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Abandoned farmland: Past failures or future opportunities for Europe's Green Deal? A Baltic case-study

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ABSTRACT

Competing societal demands on land require careful land management. In the era of the European Green Deal, farmers are required to meet some of these competing demands, specifically around production, greenhouse gas emission reductions, and biodiversity conservation. At the same time, 15.1% of total EU land is abandoned or underutilised, which means that it contributes neither to food, nor to ecosystem services, to its full potential. Reintegrating abandoned agricultural land back into production is therefore one of the potential pathways to deliver on the aspirations of the Common Agriculture Policy post-2020. In this paper we assess the potential of managing and reintegrating abandoned agricultural land in Europe to simultaneously increase primary productivity, carbon regulation and habitat for biodiversity, using Latvia as a national case-study that is representative of this challenge in a Baltic context. Our results show that for some regions, reintegration of abandoned agricultural land can lead to "triple win" synergies. These opportunities can be further exploited by applying best management practices to these reintegrated lands. In other regions, where the area of abandoned agricultural land is limited because of favourable biophysical conditions for intensive agricultural production, such "triple-win" synergies are scarce. In such areas, abandoned land plays a role in maintaining ecosystem services at local and regional scales, and even small increases in primary productivity come at the expense of biodiversity. This calls for careful management that involves diverse actor groups, including land managers, in the decision-making process, and in priority setting in each of the regions.

1. Introduction

Europe's agricultural land is subject to competing societal demands to provide multiple ecosystem services in support of sustainable land use and human well-being (Schulte et al., 2019). Meeting these multiple common objectives requires careful land management, which in turn must be supported by evidence-based policymaking (Thomson et al., 2019). The European Commission has published the European Green Deal, a cross-cutting plan to trigger action across all sectors of the European Union (EU), to make its economy sustainable, including an ambitious target to make Europe the first climate-neutral continent by 2050 (EC, 2020a).

In 2020, the Farm-to-Fork Strategy and the Biodiversity Strategy were published, outlining specific objectives related to sustainable land use and proposing a strengthening of a range of policies, such as the Common Agriculture Policy (CAP) reforms post-2020. The new CAP reforms, which were agreed upon in July 2021, include a clause stating that, "the Commission should assess the consistency and contribution of the proposed CAP Strategic Plans to the Union's environmental and climate legislation and commitments and, in particular to the Union targets for 2030 set out in the Farm to Fork Strategy and the EU biodiversity strategy" (EC, 2021a). While member states will not be legally required to meet all the objectives outlined in the Green Deal, their National Strategic Plans will need to show consistency with those targets. This requires the strategic use of tools within the agreed CAP framework that tackle multiple objectives to provide "triple win" outcomes (EC, 2020b).

Within the context of sustainable land management, soil is the most important resource that provides food, feed, fibre, water purification and regulation, nutrient cycling, carbon sequestration and regulation,

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and habitat for biodiversity (Calzolari et al., 2016; Haygarth and Ritz, 2009; Schulte et al., 2014). Soils differ in their capacity to deliver on each of these ecosystem services, and we know that it is not possible for all soils to meet all of the societal demands for these services everywhere at the same time: applying the same set of management practices to augment the soil functions on all soils for all farm systems within a country will not achieve the desired achievement of policy targets at national scale, because of the prevalence of trade-offs between soil functions and between management practices (Schulte et al., 2019). Augmenting a single soil function, which is usually intended to achieve one individual policy objective, always affects the performance of other soil functions, potentially jeopardising policy objectives from other sectors.

However, instead of maximising, we can optimise the delivery of multiple soil functions in order to meet societal demands at local, regional and national scales. Functional Land Management (FLM) provides a framework to assess both the societal demands for soil functions, and the capacity of soils to deliver on these demands (Schulte et al., 2014, 2015, 2019). The FLM concept takes the soil biophysical conditions, as well as their potential, into account to optimise rather than to maximise the supply of soil functions (namely primary productivity, water purification and regulation, carbon sequestration and regulation, the provision of habitats for biodiversity, and the provision and cycling of nutrients) in order to meet the functional and societal demands for soil functions defined at the local, national or international scales. Subsequently, it is then possible to assess the potential of each soil/land use combination to deliver soil functions (Coyle et al., 2016; Schulte et al., 2014). For instance, Schulte et al. (2016) uncovered several pathways for context-specific optimisation of production and ecosystem services in Ireland, in support of the development of knowledge-based agri-environmental policies, which have now been adopted in the draft Agri-Food Strategy 2030 by the Government of Ireland (DAFM, 2021). Through further case studies in Ireland and Latvia, Valujeva et al., (2016, 2020) showed that such regionally differentiated approaches to the prioritisation of soil functions can indeed meet national targets at a national scale.

Thus far, these case studies were based on the assumption that the amount of land is limited and cannot be expanded further. However, Pinillos et al. (2020) showed the potential of abandoned land at the Amazon frontier to better contribute multiple ecosystem services, through carefully planned land use management, and with the inclusion of local actors. There are many economic, social and ecological factors that influence land abandonment: the migration of residents from rural areas to cities in search of prosperity and higher incomes; poor infrastructure; distance to regional centres; land management challenges; low soil fertility and the lack of funds for improvement; and reduced labour requirements that result from the development of agricultural equipment (Abolina and Luzadis, 2014; Suziedelyte Visockiene et al., 2019). Rural vitality requires an increase in social and economic opportunities, which encourages young people who have emigrated to the urban areas for myriad reasons (e.g. skill expansion, or career and identity development) to remain or return to the rural areas (Riethmuller et al., 2021). Abandoned land is often viewed as a relic of historical events and migration of residents. In this paper, assess the extent to which a reversal of such processes can provide opportunities to revalue rural areas, to redevelop rural communities, to create additional jobs in the regions and to improve the regional capacity to attract investment. In addition, returning abandoned land to its previous state can improve their ecological status and provide a variety of ecosystem services. This is exemplified by the recultivation of drained and abandoned peatlands, which can increase carbon sequestration and biodiversity, and provide flood protection (Kløve et al., 2017). However, this synergy between economic returns and ecosystem services is not a given. For example, the removal of shrubs and reintegration of abandoned agricultural land into production can provide economic returns, food, fibre, fuel, and jobs—but can negatively affect environmental outcomes (Kennedy et al., 2016). Using abandoned agricultural land for short-rotation woody crops is a viable solution in areas with low-fertility and fragmented agricultural land, on which environmental, social and economic conditions are not suitable for agricultural production (Abolina and Luzadis, 2014).

In the EU, 40.4% of the total land area is actively managed by farmers. At the same time 15.1% of land is unused or abandoned with signs of previous use (Eurostat, 2020, 2015). Land abandonment is a multidimensional process affected by a wide range of drivers and their interactions, specifically differences in the degree of land management and regional differences in competitiveness (Schuh et al., 2020). It can occur in socio-economically favourable countries with high agricultural potential (e.g. such as 11.7%, 12% and 7.8% abandoned agricultural land in the Netherlands, France, and Poland, respectively), as well as in countries that are still developing towards their socio-economic potential (e.g. 12.5%, 11.2%, 9.4% for Bulgaria, Latvia and Slovakia, respectively) (Table S1). Land abandonment is a continuous process, with a further 3% of total agricultural land in EU projected to be abandoned by 2030 (Perpiña Castillo et al., 2018). The highest rates of further abandonment are projected for Spain, Poland and Slovakia (5%, 4.8% and 4.6%, respectively), and the lowest for Cyprus, Luxembourg and Slovenia (0.4%, 0.4% and 0.6%, respectively). For Latvia, a further 2.9% of total agricultural land is projected to be abandoned (Table S1).

Typical causes of land abandonment include dependence on water resources and increases in tourism in Southern European countries, limited areas for agricultural production, remoteness and decreased accessibility to the market in Northern European countries (Schuh et al., 2020), and low agricultural productivity and expansion of the settlements in mountain areas (Dax et al., 2021). In Central and Eastern European countries, land abandonment was induced by the transition to post-socialism, coupled with a decline the perceived attractiveness of the remote countryside (Van Vliet et al., 2015). Latvia exemplifies this Central and Eastern European challenge, and is therefore used in this paper as a case-study to assess the potential of reintegrating abandoned land in Europe as one of the pathways to achieve the multiple objectives of the European Green Deal. From the above we hypothesised that the reintegration of abandoned land can contribute to the simultaneous achievement of the socio-economic and environmental sustainability objectives.

2. Materials and methods

2.1. Case studies

Latvia is a country in the Baltic region located in north-eastern Europe with total area of 64,600 km^2 (Fig. 1). 52% of the total area is covered by forests, but agriculture occupies 36% of its total area. Natural conditions in Latvia are determined by its geographical location, which is in the western part of the Eastern European Plain (Nikodemus, 2019). The average annual precipitation in Latvia is 703 mm, which exceeds evaporation by an average of 245 mm each year (LVĢMC, 2017). As a result, Latvia is rich in waterbodies: large areas are occupied by bogs, and the predominant processes in soil genesis are podzolisation and gleyzation, due to the positive moisture balance (Nikodemus, 2019). Agriculture and forestry in Latvia depend largely on land reclamation, which has had an effect on soil moisture and river runoff. Small-scale climatic variation, as well as differences in relief, have determined the soil formation processes and their spatial distribution in Latvia. This has led to regional differences in natural conditions (Nikodemus, 2020).

Latvian agriculture has undergone many historic shifts, including the division of land to landless inhabitants, the establishment of farms and the boom in agricultural production, as well as the establishment of collective farms and the nationalisation of land (Zemītis et al., 2016). In 1990, the restructuring process led to fundamental changes in the structure of Latvian agriculture, namely (1) changes in land ownership and (2) the redistribution of fixed assets of large collective farms to

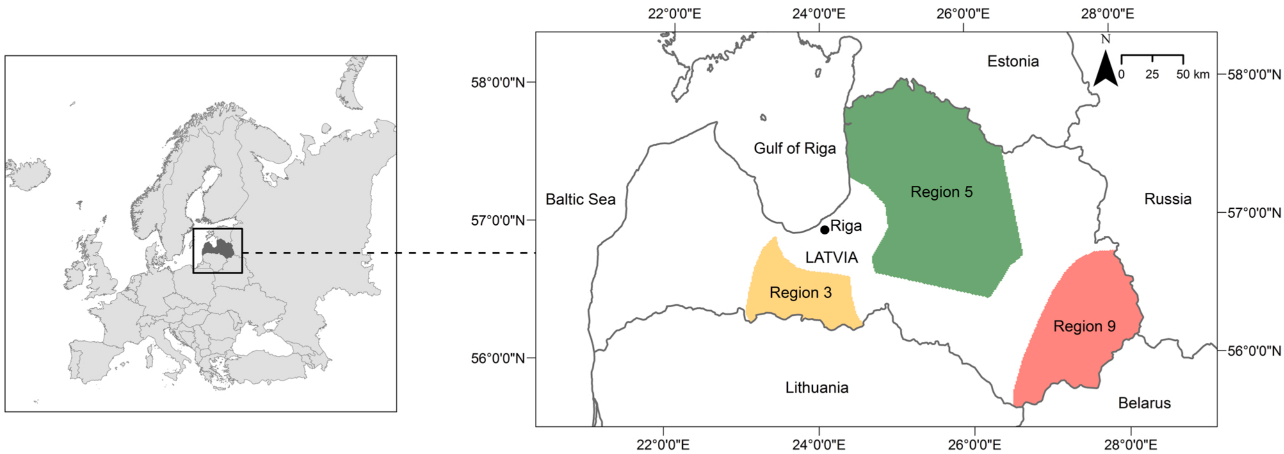

Fig. 1. Map of studied regions in Latvia.

private farms (Strīķis, 1997). These changes led to the collapse of agricultural activity with a decrease in the amount of agricultural land and livestock (Valujeva et al., 2020), and the abandonment of about 11% of agricultural land (Nipers, 2019). This lasted until Latvia joined the European Union in 2004 and benefitted from support payments of the Common Agricultural Policy (Zdanovskis and Pilvere, 2015).

In order to recover the potential of the Latvian economy, the Bioeconomy Strategy has defined two targets related to increasing production: (1) an increase in added value from the bio-economy sectors to at least EUR 3.8 billion in 2030 and (2) the promotion and maintenance of employment in bioeconomy sectors up to 128,000 inhabitants (LIBRA, 2030, 2017). Considering that this growth would increase emission, achievement of these targets is restricted by the EU Climate and Energy Framework 2030, which sets a 6% reduction in greenhouse gas (GHG) emissions from the Latvian non-ETS sector as compared to 2005.

In a previous study (Valujeva et al., 2020), we identified the supply and demand for three soil functions relevant to Latvia's agro-climatic conditions; namely, primary productivity (PP), carbon regulation (CR), and habitat for biodiversity (BD), using European and Latvian policies to guide the quantification of demand for soil functions, and the gradient from mineral to histic soils and land use for the quantification of supply of these same soil functions. In that paper, we explained the parameterisation of the demand for PP through the combination of regional bioeconomy GDP targets and unemployment rates at the municipal level using the tabular index approach by Greiner et al. (2018). Following the land use, soil characteristics, climatic conditions and the effect of management practices on the supply of PP, profits from farming and forestry were combined with labour-time requirements into one integrated societal supply metric for PP, again using the tabular index approach (Greiner et al., 2018). In addition, the demand for CR was framed according to international obligations, under which the EU is participating as a single signatory, and which divides the collective target asymmetrically between Member States depending on GDP. Therefore, 2030 target for Latvia of a six percent decrease in emissions from non-ETS sectors compared to 2005, was used and distributed evenly at the national scale. For the evaluation of CR supply soil carbon stock values from national studies (Bardule et al., 2017; Lazdins et al., 2014; Lazdiņš et al., 2015) were combined with CO_2 emission factors from drained organic soils from the IPCC Wetlands Supplement 2013 (IPCC, 2014), again using the tabular index approach (Greiner et al., 2018). The demand for BD was framed by the bird species richness and abundance as general indicators for BD. To this end, targets for forest and farmland birds from the National Development Plan of Latvia for 2014–2020 were used to derive societal demand for BD in Latvia; however, the supply indices for BD were derived from the relationships between habitat quality and land-use intensity in the EU (Reidsma et al., 2006). Mapping both the supply and demand for these soil functions showed regional differences in the challenges that land managers face, with some regions showing opportunities for short-term growth of the bioeconomy, and other regions being best placed to safeguard biodiversity and carbon storage in the long-term. For further details we refer to Valujeva et al. (2020).

For this current study on the potential role of reintegrating abandoned agricultural land in delivering on PP, CR and BD, we used three contrasting regions from Valujeva et al. (2020) to assess regionalised pathways for meeting both socio-economic and environmental targets (Fig. 1). The performance of abandoned agricultural land in the provision of soil functions is reflected in the Valujeva et al. (2020) in Supplementary Material: supply of PP of abandoned agricultural land is assumed to 0, but it provides CR and BD.

Region 3 is characterised by homogeneous agricultural landscapes with intensive agricultural production, resulting in large farms that occupy more than half the agricultural land (Fig. 2). It is the largest cereal producer with higher soil fertility than other regions of Latvia (ZPR, 2015). While Region 3 is a highly productive agricultural region, it now faces new demands to also deliver BD and CR, without compromising productivity, and to continue to improve management practices (Valujeva et al., 2020). Agricultural production in Region 5 is affected by uneven terrain and clay soils, and as a result, the majority of this region is used for grasslands and forests (VPR, 2015); there is no pressure to increase productivity in Region 5 in the short-term. This region offers opportunities to contribute to long-term environmental targets through knowledge-based and targeted land-use change (Valujeva et al., 2020). Region 9 is characterised by the widespread abandonment of farmsteads (which are historically characteristic of Latvian society), which has resulted in many abandoned agricultural fields. In this region, large and small farms account for the same amount of land, which in turn signifies that small farms outnumber large farms (ZM, 2017). Also, Region 9 is economically poor: here, increases in productivity, income, and employment are urgently needed without compromising the delivery of the CR and BD (Valujeva et al., 2020). More than 75% of agricultural lands in all regions can be found on mineral soils (Fig. 2). The database used for the study was created within a project "Evaluation of the land use optimisation opportunities within the Latvian climate policy framework" (funded by Joint Stock Company "Latvia's State Forests") (Nipers, 2019) and is described in detail by Valujeva et al. (2020): it consists of an agricultural spatial dataset at the scale of 1:5000 from the Rural Support Service (http://www.lad.gov.lv/lv/) with detailed information of: area, crop type, and farming system; a forest spatial dataset at scale 1:10,000 from the State Forest Service (http://www.vmd.gov.lv/lv/) with detailed information of forest type, age of forest stand, main species in forest stand and restrictions in forest stand; a land use and landholder spatial dataset at the scale of 1:2000 from the

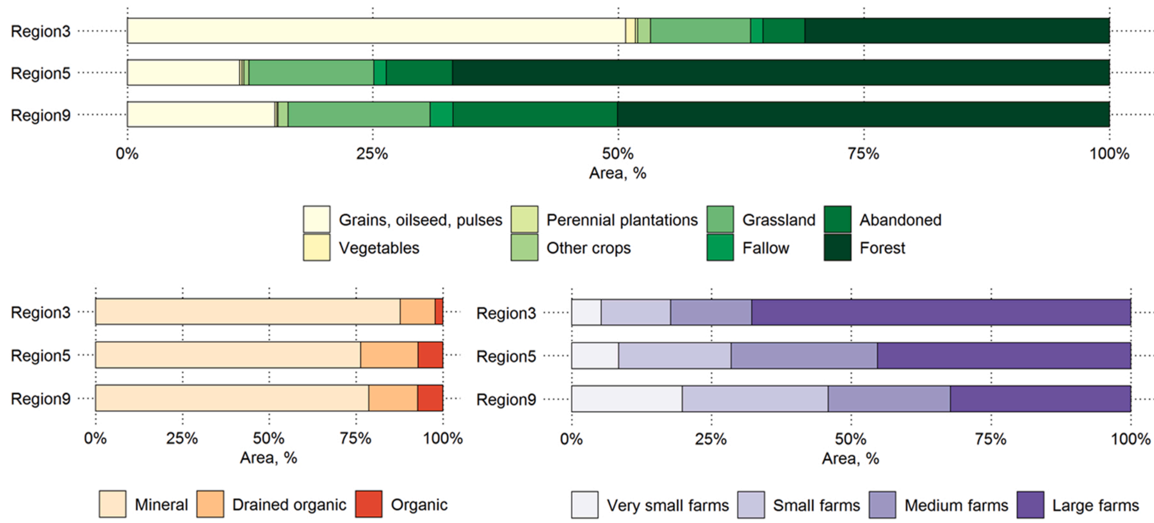

Fig. 2. Overview of land use, soil type and farm distribution in regions. Groups of farm sizes for different agricultural sectors are described in Supplementary Material Table S2.

State Land Service (https://www.vzd.gov.lv/lv/) with information of property, landholder, land area, land use, value, encumbrances, buildings and their elements; the CORINE Land Cover database at the scale of 1:100,000; a land reclamation map at the scale of 1:10,000 from the State Limited Liability Company, "Ministry of Agriculture Real Estate" (https://www.melioracija.lv/) with information regarding the drainage status of agricultural fields; an agricultural soil dataset from digitised historical soil maps at the scale of 1:10,000. The database is static and consists of 4.4 million agricultural land-use polygons and 2.3 million forestry land-use polygons and represents the situation in 2016.

From the aforementioned database, we created data matrices for the optimisation of each region. The data matrix for each region consists of a combination of 53 land uses (grain, oilseed, pulses, vegetables, perennial plantations, other crops, fallow, grassland, abandoned agricultural land, forest), soil classes (mineral, drained organic, organic) and farm sizes (very small, small, medium, large) (Table 1). An overview of the farm size by main crop is summarised by Nipers (2019), in Supplementary Material Table S2. For each region, the total area of each combination is known. It is not possible to determine the farm size of the abandoned agricultural land and forest land. Furthermore, natural bog areas and peat extraction fields are excluded from the study, and therefore the organic soil class, which is defined as organic soil that is not affected by artificial drainage, is found only in forest land (Valujeva et al., 2020).

2.2. Optimisation scenarios

In the current study, we created optimisation scenarios for each region, specific to the supply and demand balances for each region (Table 2). All scenarios were run twice: in the first run, only two of the three functions were included as the primary objective variables (in most cases PP and CR), whereas in the second run, all three soil functions were included as objective variables for the optimisation. Furthermore, all runs of all scenarios were performed twice: first, where we only allowed changes in land use for the abandoned agricultural lands optimisation decision variables, and secondly, where we included the introduction of improved management practices as additional optimisation decision variables. These management practices and land-use changes to regions were selected from Valujeva et al. (2020) to improve or maintain the supply of the three soil functions, namely primary productivity, carbon regulation and biodiversity (taking into account the supply-demand balance for each soil function in each region).

Management practices included: A) Afforestation of fertile well drained organic soils; B) Use of farmyard manure and green manures along with returning crop residues; C) No till increases fungal biomass in general, which leads to improved soil structure that increases infiltration and reduces erosion; C) High-precision management of nutrients, chemistry, water, pests, and pathogens; D) Diversification of crop types, permanent plant cover, buffer strips; E) Increase groundwater level on organic soils for shallow rooting vegetable production; F) Application of organic amendments in combination with inorganics in wheat cropping system; G) Conversion of some of the current annual crops to grassland; H) Rewetting organic soils under grassland leads to these ecosystems becoming neutral or small C sinks. Expert judgement was used to contain the relevance and applicability of each of these management practices to region, land use, soil type and farm size (Supplementary Material Table S2).

Table 1
Data matrix for optimisation. The numerical labels are used in the coding of land use/soil class/farm size combinations of the study.

Land use	Mineral soil				Drained organic soil				Organic soil
	Very small	Small	Medium	Large	Very small	Small	Medium	Large	
Grain, oilseed, pulses	1	2	3	4	5	6	7	8	N/A
Vegetables	9	10	11	12	13	14	15	16	N/A
Perennial plantations	17	18	19	20	21	22	23	24	N/A
Other crops	25	26	27	28	29	30	31	32	N/A
Fallow	33	34	35	36	37	38	39	40	N/A
Grassland	41	42	43	44	45	46	47	48	N/A
Abandoned agricultural land	49				50				N/A
Forest	51				52				53

Table 2
Overview of the optimisation scenarios applied to the regions in the study.

Region	Supply-demand balance from Valujeva et al. (2020)	Scenario	Run	Objective
Region 9	High demand for primary productivity and carbon regulation function with short-term returns on investments	Scenario 1	Run 1	Maximise PP and increases CR
			Run 2	Maximise PP, increase CR and BD
		Scenario 2	Run 1	Maximise CR and increase PP
			Run 2	Maximise CR, increase PP and BD
Region 5	Potential to increase supply of CR through longer-term measures, specifically relating to optimising land use	Scenario 1	Run 1	Maximise PP and increase CR
			Run 2	Maximise PP, increase CR and BD
		Scenario 2	Run 1	Maximise CR and increase PP
			Run 2	Maximise CR, increase PP and BD
Region 3	Highly productive area with additional demands for CR and BD. Opportunities for management practices that increase CR and BD while maintaining PP.	Scenario 1	Run 1	Maximise PP and increase CR
			Run 2	Maximise PP, increase CR and BD
		Scenario 3	Run 1	Maximise CR and increase BD
			Run 2	Maximise CR, increase BD and PP
		Scenario 4	Run 1	Maximise BD and increase CR
			Run 2	Maximise BD, increase CR and PP

2.3. Optimisation

Considering the conflicting objectives of soil functions, the ε-Constraint approach for multi-objective optimisation (Kaim et al., 2018) was applied to identify the optimal land use for abandoned agricultural land that has been returned to production, using the lpSolveAPI package in R 3.6.3. LpSolveAPI is an interface for freely available lpSolve software; it is a Mixed Integer Linear Programming (MILP) solver for linear, integer, mixed integer, binary, semi-continuous and special ordered sets models (Konis, 2020). Fig. 3 shows the concept of the optimisation model for this study. The following control parameters were used in the optimisation of each run:

a) Objective function: in our case studies, regional objectives were defined individually through a supply-demand balance for the three soil functions (Valujeva et al., 2020);
b) Decision variables: these represent land-use areas that can be changed during the optimisation to meet the objective functions. In our case, the decision variables are the areas were divided into groups depending on land use and crop grown in 2016 (grains, oilseed, pulses, vegetables, perennial plantations, other crops, grassland, fallow, abandoned agricultural land, forests), soil type (mineral soil, drained organic soil, organic soil) and the farm size to which this area belongs (very small farm, small farm, medium farm, large farm). Also, for each 'land use-soil type-farm size' group, the supply indices of soil functions from Valujeva et al. (2020) were assigned; these indices are the constants that determine the suitability of land to provide the specified supply of soil function.
c) Constraints: these are boundaries for land areas to which the optimisation process must adhere:

– Total land availability: there are limitations of total land availability for agriculture and forestry; only abandoned agricultural land can transfer to the forest or agriculture.
– Land consolidation: land use changes via optimisation do not change the farm sizes; only abandoned agricultural land can move to production.
– Soil type: the total areas for mineral soils and organic soils remain constant; this means that soil type cannot change from mineral to organic or vice versa.

a) The effect of management practices: these were calculated only for abandoned agricultural land that was transferred back to production. In the scenario runs, we assumed that management practices remain unchanged in the areas that are currently already under cultivation, but improved management practices are optimised for new cultivation on previously abandoned agricultural land, as per the work of Valujeva et al. (2020). In addition, expert judgement was used to

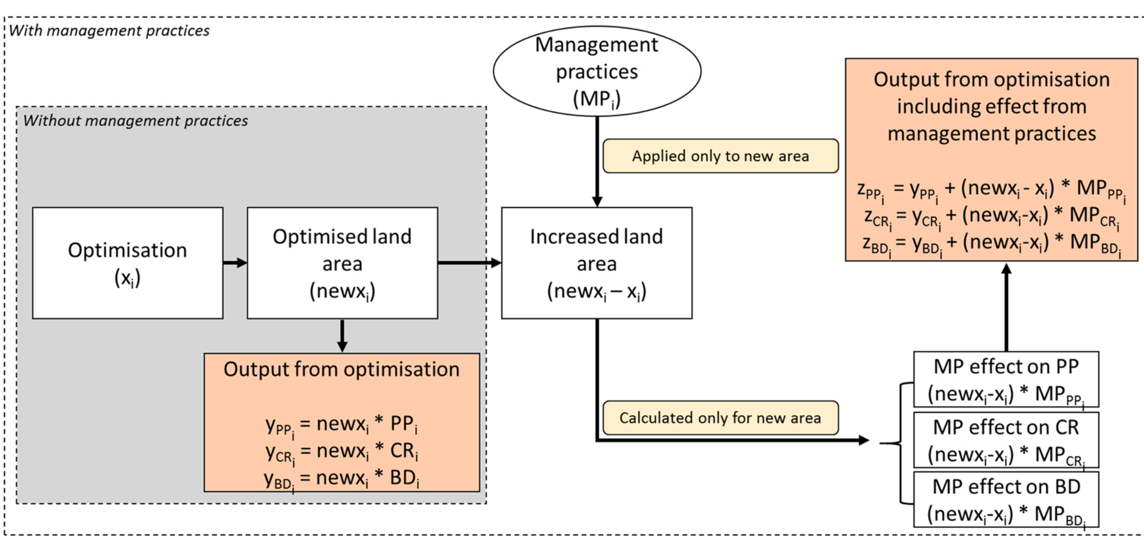

Fig. 3. The modelling framework for the optimisation of land uses and the assessment of the impact of the proposed management practices (x_i – area of land use i; $newx_i$ – area of land use i after optimisation; PP_i – index for primary productivity of land use i (Valujeva et al., 2020); CR_i - index for carbon regulation of land use i (Valujeva et al., 2020); BD_i - index for biodiversity of land use i (Valujeva et al., 2020); MP_i – sum of effect management practices to soil functions applied to land use i).

constrain management practices to associated farm sizes, depending on their financial capacities (Supplementary Material Table S1).

3. Results

Fig. 4 shows the results for Region 9 under all optimisation runs. It shows that there is a significant opportunity to improve PP in Region 9, simply by bringing abandoned agricultural land back into production. It is even possible to do so without increasing the environmental impact. Scenario 2 shows that it is even possible to increase PP, albeit to a lesser extent, while maintaining both CR and BD. If management practices are additionally added to the optimisation, opportunities for ”triple win” outcomes are further increased, and it would be possible to significantly increase PP and to simultaneously increase the supply for CR and BD.

Optimisation results for Region 5 also show the opportunity to improve the supply of PP, as was seen in Region 9. Smaller gains and smaller losses suggest that Region 5, too, has potential to optimise the supply and demand of three soil functions simultaneously, but to a lesser extent than in Region 9 (Fig. 5). By adding management practices, the supply of soil functions increases for all three functions, but again, to a lesser extent than in Region 9.

The results from Region 3 were markedly different from the other two regions' results. In Scenario 3 and Scenario 4, the increase or the decrease of supply of soil functions is below 1% compared to the baseline (Fig. 6). Opportunities for further optimisation are very limited; further increases in productivity are at the expense of BD, and also the opportunities to further augment CR or BD are insignificant. The area of abandoned agricultural land in Region 3 is relatively small, so their shift back to production has little impact on the supply of soil functions.

4. Discussion

4.1. Optimisation of soil functions

Our Baltic case-study demonstrates that bringing abandoned agricultural land back into production is a promising pathway to develop the European bioeconomy while minimising trade-offs with CR and BD; indeed we found plausible scenarios that benefit all three functions of land. For instance, in Regions 5 and 9, we can increase PP while maintaining CR and BD, or we can choose to increase PP to a lesser extent, and increase CR and BD at the same time. Soils can deliver multiple functions simultaneously, but we cannot expect that each farmer is able to maximise all of them at the same time; as shown by the Zwetsloot et al. (2020) following the FLM approach, it is possible to deliver three out of the five soil functions at a high capacity. These opportunities can be further enhanced by applying best management practices (that have a positive effect on soil functioning) to these reintegrated lands, provided that the suitability of these management practices are assessed for the specific region. For example, high-precision management of nutrients increases PP and reduces production costs for farmer without affecting CR and BF, while crop diversification, permanent plant cover and buffer strips simultaneously increase the supply of all soil functions (Hedley, 2015; McDaniel et al., 2014; Nielsen et al., 2015; Osterholz et al., 2018; Zuber et al., 2015). Within our national case-study, individual regions differed in their potential to contribute to such triple-win scenarios: Region 9 showed the most opportunities synergies arising from the revitalisation of abandoned agricultural land, while Region 3 had already been optimised: here, even small increases in PP resulted in a decrease of BD, which underlines the importance of a regional approach. These differences show that our original hypothesis that reintegrating abandoned agricultural land contributes to triple-win scenarios must be nuanced with a regionally differentiated approach. This nuanced finding is supported by studies on land abandonment from other regions: for example, Beilin et al. (2014) found that in an Australian case study, well-managed abandonment of agricultural land that promotes the formation of forest patches is highly beneficial for biodiversity and brings opportunities for alternative rural development; whereas agricultural land abandonment in case studies in Sweden and Portugal were perceived as a threat to biodiversity and the heterogeneous landscape that is associated with high-nature-value farming areas (Beilin et al., 2014). Whilst our analysis is not aimed at determining the specific land use and management practices that should be applied to individual parcels of abandoned agricultural land, our results do inform policy-makers in their allocation of limited resources (funding, knowledge transfer) to the areas where there effectiveness and contribution to regional and national policy objectives will be highest.

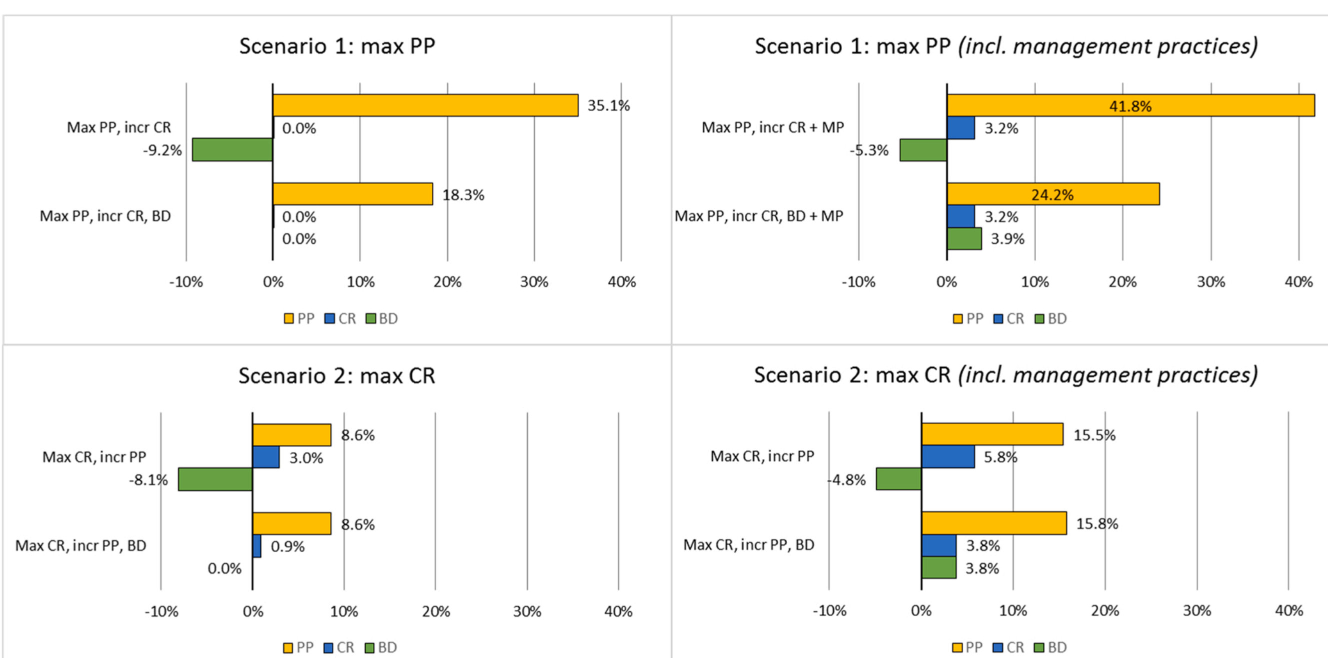

Fig. 4. Outcomes of Region 9 optimisation. Changes in the supply of soil functions for two scenarios, with and without management practices, compared to the baseline (0%): PP - primary productivity; CR - carbon regulation, BD - biodiversity function.

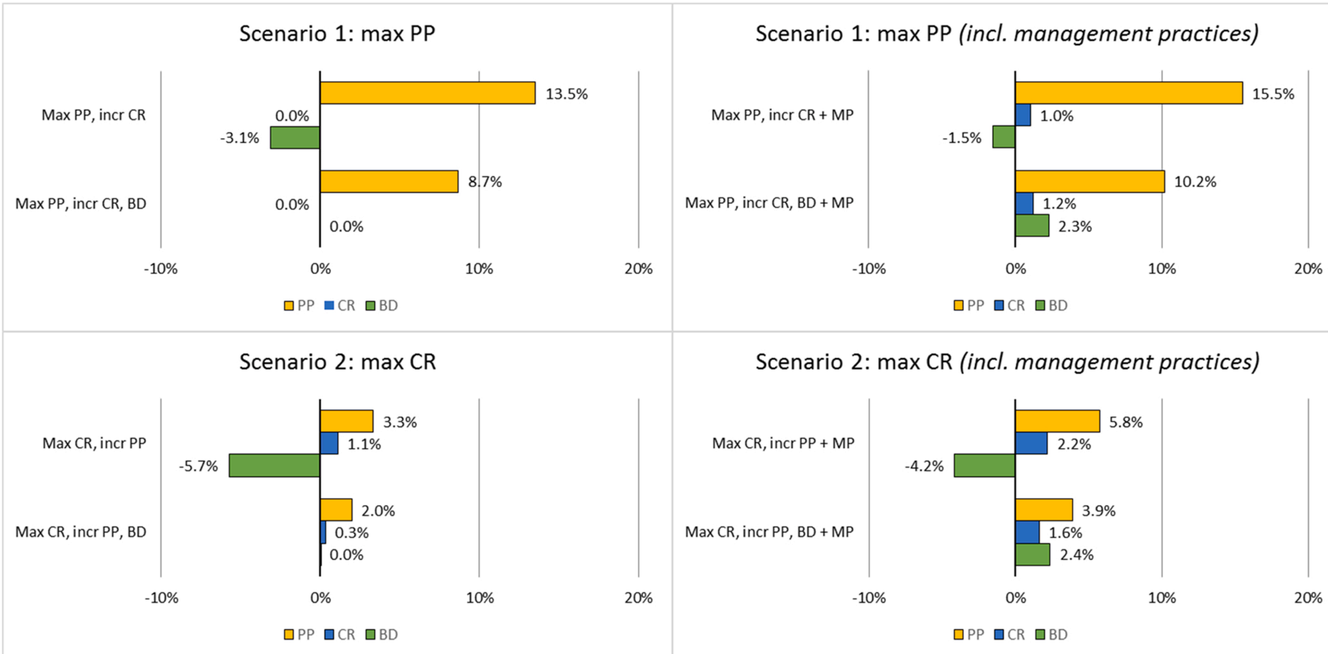

Fig. 5. Outcomes of Region 5 optimisation. Changes in supply of soil functions for two scenarios with and without management practices compared to the baseline (0%): PP - primary productivity; CR - carbon regulation, BD - biodiversity function.

Scale is crucial in the optimisation of soil functions, as land use change and the introduction of management practices operate at farm-scale. Farmers often prioritise PP, which affects the achievement of CR and BD objectives at the national level (Valujeva et al., 2016); as our results show, in some areas even small increases in productivity come at the expense of BD and CR. Adapting sustainable land management at the national scale, which includes both the development of production and the achievement of environmental objectives, requires financial support for land managers based on legal frameworks and the dissemination of additional knowledge around applicable management practices (Liniger et al., 2019). The farmer is a key actor in this arena, and should be included in the development of optimisation scenarios; the major driving force for farmers in implementing management practices are short-term benefits and reductions in production costs (Lahmar, 2010). Moreover, to motivate conventional farmers to switch from monoculture systems to diversified cropping systems, new systems must go beyond profitability: they must also be mechanised (Teixeira et al., 2018). Educational programs, social pressure, and economic incentives can encourage behavioural changes among the farming community, and increase the implementation of changes that positively affect environmental outcomes (Bijttebier et al., 2018).

4.2. *Targeted reintroduction of abandoned agricultural land as an opportunity for National Strategic Plans*

In this context, the reform of the EU CAP (2023–2027) offers opportunities to change the narrative on abandoned land: while the CAP was originally developed to provide farmers with support measures to compensate market volatility, it has since evolved into a tool to also reduce the environmental impacts of agriculture across Europe. The New Delivery Model of the CAP (2023–2027), will provide Member States more flexibility to design tailor-made measures through National Strategic Plans (NSP) (EC, 2021a). While the next CAP will not take effect until 2023 after a two-year transitional period, Member States will be submitting drafts of their NSPs by the end of 2021 to the European Commission (EC) for approval. In order to support the Member States' drafting of their NSPs, and to encourage the adoption of the Green Deal objectives in these plans, the EC published Staff Working Documents in December 2020, which outline, for each Member State, recommendations on how to: foster resilience, bolster environmental care, strengthen the socio-economic fabric of rural areas, and foster knowledge and innovation (EC, 2020c).

In this context, Latvia has been conducting its own national analysis of needs. For example, in 2019, regional discussions, led by the Latvian Rural Network Unit, with agri-environmental stakeholders in Latvia identified fair income, generational renewal, and competitiveness as key priorities for the post-2020 CAP (LLKC, 2019). A reduction in regional yield differences was identified as one of the main challenges. Our current study addresses this challenge by allowing for differentiated pathways for different regions while striving for similar outcomes in terms of socio-economic and environmental sustainability. Additionally, these discussions recognised the need to simultaneously support productive farms in their economic development, and small farms in maintaining a heterogeneous landscape, and therefore biodiversity, as shown by the optimisation results of Region 3: here, an increase in BD and CR can only be secured by preserving and promoting landscape heterogeneity. Therefore, it is necessary to define regionally clear objectives to support connectivity, heterogeneity and landscape elements in order to promote the conservation of biodiversity, because broad conservation measures at national or European scale do not consider the specific needs and values of individual regions (Concepción et al., 2020).

Addressing land abandonment is not listed as a primary objective in Latvia's draft recommendations from the EC (EC, 2020d), nor does it feature in the European Green Deal communications, such as the Farm to Fork Strategy and Biodiversity Strategy for 2030. It is only mentioned once in the European Commission's Long Term Vision for Rural Areas, stating that, "it is therefore important to account for the needs of small and medium sized farmers, attracting young, new and female farmers and preventing land abandonment as well as facilitating land access" (EC, 2021b). The measures in the CAP that could potentially address land abandonment, as outlined in a study by Schuh et al. (2020) commissioned by the European Parliament, are synergistic with the NSP recommendations for Latvia and the regional discussions led by the Latvian Rural Network. Tools such as: capping direct payments, complementary redistributive income support, small farmer schemes and young farmer measures have been proposed to address land

Fig. 6. Outcomes of Region 3 optimisation. Changes in supply of soil functions for two scenarios with and without management practices compared to the baseline (0%): PP - primary productivity; CR - carbon regulation, BD - biodiversity function.

abandonment as well as multiple other socio-economic objectives. The use of these tools, however, must be regionally-specific, and based on an understanding of the locally relevant drivers of land abandonment. Other measures identified by Schuh et al. (2020), such as payments for Areas with Natural Constraints (ANCs), may also promote beneficial production on abandoned land, depending on the region in which they are applied. For instance, increasing the budgetary ring-fencing for ANCs in Region 5 of this study may potentially be more effective than in Region 3, in which topography may not be such a driver of land abandonment.

The results of our study suggest that for Latvia and other Member States, policy makers can utilise regional differences within a country to meet national objectives and international commitments: Latvia's strength lies in its bioeconomy, in which natural resources are used for the sustainable production of food, feed, industrial products, and energy. However, the development of its bioeconomy has thus far been associated with an increase in GHG emissions. Our study shows that, if carefully managed, the reintroduction of abandoned agricultural land provides opportunities for "triple win" synergies between productivity, climate mitigation commitments and the preservation of biodiversity. However, without careful management, the reintroduction of abandoned agricultural land may lead to increases in only PP, with a failure to deliver on CR and BD objectives, or international commitments. This calls for the introduction of incentivisation mechanisms and knowledge programmes that involve land managers and other actors in the decision-making and priority-weighing processes across scales to translate "thinking solutions" into "doing solutions", which refer to as the Think-Do-Gap (O'Sullivan et al., 2017), for each of the regions; additionally it requires understanding of which stakeholders influence land-use decisions concerning soil functions, which is the subject of further ongoing studies. Understanding societal actors, networks and their interaction in land management issues will help to identify existing stakeholder alliances, gaps in networks and possible solutions in order to promote cooperation and entry points to steer stakeholders and decision-makers towards a regionally differentiated approach to reorienting abandoned agricultural land to achieve the regional and national policy objectives.

5. Conclusions

By using a regionalised approach to FLM in Latvia, we showed the untapped potential of revaluing, reintegrating and re-managing abandoned agricultural land in helping Member States meet socio-economic and environmental sustainability objectives simultaneously. Indeed, our conclusions call for a change in perspective towards abandoned land: from relics of past failures towards beacons of future opportunities.

Our optimisation results confirm the merits of a regionalised approach to reintegrating abandoned agricultural land: trade-offs between soil functions, and regional differences in the societal demand for economic development, climate regulation and biodiversity preservation lead to contrasting opportunities for individual regions to contribute to national targets. While some regions may already be optimised towards the national bioeconomy, these may benefit from other regions that make larger relative contributions to climate regulation and biodiversity preservation.

However, such purposeful interregional development requires careful knowledge-based management and incentivisation. In absence of this, the reintegration of abandoned land may simply repeat the historic trajectory of increased productivity at the expense of environmental integrity. This calls for the development of clear and coherent guidance tools for actors involved in the formulation of the National Strategic Plans, from farmers at local level, to regional decision makers, to national policy makers, to facilitate priority setting, as well as effective incentivisation mechanisms across scales.

CRediT authorship contribution statement

Kristine Valujeva: Conceptualization, Methodology, Software, Writing - original draft, Visualization. **Mariana Debernardini**: Validation, Writing - review & editing. **Elizabeth K. Freed**: Writing - review & editing. **Aleksejs Nipers**: Conceptualization, Resources, Supervision, Writing - review & editing. **Rogier P.O. Schulte**: Conceptualization, Methodology, Supervision, Writing - review & editing.

Declaration of Competing Interest

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

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2021.11.014.

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