Transformative land use change scenarios for net zero

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JHI-C3-1, Evaluating LUC scenarios and adding farm structure

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Key questions

- What is the feasibility of achieving net-zero CO_2e emissions in Scotland's Scotland's land-use sector by 2050 ?
- Can transformative changes, like multi-functional widespread afforestation and livestock reduction, achieve it?
- What's the effect on feasibility of considering farm structure (dairy farms)
- How do we introduce land use change that has multiple other benefits ?

=> A detailed spatial analysis

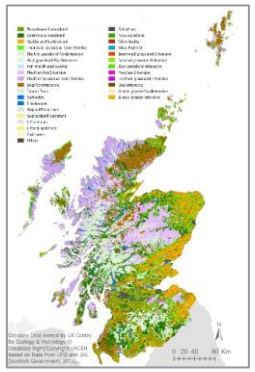
Methods: Spatial Modeling Approach

CCC Recommendations
(Tailwinds; Climate Change Committee)

SSP1-narratives
RCP2.6

Scenarios assumptions

(> 800k ha of afforestation + agroforestry;
~ halving the stocking rates)



1 Baseline land cover

We used spatial datasets at 100m resolution to model land use changes across Scotland, with baseline land cover from UKCEH Land Cover Map 2019 and agricultural systems mapped using SAF, IACS, and JAC databases.

2 Opportunity Mapping – where to introduce change

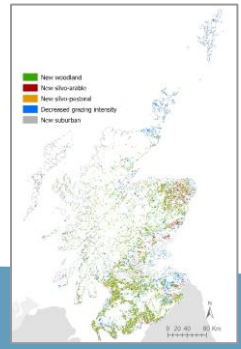
- Woodland and agroforestry expansion to decrease diffuse pollution, alleviate flooding, mitigate river thermal stress, improve connectivity while avoiding soil C loss and minimizing encroachment on open ground habitat.
- Decrease of stocking rates to conservation grazing threshold.

3 Simulation

Using the LandSFACTS model with a stochastic algorithm, we optimized land use changes while adhering to constraints. Carbon capture was calculated using modelled Yield Class data and UK Woodland Carbon Code estimates.

4 Scenario Comparison

- **SSP1-LE** implementing all mitigation measures, where suitable.
- **SSP1-LE-DF** as above, but preserving dairy farm's intensively grazed improved grasslands from land use change.

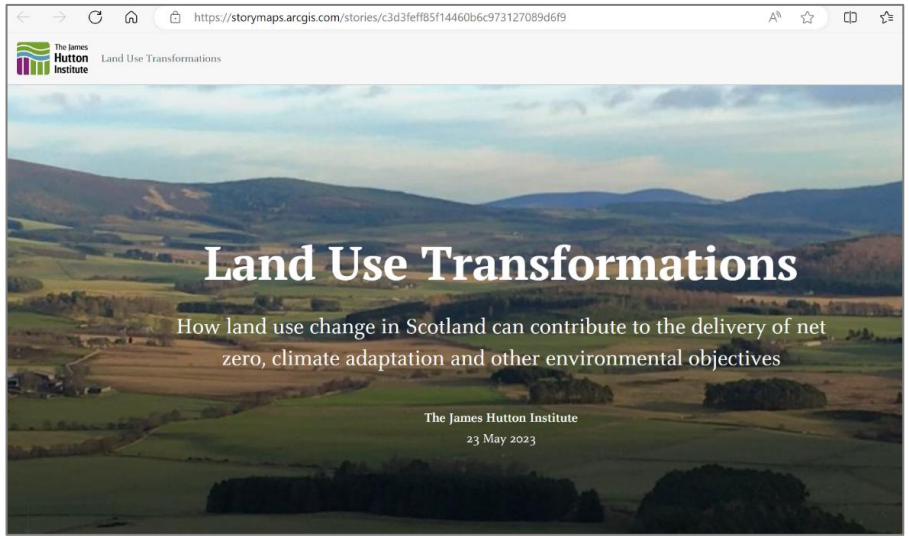


5 Assessments

Land use change per agricultural regions and farm types; Carbon emission; Net Zero threshold; Nitrogen exports

Further Information: On-line Story maps

Examples of SSP1-Low emissions Scenarios as Storymaps,
created as part of Strategy Research Programs: JHI-C3-1: Land use Transformations



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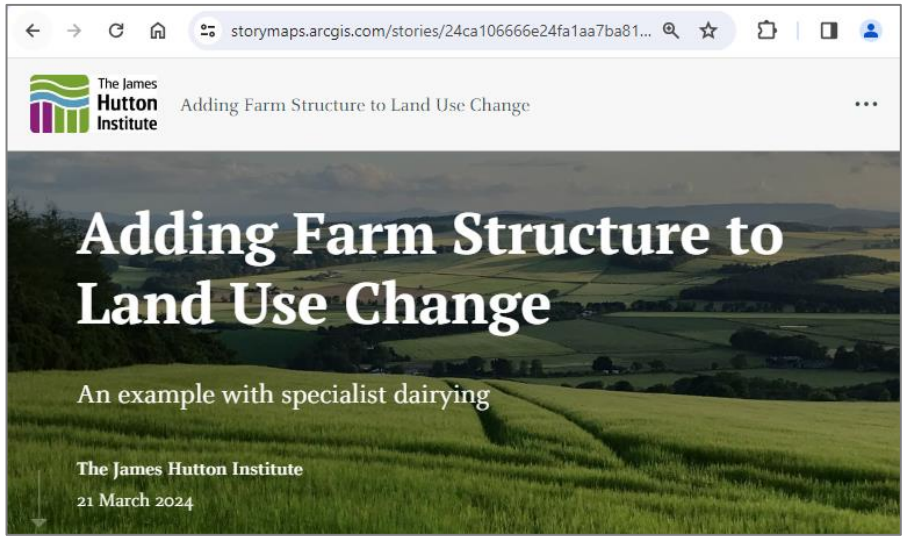

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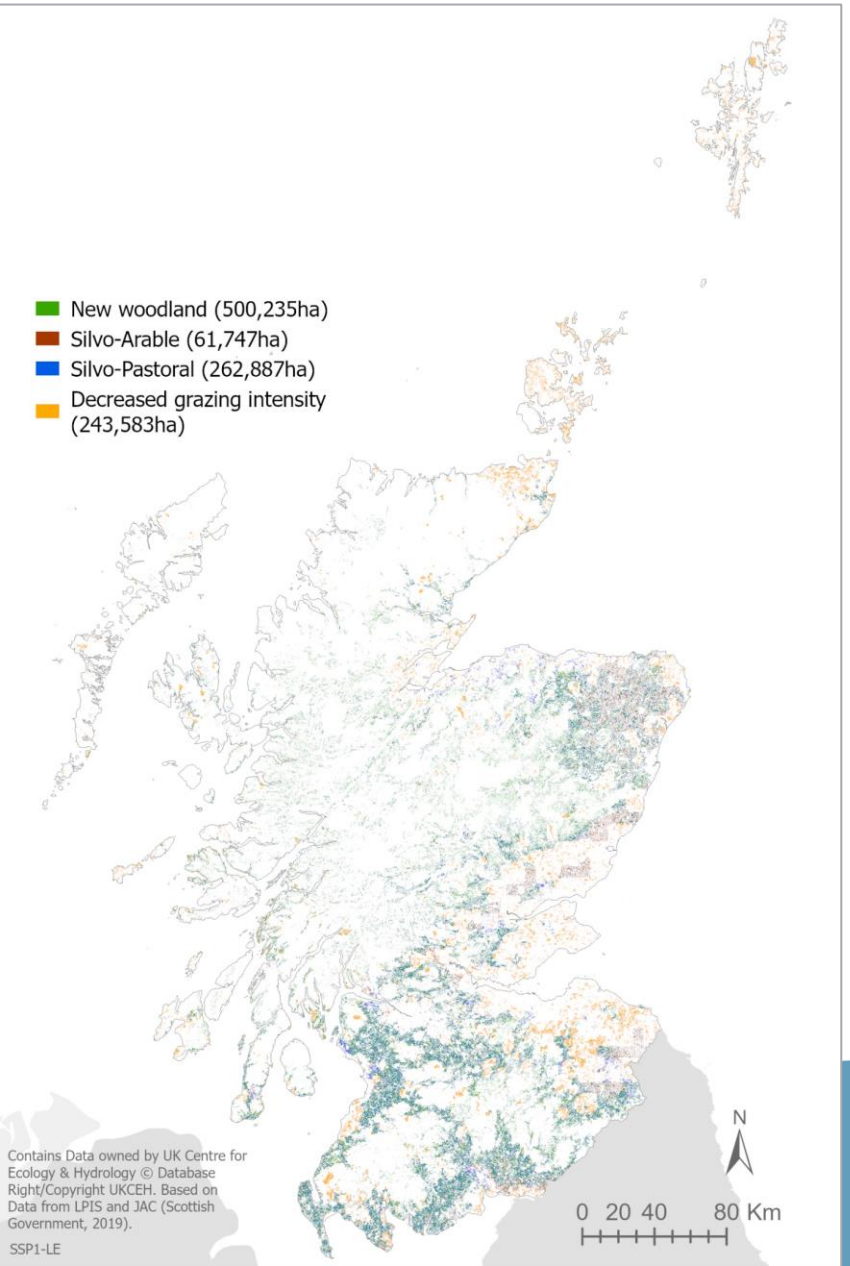
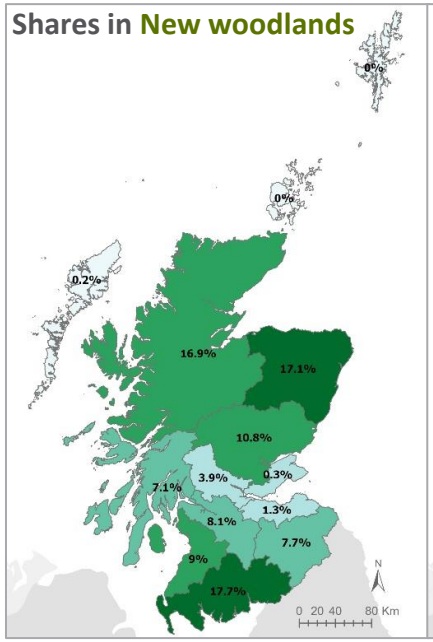
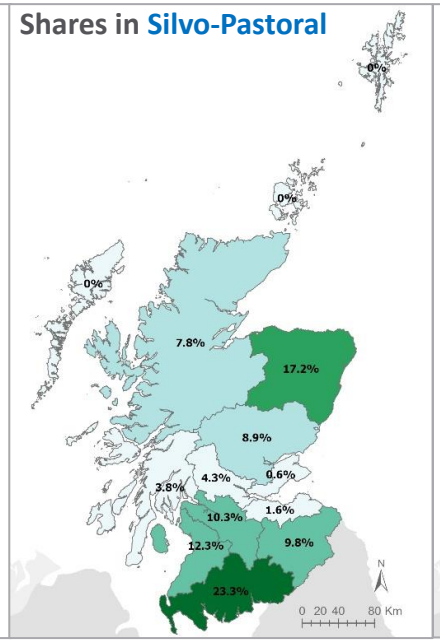
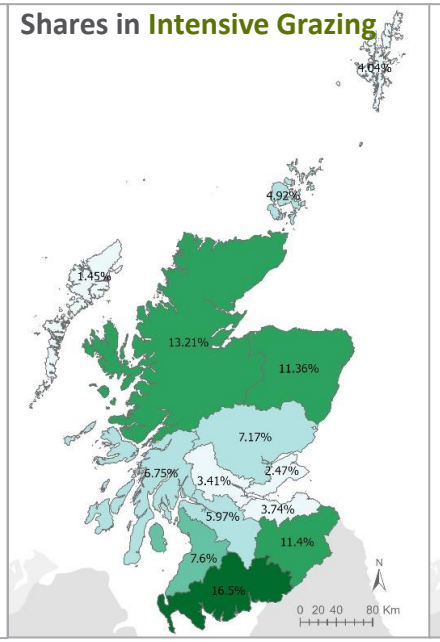
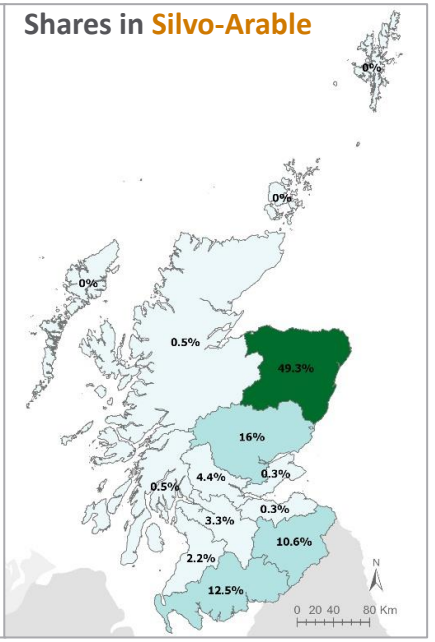
Land Use Change in SSP1-LE

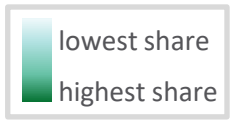












Land Use Change in SSP1-LE-DF (dairy) in comparison to SSP1-LE

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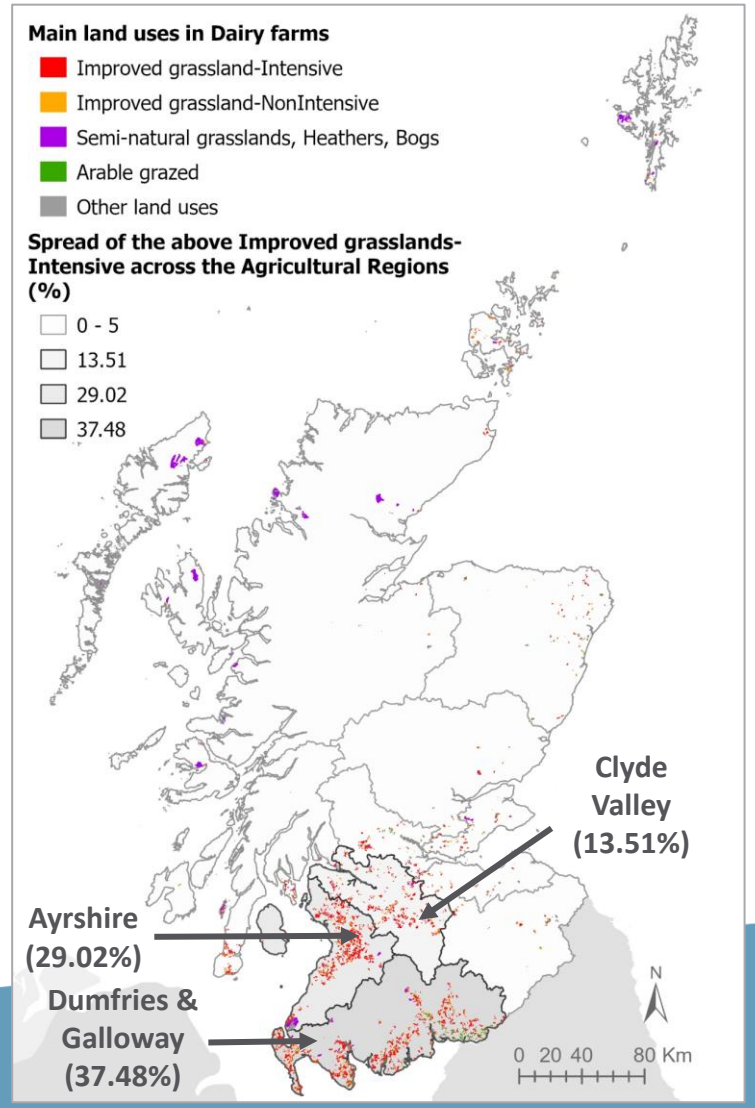
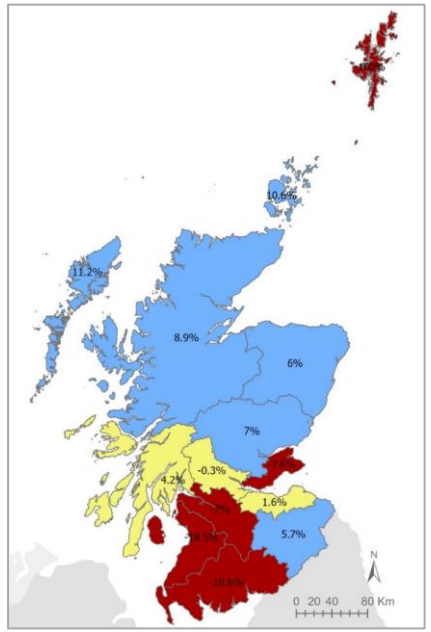
Location of dairy farms

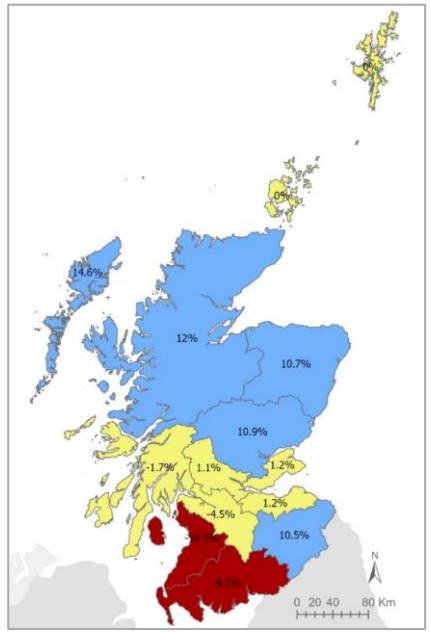


Comparing the two scenarios

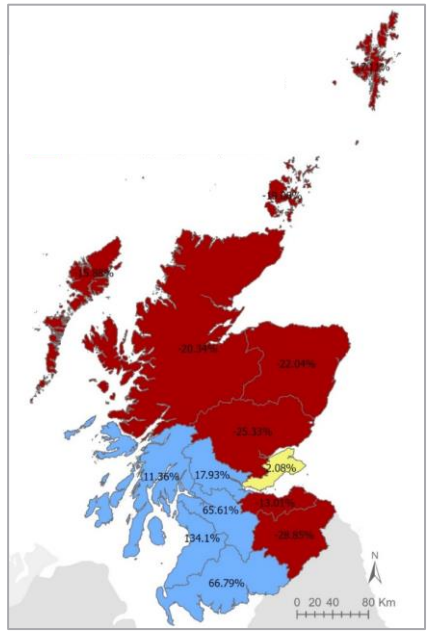
(with/without protecting dairy farms intensively grazed improved grasslands)



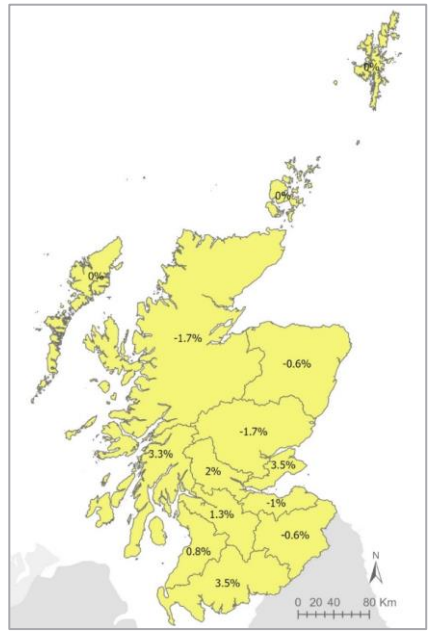
Gain/Losses in **New woodlands**



Gain/Losses in **Silvo-Pastoral**



Gain/Losses in **Intensive Grazing**



Gain/Losses in **Silvo-Arable**

in SSP1-LE-DF in comparison with SSP1-LE

More land use change in Dairy scenario
Low variation
Less land use change in Dairy scenario

Cumulative emissions 2020-2050 (Megatons of CO_2e)

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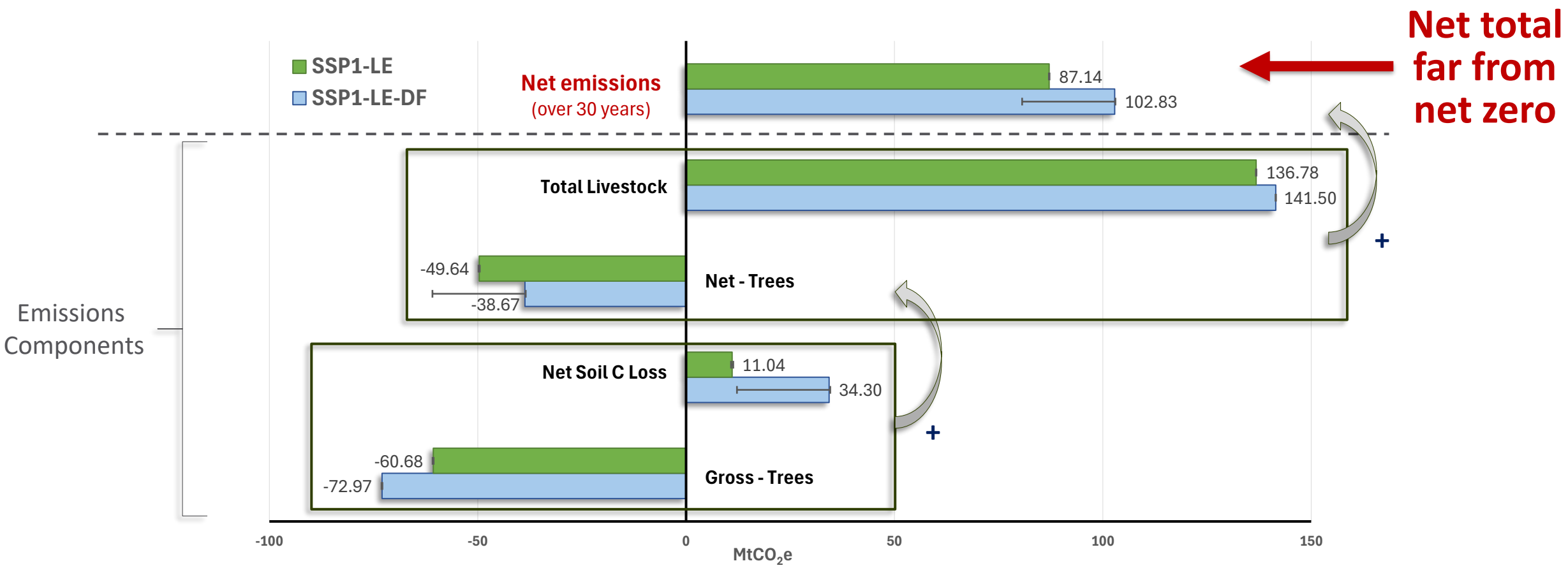

Net emissions 2020-2050 (CO_2e)

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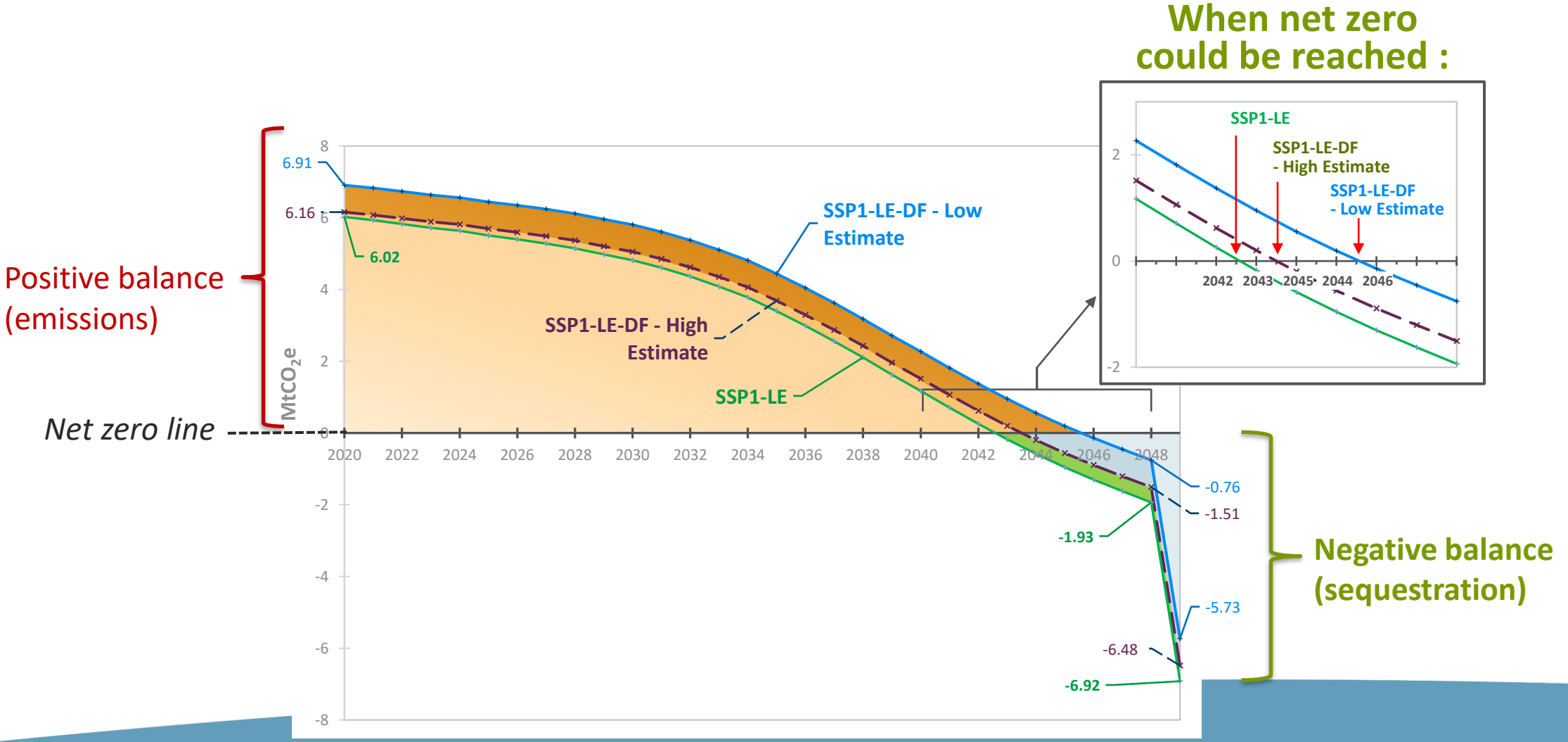

Nitrogen Exports (SEPA catchments)

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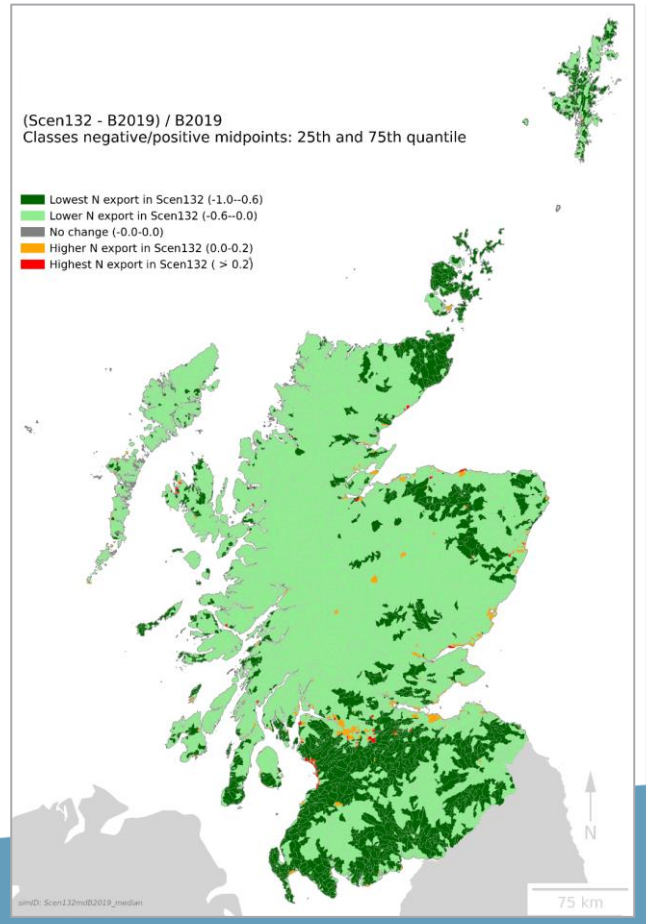
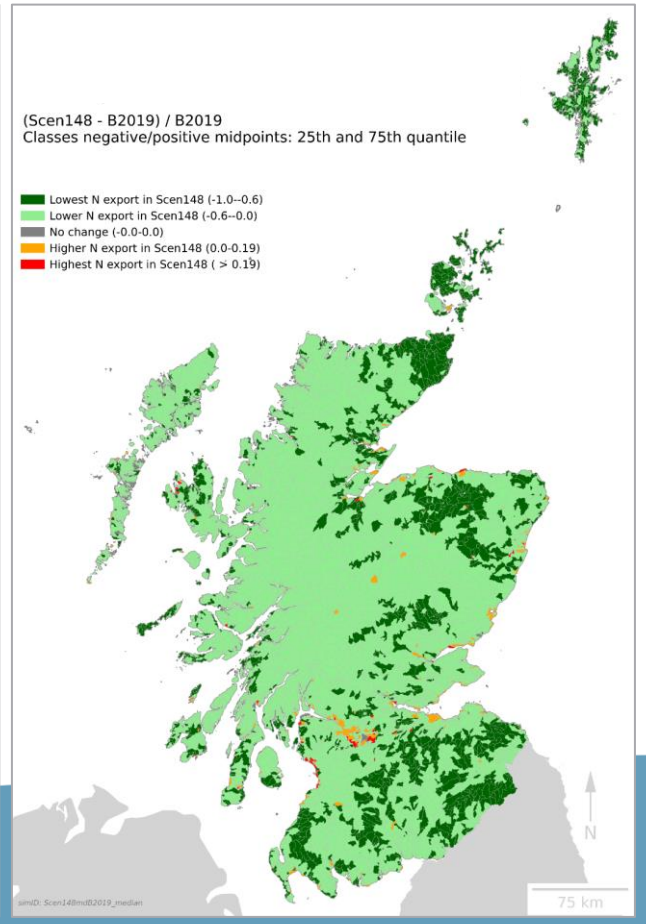
Highest improvement in scenario
Highest degradation in scenario

Highest improvement in Dairy scenario
Highest degradation in Dairy scenario

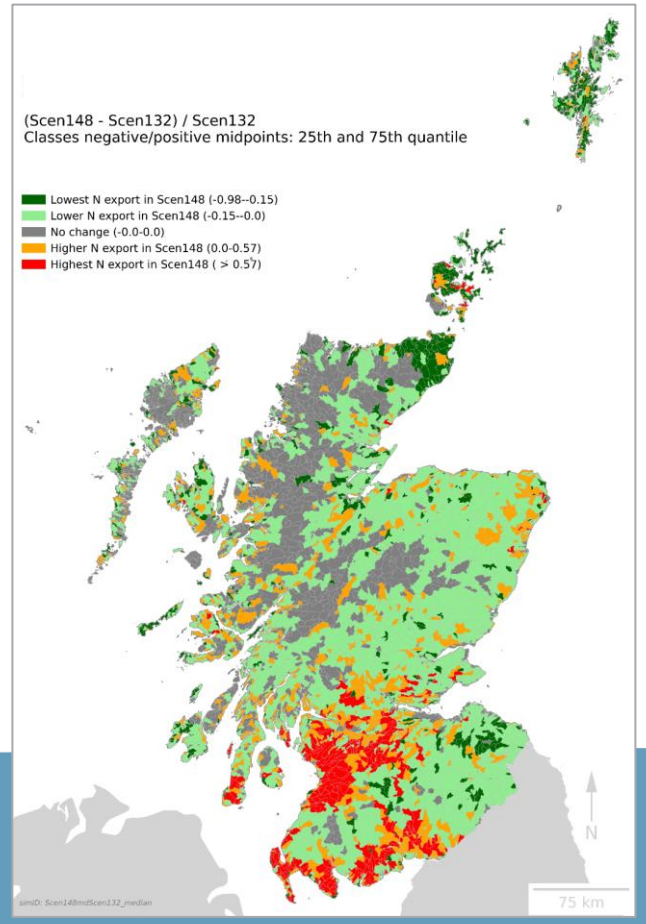
SSP1-LE compared with Baseline



SSP1-LE-DF compared with Baseline



SSP1-LE-DF compared with SSP1-LE



SSP1-LE and SSP1-LE-DF: median over 10 replicates

Conclusions

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- **Feasibility of Net-Zero Livestock Emissions**
  - Possible by 2050 under strong assumptions but only temporary.
  - 81% reduction by 2035 is not feasible.

- **Mitigation Strategies & Carbon Sequestration**
  - 34-39 Mt of emissions avoided by livestock reduction. 39-50 offset by trees
  - Poorly targeted afforestation (e.g. many upland soils) can result in higher net emissions.

- **Ecosystem Services & Biodiversity Co-benefits**
  - Well-planned afforestation and agroforestry enhance biodiversity and water regulation.
  - Spatial planning avoids negative ecological trade-offs.

- **Livestock Reduction & Policy Alignment**
  - Cattle (-47%) and sheep (-25%) reductions needed to cross net zero line by 2050 or earlier.

- **Carbon Budgets & Offsetting Challenges**
  - Voluntary carbon markets may face supply issues.
  - Methane's high short-term warming impact complicates net-zero goals.

References

SSP1-Low emissions scenarios Storymaps :

Tavana, M.; Wardell-Johnson, D.; Miller, D.; Castellazzi, M.; Gimona, A.; Rivington, M.; Matthews, K. (2022) Story Map Land Use Transformations: How land use change in Scotland can contribute to the delivery of net zero, climate adaptation and other environmental objectives, Project Deliverable Report, D1, Land Use Transformations, https://storymaps.arcgis.com/collections/20665a1964b54e429d32ca61f897bd47?item=1

Tavana, M.; Wardell-Johnson, D.; Castellazzi, M.; Gimona, A.; Rivington, M.; Miller, D.; Matthews, K., (2024) Adding Farm Structure to Land Use Change: An example with specialist dairying, Online - Story Map. https://storymaps.arcgis.com/stories/24ca106666e24fa1aa7ba81e42ad0b81

Submitted publication (under peer review) :

Gimona, A., Castellazzi, M., Wardell-Johnson D., Miller, D., Matthews, K. (SUB) Transformative land use change for net zero: balancing carbon with woodland expansion and livestock reduction in Scotland. Journal of Environmental Management. Under review.

Advanced opportunity mapping (not fully in the above scenarios) :

Gimona, A., Castellazzi, M. (2025) Transformative landscape change to tackle the climate and biodiversity crises: a Scotland-wide zonation for restoration (v.1.1). RESAS Research Program 2022-27, grant JHI-C5-1, Deliverable 3.2-Landscape Zonation.

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Castellazzi, M., Gimona, A. (2016) Sustainable Land Management Project, Sustainable Land Options Tool. ESCOM16 Conference, 17 May 2016. https://oppla.eu/sites/default/files/resources/escomslm-optionstool200416part1.pdf

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Castellazzi, Marie; Brown, I.; Poggio, L.; and Gimona, Alessandro, "Modelling land use change and its spatial variability for ecosystem services assessments" (2012). International Congress on Environmental Modelling and Software. 122. https://scholarsarchive.byu.edu/iemssconference/2012/Stream-B/122

Castellazzi, M. S.; Brown, I.; Gimona, Alessandro; and Poggio, L., "Exploring path-dependencies and spatial variability in landscape scale scenarios for ecosystem services assessments" (2012). International Congress on Environmental Modelling and Software. 106. https://scholarsarchive.byu.edu/iemssconference/2012/Stream-B/106