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SUPER-G

SUSTAINABLE PERMANENT GRASSLAND

Deliverable 5.7

Final Version of the Policy Tool

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Dissemination Level

PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
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1. Introduction

The aim of Work Package 5 (WP5) of the SUPER-*G* project was to develop decision support tools (DSTs) to assist farmers and policy makers to assess ecosystem service (ES) provision on permanent grassland (PG).

This report describes the development of a policy tool being developed under Task 5.6, building upon the review of DSTs (Task 5.1) and the workshops held to identify what policy tools should be developed (Task 5.3).

The intention was to build upon the knowledge and information gained in the other work packages within SUPER-*G*, in particular the PG typology (Task 2.1), the farming systems classification (Task 2.2), the review of ES provided by PG (Task 2.3), and benchmarking and testing within SUPER-*G* farm networks (WP3). There was also a desire to investigate the potential to link the farm and policy DSTs being developed in SUPER-G, or for them to share a common approach.

1.1. Design Approach

The initial design decision was made for the policy tool to be European in scale, rather than country scale. Although a country scale tool could potentially provide more detailed spatial resolution, this would be at the expense of greater input requirements (which could limit the applicability of the tool to certain countries) and potentially require more detailed modelling of country specific factors, adding to the complexity of the tool if it was to remain applicable to multiple countries. European scale was also the scale at which the SUPER-*G* PG typology was being delivered. Because of this decision, interactions with stakeholders during the development of the tool have been focused on those operating at European scale, notably the Joint Research Council (JRC)and the European Commission Directorate-General for Agriculture (DG-AGRI) and the Environment (DG-ENV), rather than policy makers in specific countries.

The workshops held under Task 5.3 identified a wide range of policy issues that users would like to investigate, 'levers' within the tool they would like to be able to manipulate

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and questions for the tool to be able to answer. The decision was made to primarily focus on stocking density and fertiliser use, and the ecosystem services which they impact (e.g. food provision and water quality). The policy tool that has been developed thus allows a user to modify the number of livestock present in an area (reflecting a potential future scenario of consumer demand or policy impact) and see the effect this will have on the ES considered.

The policy tool is not able to meet all of the ideas suggested in the workshops by policy makers - some of the levers and questions suggested would have required a very different model to that developed (e.g. looking at socio-economic impacts) and/or would have required datasets that are not readily available or could vary significantly in availability or relevance by country (e.g. the role of advisory services or the impacts of land tenure on innovation).

The policy tool has been developed as a web application, designed to respond to user changes in real time. This has informed the complexity of the datasets and calculations, which are described in the next section.

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2. Methodology

2.1. Concept

The tool has been designed around the idea that within any given area, the amount of energy required by the livestock present is equal to the energy available. This energy requirement can be met by some combination of purchased feed (either from neighbouring farms or imported from other countries), from arable crops or from grassland (Figure 1). For a specified amount of purchased feed and arable material, sufficient fertiliser would be applied to the grassland in order to produce enough grass to meet the livestock energy requirement. Increasing the amount of livestock in an area thus requires an increase in the amount of fertiliser applied (if other variables remain unchanged) and vice-versa for a decrease in livestock. Implicit in this calculation is that grassland is not over-fertilised.

The ecosystem service values can then be determined from the number of livestock, the areas of arable land and grassland, the fertiliser rates and any other variables required.

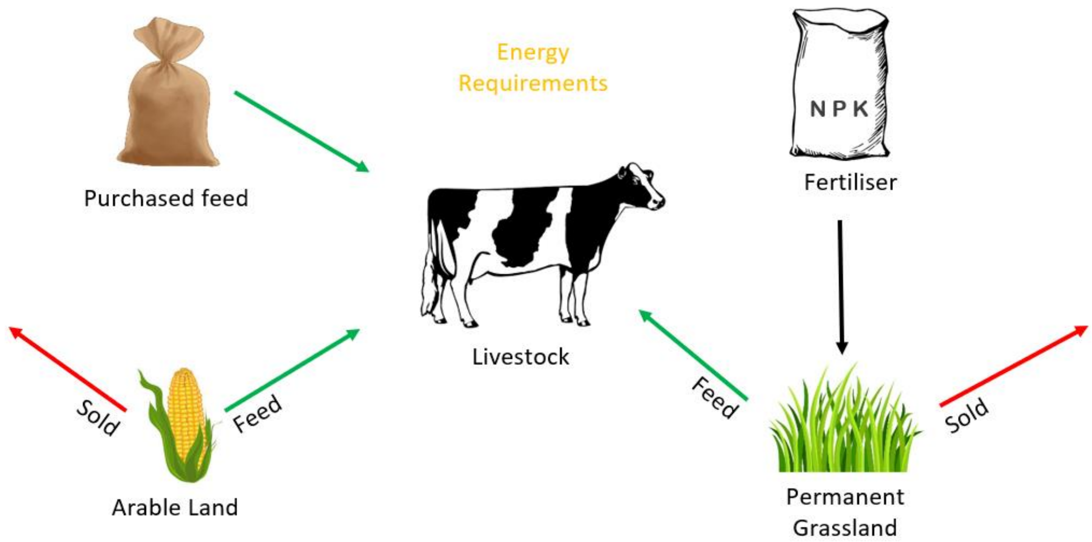

Figure 1 Model schematic for the SUPER-G Policy Tool

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The policy tool has been developed to operate at NUTS2 (Nomenclature of territorial units for statistics) scale[1], of which there are 242 regions within the EU. NUTS2 was considered to be the most appropriate given the European scale of the tool, data availability, the complexity of the calculations and the desire to have the tool respond in real time to user inputs. A farm type component was included to reflect different livestock and intensity of management within a region.

2.2. Source Data

This section focusses on the key land use dataset used to drive the policy tool. Additional data are used for calculating energy requirements / grass growth and the ecosystem service scores, which are described in their appropriate subsections in Section 2.3 and 0 respectively.

Eurostat

Eurostat produces European statistics in partnership with National Statistical Institutes and other national authorities in the EU Member States, with data provided at a range of NUTS resolutions. The main use of the Eurostat data in the tool is to provide the following at NUTS2 scale:

- Area of arable land
- Area of grassland
- Livestock numbers

Although the SUPER-*G* project is focused on permanent grasslands, the policy tool includes both permanent and temporary grassland within its grassland category. This decision was made in consultation with policy users and reflects the significant areas of grassland in Nordic countries which are considered as temporary (up to 60% of the agricultural area, compared with an average of c.5% across Europe). Livestock numbers were available as both head counts or livestock units for a small number of livestock

[1] NUTS 2 regions are designed to have between 800,000 and 3,000,000 population and follow administrative boundaries within each member state.

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categories. Data for grazing livestock types were aggregated as livestock units for use within the policy tool.

These data items were available for up to 22 different farm types. Because the tool is focusing on permanent grassland, grazing livestock farms were considered the primary ones of interest. To keep the tool interface manageable, data were retained for 4 types of grazing livestock farms, with the data for the remaining farm types (e.g. cereals, cropping, vineyards, granivores, mixed farms) aggregated together, producing the list used in the tool (Table 1).

Table 1 Farm Types in Eurostat and the Policy Tool:

Eurostat Farm Type Name	Policy Tool Farm Name
Specialist dairying	Specialist Milk
Specialist cattle-rearing and fattening	Specialist Cattle
Cattle-dairying, rearing and fattening combined	
Mixed livestock, mainly grazing livestock	Mixed Livestock
Field crops-grazing livestock combined	
Various crops and livestock combined	
Sheep, goats and other grazing livestock	Specialist Sheep and Goats
All other farm types	Other farms

Data were available for most countries for 2020, with the following exceptions, where the most recent available datasets were used instead:

- United Kingdom (2016)
- Norway (2013)
- Montenegro (2010 / 2016)
- Macedonia (2013 / 2016)
- Serbia (2010)

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Alternative datasets considered

Initial plans for the policy tool had been to build upon the CAPRI (Common Agricultural Policy Regionalised Impact) model and the PG typology Atlas being developed in SUPER-*G* WP2.

A direct link to CAPRI outputs would have been ideal for determining the impacts of policy scenarios modelled by CAPRI – however, this idea was ultimately rejected for several reasons including i) The CAPRI model is very complex, and users need extensive training and licensed software to run it, so it would not actually be possible for policy makers to create their own scenario in CAPRI; ii) the model outputs are extensive, so it would have been difficult to modify them directly to represent scenarios; iii) the most recent publicly available datasets were from 2012, with only a limited number of scenarios available; iv) publicly available baseline runs of the model do not report all key metrics; v) the tool to downscale results to 1km^2 was not publicly available.

The SUPER-*G* PG typology (which provides information on productivity potential and the probability and distribution of PG management intensity levels within each region) was being developed at the same time as the policy tool, which ultimately made it impractical to build upon. There would be benefits in trying to couple the policy tool and PG typology together should future opportunities arise.

2.3. Energy and Fertiliser Calculations

Livestock Energy Requirement

The policy tool works on the theory that the amount of grass, silage, concentrate feed and other forage material produced or purchased by farm type within each NUTS2 region is sufficient to provide the energy required for maintenance, growth and output of the grazing livestock present. More intensively stocked farms will require some combination of i) greater use of fertiliser to grow more grass; ii) a greater proportion of land use to produce silage or food for use on farm rather than for products for sale off-farm or iii) more imported/purchased feed.

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The amount of metabolisable energy required for a livestock unit is based on published data on energy requirements for livestock of different weights and outputs[2].

For specialist cattle farms, 37,000 MJ LU^{-1} has been assumed, based upon the requirements for a 500 kg suckler cow (which is 0.8 LU). For specialist sheep and goat farms, 46,000 MJ LU^{-1} has been assumed, based upon a 60 kg ewe with a single lamb (0.1 LU). For mixed grazing livestock farms, an average of these two values was assumed. For dairy cattle, energy requirements are strongly correlated with milk production, so for the specialist dairy farms, energy requirements were based on milk yields and a derived relationship (assuming heavier cows are required for greater milk yields) of 5,500 MJ cow^{-1} plus 8 MJ per litre of milk. Milk yield by country was obtained from the Eurostat database, with EU averages assumed where country-specific data was unavailable. The EU average energy requirement was estimated as 64,700 MJ LU^{-1}.

Energy Production

The amount of metabolisable energy produced is based upon dry matter production and energy contents per unit dry matter. For arable cropping, cereal yields were obtained from the Eursotat database by NUTS1/NUTS2, with an assumed energy content of 12 MJ kg^{-1} dry matter. For grassland, yields are calculated dynamically in the tool, with an energy content of 10-11.5 MJ kg^{-1} dry matter.

The grassland yields are calculated within the tool so as to produce sufficient energy for the livestock present on the farm (given the other values chosen for the amount of land on farm used for silage and the amount of feed imported/purchased). Yield response curves have been derived from the UK Fertiliser Recommendation Guidance 'RB209', with the tool automatically adjusting the grassland fertiliser rate in order to produce sufficient yield. Six yield response curves were produced, reflecting different grass growth classes (Figure 2). A grass growth class was assigned to each NUTS2 region (Figure 3) based upon:

[2] https://www.triedandtested.org.uk/media/43cbe5lc/feed-plan-cows-and-sheep.pdf

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- Soil available water capacity (taken from LUCAS data[3])
- Average annual rainfall (from Copernicus data[4])
- Thermal growing period > 5ºC (FAO GAEZ data[5])

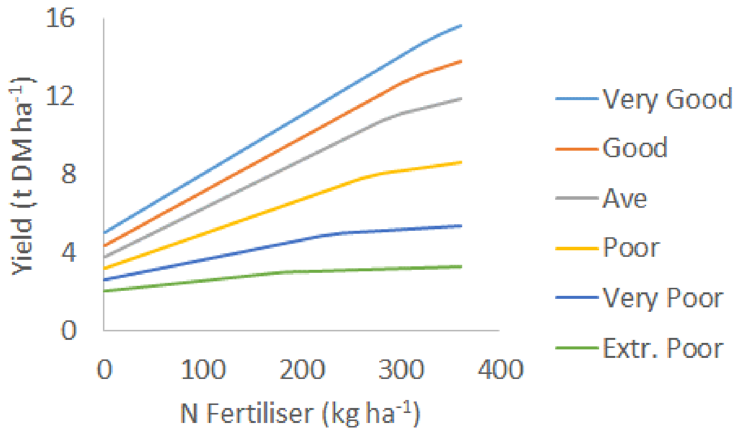

Figure 2 Yield response curves assumed in the policy tool

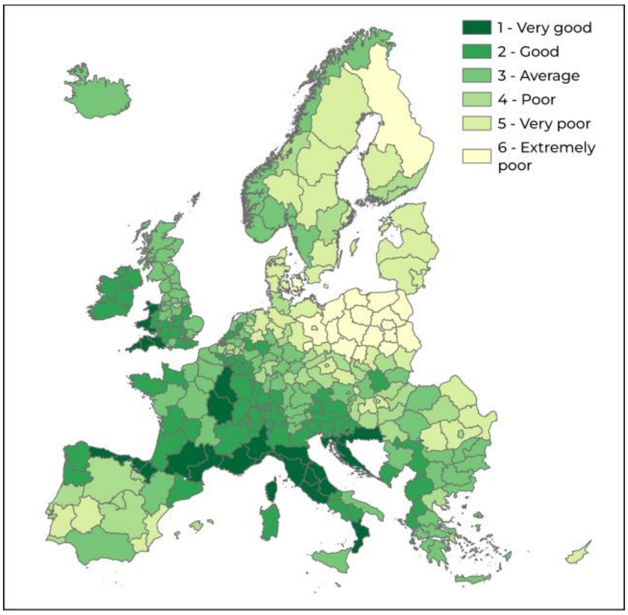

Figure 3 Grass growth class by NUTS2 region used in the policy tool

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[3] https://esdac.jrc.ec.europa.eu/content/topsoil-physical-properties-europe-based-lucas-topsoil-data
[4] https://surfobs.climate.copernicus.eu/dataaccess/access_eobs.php#datafiles
[5] https://gaez.fao.org/pages/data-viewer

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Purchased Feed / Use of arable land for feeding livestock on farm

The policy tool needs to know the proportion of the livestock energy requirement that is met through purchased feed, and also the amount of arable land on the farm type in each NUTS2 region that is used for feeding livestock on the farm (to allow the energy remaining to be provided by the grassland to be determined). This information is not readily available across Europe, so in the first instance, expert opinion on these factors was sought from within the SUPER-*G* consortium. Once all the tool datasets and equations had been assembled, these factors were then iteratively either lowered (so that at least the minimum grassland yield from the relevant response curve in Figure 2 would be utilized) or raised if the grassland fertiliser requirement was too high. Further minor modifications were made to ensure that national fertiliser rates to grassland and rates by farm type were sensible. These factors can also be altered by the user via the policy tool interface. Figure 4 shows a comparison between the policy tool and national fertiliser rates from Einarsson et al., (2021), with broad general agreement (given uncertainty in the published data of +/- 30 kg based upon comparison with official published data for the UK[6] and the inclusion of temporary grassland within the policy tool, which typically receives more fertiliser). The policy tool applies small amounts of fertiliser in countries whereas the Einarsson paper makes the assumption fertiliser rates to grassland are zero. Figure 5 shows that the policy tool broadly increases fertiliser rate as livestock density increases.

If the percentage purchased feed and arable land used for feed remain constant, it is possible to determine a maximum stocking density given the maximum yield from Figure 2.

[6] Einarrson et al 2021 estimate 16.8 kg N ha^{-1} to permanent grassland, the British Survey of Fertiliser Practice for 2019 states 45 kg N ha^{-1} to grassland over 5 years old.

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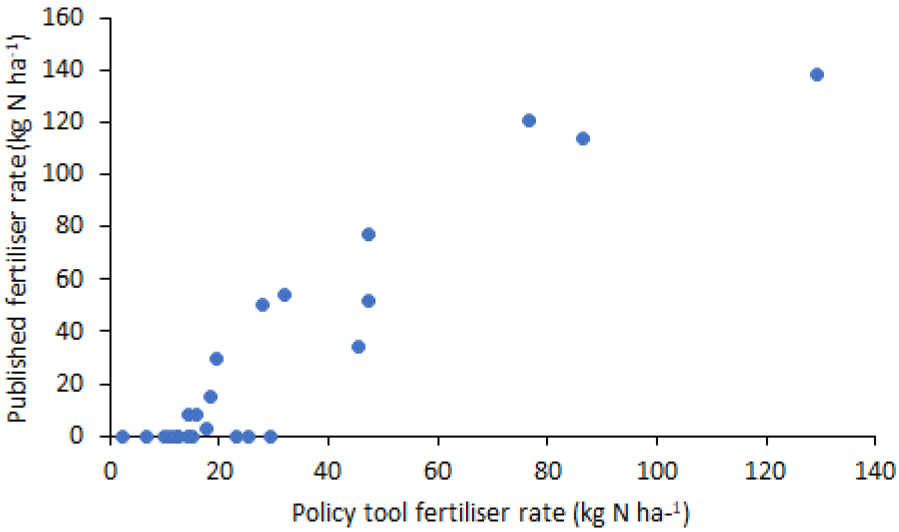

Figure 4 Comparison of national fertiliser rates to grassland with those produced by Einarsson et al., 2021

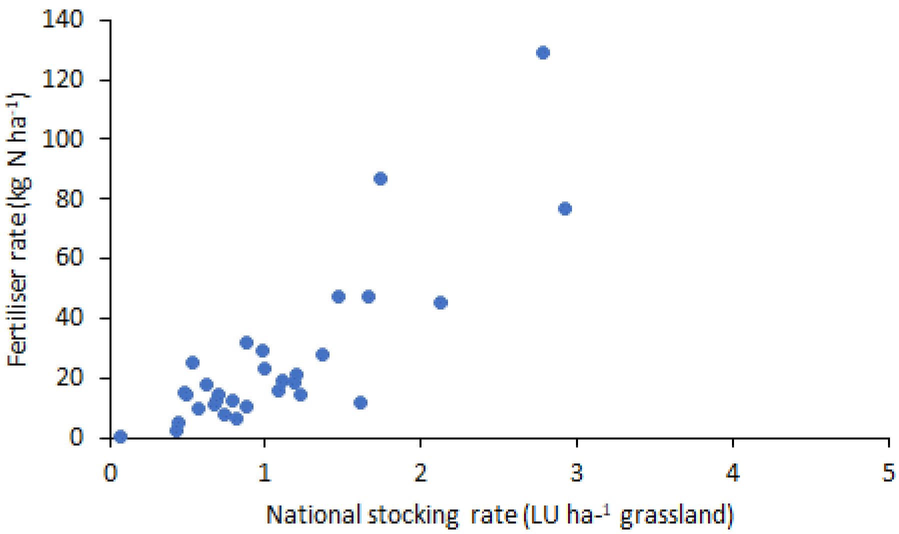

Figure 5 Average fertiliser rate to grassland by country versus average grazing livestock density.

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2.4. Ecosystem Service Calculations

The policy tool calculates scores for the following ecosystem services:

- Production
- Climate regulation
- Erosion control
- Water quality
- Species richness

These services are all a function of land use, stocking rate and fertiliser use (among other factors), with the equations used in their calculations described in the following subsections. The ecosystem service scores are designed to reflect the broad scale consequences of changes in management within a region, rather than being accurate predictions. However, factors have been accounted for to reflect the variation in magnitude of services between regions (so for example, erosion control scores are lower in wetter, steeply sloping areas).

To allow the ecosystem service values to be easily compared and plotted in the tool on a spider diagram, they have all been scaled to range from approximately 0 (unfavourable) to 100 (favourable). All scores were calculated per hectare of agricultural land so that the size of the NUTS2 region was not important.

Production

The production service is based upon the output value of any arable produce or grass not used to feed the livestock on the farm, plus the output value of the livestock themselves. Values used are taken from 2019 to remove any recent variations caused by Covid-19 and the war in Ukraine.

The livestock values are represented by a relationship derived from the Farm Accountancy Data Network for 2019 (Figure 6), with greater outputs from dairy / milk farms compared with other grazing livestock (€1144 LU^{-1} for milk, €840 LU^{-1} for non-milk grazing livestock). Any grass not used to feed livestock has a value of €104 t^{-1} dry matter, taken from the John Nix Farm Management Pocketbook (Redman, 2018) value for clamped silage. Arable values use the cereal yield taken from the Eurostat data (as used

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in the energy requirement calculations) and a value of €180 per tonne, reflecting average wheat prices in 2019[7,8]. The productivity value was divided by 30 so that the maximum current value found for any NUTS2 region was close to 100.

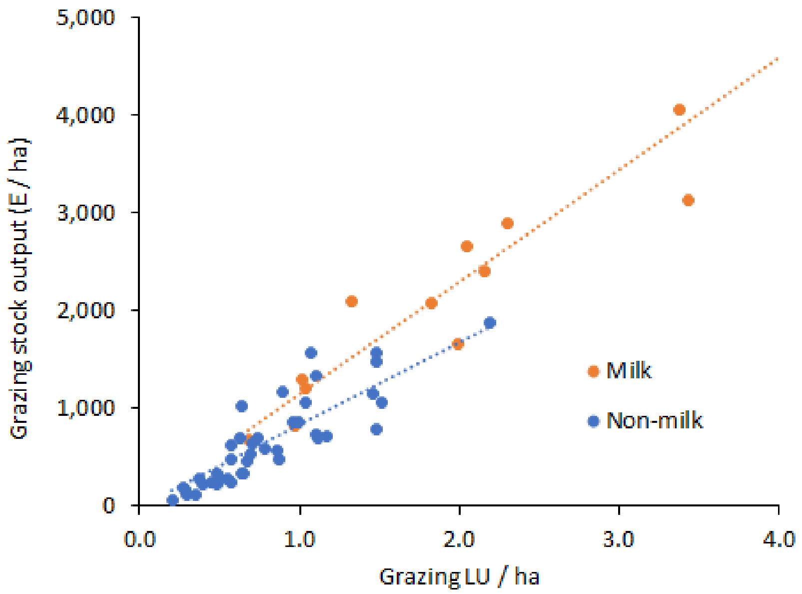

Figure 6 Relationship between grazing livestock density and output, derived from FADN data for 2019.

Climate regulation

Climate change regulation was represented by emissions of nitrous oxide and methane, calculated with country specific coefficients derived from tables in the Annual European Union Greenhouse Gas Inventory Report 2020 (European Commission, 2020). Where data was not available for a country, EU average values were used instead. These tables allowed separate coefficients to be derived for dairy cattle and non-dairy cattle, which were then re-expressed per livestock unit. The following coefficients are used in the tool, multiplied by the relevant scalar data for each farm / NUTS2 combination:

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[7] https://www.indexmundi.com/commodities/?commodity=wheat&months=60&currency=eur
[8] https://www.fwi.co.uk/business/markets-and-trends/market-prices-2019-performance-in-review

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- Per LU dairy
- Per LU non-dairy
- Per kg fertiliser
- Per ha of arable land

The coefficients represent the following main components of the European agricultural GHG inventory:

- Enteric methane emissions from livestock
- Methane emissions from manure management
- Nitrous oxide from manure management
- Direct emissions from manufactured fertiliser
- Direct emissions from organic manure and excreta at grazing
- Direct emissions from arable crop residues
- Indirect emissions from ammonia deposition[9]
- Indirect emissions from nitrate leaching

Direct emissions from organic manure and excreta at grazing used country specific nitrogen excreta amounts tabulated in the inventory report. As ammonia emissions were not calculated, the nitrous oxide emissions from ammonia deposition were assumed to be 50% of the relevant direct emissions, which is the average ratio of the two for Europe. Emissions from crop residues were estimated as 0.1 kg N_2O per tonne dry matter, derived from the UK GHG inventory values for cereal crops. Losses from nitrate leaching used country specific FracLeach and emission factor values.

Methane and nitrous oxide values were converted to CO_2 equivalents using global warming potentials of 28 and 265 respectively, as per the IPCC Fifth Assessment Report. As greater GHG emissions are unfavourable, the final climate regulation score was determined as 100 * (1 - (GHG emissions / 10,000)), with a minimum value of 0. The value of 10,000 was determined based on the maximum predicted emissions in the tool for the baseline situation.

[9] .

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Erosion control

Erosion control is determined using the RUSLE (revised universal soil loss equation) methodology, where erosion is a function of climate, soil, topography and land use. Panagos et al., (2015) produced three key components of the RUSLE equation for a 100 m resolution grid across Europe:

- Rainfall erosivity
- Soil erodibility
- Topography (length-slope factor)

This dataset was aggregated by NUTS2 region and then combined with a cover factor. The arable factor was assumed to be 0.2, reflecting the value for cereal crops in Panagos et al., (2015a). Donovan and Monaghan (2021) found cover factors for grassland were typically twice as high (i.e. higher erosion risk) for grazed grass as ungrazed grass. Based on the range for grassland in Panagos et al. (2015b) of 0.05 to 0.15, and a crude average stocking density of 1 LU ha^{-1} across Europe, the grassland cover factor was assumed to be 0.05 + 0.05 * LU ha^{-1} (such that the cover factor is doubled from 0.05 to 0.1 for typical grazing rates) up to a maximum of 0.15.

To convert erosion rates (where low is favourable) to an erosion control value where a higher value (close to 100) would be favourable, the final water quality score was determined as 100 * (1 - (erosion rate / 500)), with a minimum value of 0. The value of 500 was determined based on the maximum predicted erosion rates in the tool for the baseline situation.

Water quality

The water quality ecosystem service represents the risk of nitrate leaching only, and not the other aspects of water quality that agriculture impacts upon, such as phosphorus or pesticides concentrations.

The approach taken was to assume that 30% of any applied fertiliser, excreta or manure could potentially be leached, mimicking the Tier 1 GHG inventory approach for estimating indirect losses of nitrous oxide from nitrate leaching.

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This was then refined by estimating the actual amount of this 30% that would be leached using a leaching function taken from the Miterra-Europe model (Velthof et al., 2009), where leaching is a function of:

- Soil type
- Effective rainfall
- Denitrification (soil carbon and temperature)
- Land use

Soil type was determined from the LUCAS dataset, whilst effective rainfall data was taken from the TACTIC project[10]. The percent of each NUTS2 region covered by the different soil types was calculated, so that the soil type factors could be appropriately weighted. Average values for each NUTS2 region were determined for effective rainfall, soil carbon content and temperature.

Arable fertiliser rates by country are taken from Einarsson et al. (2021), while the grassland fertiliser rates are determined within the policy tool. Country-specific values for nitrogen excretion by livestock were taken from the GHG inventory data used in the Climate Regulation calculations. Separate values were included for dairy and non-dairy animals, converted to livestock unit equivalents and with an allowance made for losses of nitrogen during housing and storage.

To convert from a nitrogen leaching value (where low is favourable) to a value where a higher value (close to 100) would be favourable, the final water quality score was determined as 100 * (1 - (nitrate leaching / 40)), with a minimum value of 0. The value of 40 was determined based on the maximum predicted nitrate leaching values in the tool for the baseline situation.

Species richness

The species richness ecosystem service score is based on the observed relationship that species richness declines linearly with increasing fertiliser use (e.g. Kleijn et al., 2009, Francksen et al., 2022; Conijn S. 2024). The initial value for arable land (i.e. with no

[10] https://geoera.eu/projects/tactic9/

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fertiliser) in the service calculation was set at 80% of the initial grassland value, with the arable land having a smaller reduction in species richness per unit fertiliser applied than for grassland, such that intensively managed grassland would have similar species richness to arable land.

There is a known general trend for greater species diversity towards the tropics and lower diversity towards the poles (e.g. Pianka, 1966, Hillebrand 2004). To provide some variation in species richness between regions, a simple latitudinal factor was used to provide the baseline value for each NUTS2 region, to which the land use and fertiliser use modifiers were applied. This factor was derived from Chartier et al., (2021), where the average number of plant species varied from approximately 40-60 across the latitudinal range of Europe. The value was multiplied by 1.6 to achieve a score ranging up to 100.

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3. Policy Tool

3.1. Tool Development

The policy tool has been developed as a web application, accessible using a web browser, with no download or installation of software or data required. The tool has been developed using Dash[11], a software framework for building web-based data visualization interfaces using the Python programming language. Mapping elements of the tool used Leaflet, a library used to create interactive web maps, with Plotly used to create interactive charts and figures.

3.2. Tool Interface

Figure 7 shows the policy tool interface. A user can select a NUTS2 region from the map viewer and can then alter the following properties for each of the 5 farm types listed in Table 1, using the sliders located on the left-hand side of the tool:

1. The split of the current agricultural area between grassland and arable land
2. The grazing livestock density
3. The percentage of the diet provided by purchased feed
4. The percentage of the grassland area used for grazing and silage production for consumption by livestock on farm
5. The percentage of the arable area used for fodder and silage production for consumption by livestock on farm

Changing these values from the default ones included within the tool results in the production of new ecosystem service values, as shown on the right-hand side of the tool.

Alternatively, a user can:

i) alter the overall livestock density for the selected NUTS 2 region. This will modify the livestock densities by farm type within the region *pro rata*, subject to not exceeding the maximum stocking limits for the farm types (in order to have

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a higher overall stocking density, it would be necessary to alter the individual properties of the farm types such that they could produce more feed on farm and / or purchase more feed).

ii) change the distribution of the area in the selected NUTS2 region across the farm types. This will impact on the overall stocking rate and land use apportionment, as the land changing farm type will adopt the land use and stocking properties of the new farm type.

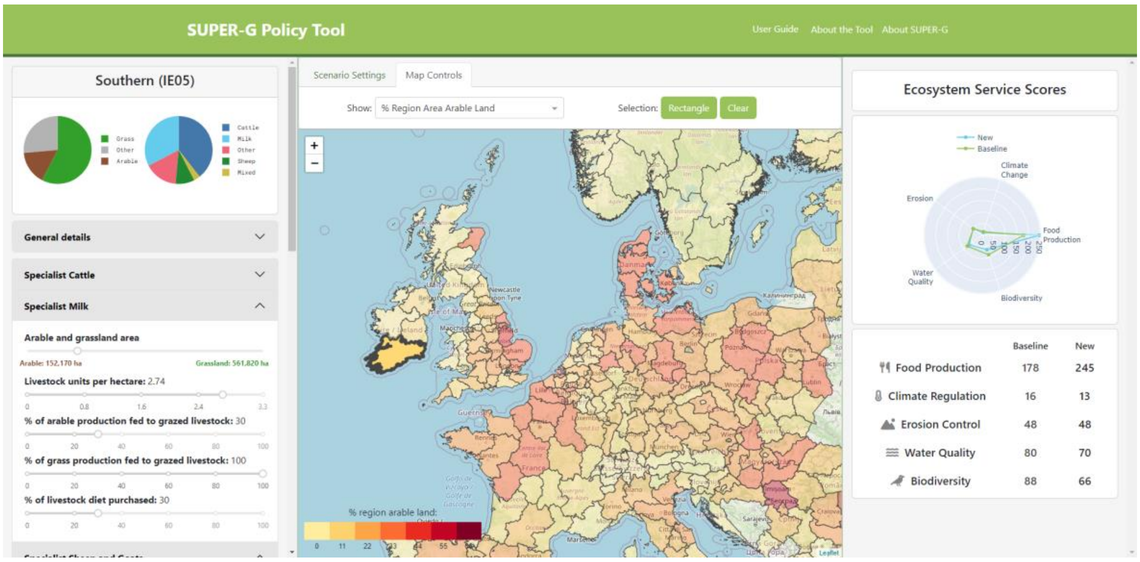

Figure 7 Policy tool interface

A user can select multiple NUTS2 regions. This allows the tool to display the combined data for the regions (e.g. total areas and ecosystem service values) and average data by farm type (e.g. percentage of feed purchased), but the data cannot be altered. To alter the data for multiple regions, each region must be modified individually.

The map display in the center of the tool can show a selection of input properties (e.g. stocking density) and all the ecosystem service values.

The values for all the sliders can be exported / imported to allow a scenario to be saved and retrieved later. All the other data used by the tool (e.g. energy requirements per unit livestock, coefficients in the ecosystem service calculations) are stored in a file

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which cannot be edited by the user but can easily be altered by someone with access to the tool development environment.

3.3. Example application of the tool

Figure 8 shows the outputs of the policy tool where the three NUTS2 regions of Ireland have been selected. Figure 9 then shows the outputs where livestock numbers across these regions have been halved, to see the impacts of a hypothetical policy, trade or other scenario. Stocking rate drops from almost 1.2 livestock units per ha down to 0.6 units. Unsurprisingly, given the dominance of livestock farming, food production is almost halved, dropping from a score of 50 to 29. The other ecosystem service scores are all predicted to increase, due to fewer livestock and lower fertiliser use, with the biggest increase in climate regulation. Although the change water quality may seem small given the large reduction in livestock (81 in the baseline to 87 in the scenario), this represents a reduction in leaching of one third (water quality is already high due to the predominantly grassland agricultural area and the relatively high carbon content of the soil resulting in denitrification).

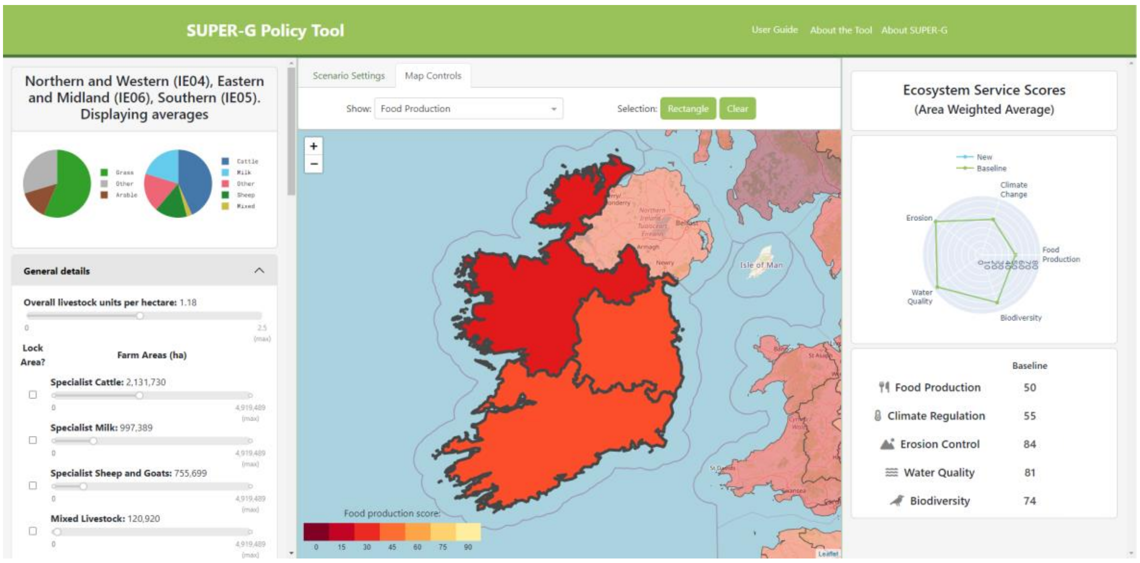

Figure 8 Baseline tool outputs for the three Ireland NUTS2 regions

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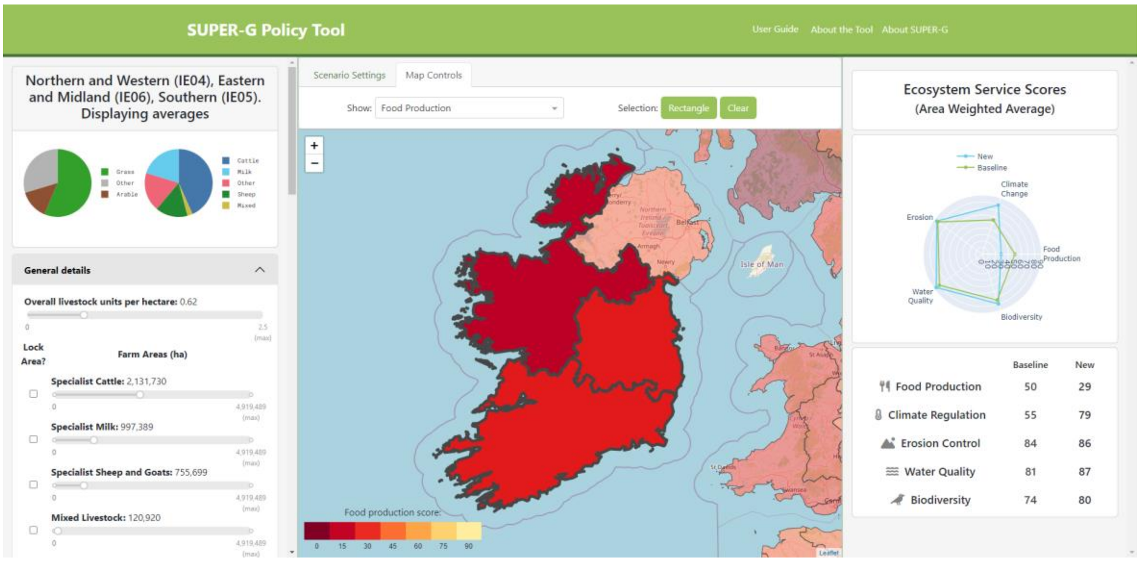

Figure 9 Tool outputs for the three Ireland NUTS2 regions with livestock numbers halved

3.4. Future development

The policy tool has been developed as a relatively simple tool, responding to user inputs in real time, to quantify potential benefits in ecosystem services from broad scale changes in grassland management intensity.

There are a number of areas where future development could enhance the applicability and robustness of the tool predictions. These include:

- Allowing users to edit more of the coefficients and data, such as the livestock energy requirements, or improving the current parameterisation of the coefficients.
- Making it easier to modify parameters for multiple NUTS2 regions at the same time
- Developing a version with greater spatial resolution, particularly where more detailed spatial data was available for parameterising the model (e.g. not using national average arable fertiliser rates, livestock sizes or milk yields). This would most likely be the case for a single country.

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- Allowing for other management factors to be accounted for in the calculation of grassland fertiliser rates and ecosystem services, such as the use of legumes, extent of nutrient management and the duration of livestock housing.

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