* online.

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Data availability statement

The code (from the SWISSland model) is not shared because the model is only developed and used at Agroscope. The data used for the model (from the farm accountancy data network and the Swiss agri-environmental data network) are not publicly available due to reasons of confidentiality and data contracts. The important results of the SWISSland model are included in an understandable form in the tables of the paper.

End Notes

1 In Switzerland, ecological focus areas are called ‘biodiversity promotion areas’.
2 If we consider agricultural sources in a broad sense (including e.g. CO_2 balance of agricultural soils and energy use), the CO_2 balance of agricultural soils has a similar importance as that of manure storage (FOAG 2019).
3 These PPPs are defined differently compared to the RPPP in the IBDPS.
4 Ley denotes the cultivation of grass in crop rotation.

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