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D29: Trade-offs and Synergies

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Non-Technical Summary

This deliverable (D29 – Trade-offs and Synergies) reports on the use of SUMMA (Sustainability Multi-criteria Multi-scale Assessment) one of the DECOIN[1] tools and is part of the project Synergies of Multi-Level Integrated Linkages in Eco-social Systems (SMILE)[2]. D29 is a contribution to WP4: *Synergies and Trade-off Analysis and Scenario Building*. The report builds on the previous work by the MLURI team in the *Scottish Case Study* (D16) and the *Utility of tools to Stakeholders* analysis (D23). The analysis undertaken was an assessment of the trade-offs and synergies within the Scotland and Cairngorms National Park (CNP) agricultural sectors. The analysis was based on improvements to the SUMMA model application, including the inclusion of GHG emissions from the livestock and manures components of the agriculture; more comprehensive coverage for data from 1991-2001 and better data on material use. The findings of the research are presented in terms of emissions, environmental impacts and emergy indicators.

- Emissions: both extents and intensities of emissions from the Scottish and CNP agricultural sectors have decreased 1991-2007, although some increased 1991-2001. This suggests an extensification of agricultural systems; and the intensity indicators illustrates that a system like the CNP requires more energy (generating more emissions) to produce a kg of product or generate income for the economy.
- Environmental Impacts: again both extents and intensities of impacts from Scottish and CNP agricultural sectors decreased 1991-2007. The data illustrates that whilst the CNP have lower impacts per hectare, the sector produces more impacts per product than the Scottish average.
- Emergy: The indicators suggest that both CNP and Scotland have increased their extent of emergy inputs to the agriculture sector. Using intensity indicators, Scotland appears to be becoming marginally more sustainable, but the CNP indicators show a trend to being less sustainable. However, it is important to remember that the overall extents of impacts from the CNP sector is very small, compared to Scotland as a whole.
- Overall, the data suggests there are unavoidable trade-offs between production and environmental impacts and little or no evidence of synergies, win-wins, dematerialisation or sustainable growth.

The SUMMA-based research within D29 will continue to be developed within the new Scottish Governments research programme (2011-16).

[1] http://www.decoin.eu
[2] http://www.smile-fp7.eu/

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Acknowledgements

The authors would like to thank the SUMMA development team for their assistance over the course of this analysis, in particular Silvio Viglia who undertook the most recent revision to the SUMMA models and data.

1 Introduction

The Synergies of Multi-Level Integrated Linkages in Eco-social Systems (SMILE)[3] project seeks to further develop and apply the DECOIN[4] tool kit. This toolkit consists of three models: SUMMA (Sustainability Multi-criteria Multi-scale Assessment); MuSIASEM (Multi-Scale Integrated Analysis Societal Ecosystem Metabolism) and ASA (Advanced Sustainability Analysis). The ambition of the SMILE project is to combine these tools into a system of sustainability accounting that provides a useful insights into the dynamics of the sustainability of complex coupled eco-social systems (Giampietro et al. 2009).

This report (D29) is a contribution to WP4: *Synergies and Trade-off Analysis and Scenario Building*. The report builds on the previous work by the MLURI team in the Scottish Case Study (D16) and the Utility of tools to Stakeholders analysis (D23). In D16 a case-study of sustainable development within the Cairngorms National Park was developed in partnership with the Cairngorm National Park Authority (CNPA). In D23, the utility of outputs from the SUMMA and MuSIASEM tools[5] were assessed again with the CNPA. Neither analysis was seen as lacking in merit or as being irrelevant to the CNPA deliberations on sustainability. The MLURI research team, however, recognised that neither approach had overcome the "implementation gap" and neither would feature strongly as an evidence base for decision making in relation to the next Cairngorms National Park Plan (the aspiration at the start of the SMILE research). This partially reflects the inexperience of the MLURI team in using the DECOIN tools and the challenges of using a non-standard statistical region, but also the challenge in resource terms of one SMILE partner making operational two of the DECOIN tools for a single case-study[6]. The importance of taking the tool kit beyond the academic community and demonstrating its policy relevance, however, was highlighted in the external review of the SMILE project by Redclift in 2010. In the light of these findings and the limited resources remaining to the project team[7] the scope and nature of the analysis for D29 was modified, still retaining the objective of assessing trade-offs and synergies at a range of scales but doing so with a strong emphasis on analyses that were seen as relevant to the cast-study stakeholders. The rationale and objectives for the D29 report are set out below.

For D29 the SUMMA analysis is the most relevant for looking at the trade-offs and synergies looking within the Scotland and CNP agricultural sectors. In D23 it was possible to identify some high priority issues and modification to the analyses that would greatly increase the salience and credibility of the outputs. These issues were prioritised rather than opening up

[3] http://www.smile-fp7.eu/
[4] http://www.decoin.eu
[5] The ASA tool was not implemented in the Scottish case study, as its requirement for specific data to be available as time series were unable to be met for the Cairngorms National Park (CNP).
[6] The MLURI team have also been less able to devote additional resources to SMILE within the SG funded research programme as higher priority policy research has been commissioned.
[7] The analysis has been heavily supported by the MLURI core research funds as well as RTD.

new avenues of research. Thus this report has continued to use Scotland and the CNP's agricultural sectors are the basis for the case study rather than extending the analysis to the tourism sectors as had been planned. The most crucial SUMMA issues identified by the stakeholders in D23 have been addressed but others remain due to limitations on the staff time available (see Section 5). The D29 analysis is complemented by the D28 analysis of growth that uses the outputs from the MuSIASEM analysis. Policy implications of the two analyses are reported in D30.

2 Materials and Methodology

This section briefly outlines the basis of the case study and the improvements made to the SUMMA analysis since the completion of D23. For more detail see the original Case-Study report (D16) and the updates within the Utility report (D23).

2.1 Setting for the case-study

Figure 1 shows the location within Scotland of the CNP. The CNP is made up a series of valleys radiating from a mountainous centre. While conventional agriculture is restricted to lower elevations it can be argued that all but the highest altitudes are managed by human systems of land management and even the highest altitudes are affected at least to some degree by human activities even if indirectly[8]. The case study is thus useful in assessing both more intensive systems (lowlands) and more extensive systems (hills).

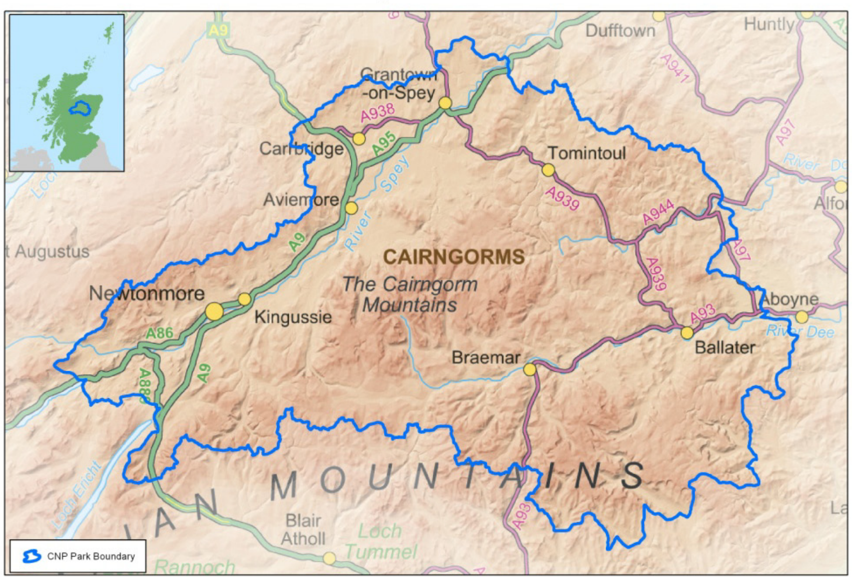


Figure 1: Location and relief map of the Cairngorms National Park

[8] For example through previous and current acidic rainfall.

Through previous analysis the "Campania" SUMMA model of the agricultural sectors was modified to better represent the Scotland and CNP case ($Scot_{AG}$ and CNP_{AG} models). This process of modification was guided by participatory systems diagramming activities conducted with CNPA stakeholders and by a review of the relevant grey literature (see D16). This process defined the stocks and flows within the agricultural sector and its relations to other sectors, see Figure 2.

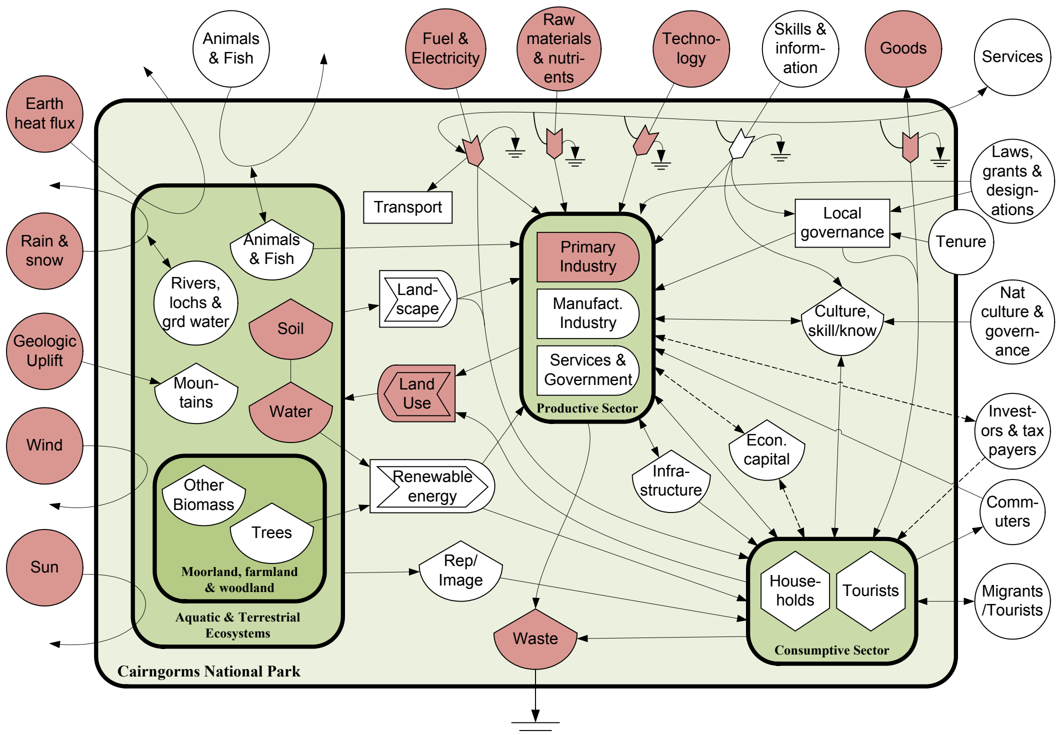


Figure 2: Simplified energy systems diagram for CNP with the agricultural sector highlighted

2.2 Improvements to the $Scot_{AG}$ and CNP_{AG} SUMMA models since D23

Following the D23 work with the CNPA it was clear that one of the main limitations on the credibility of the SUMMA analysis was the omission of GHG emissions from the livestock and manures components of the agriculture. These livestock emissions had not been a significant part of the "Campania" SUMMA models. Such emissions are in some cases accounted for separately to those direct from land use / land use change but for Scotland with an agricultural sector strongly dependent on livestock production, omitting such emissions gives an unbalanced view of the synergies and trade-offs.

For the analysis reported here the approach to emissions from livestock is an IPCC Tier 1 analysis[9]. The IPCC uses a two tier approach for the accounting of livestock emissions. The first

[9] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Chapter 10: Emissions from Livestock and Manure Management

tier uses fixed emission factors (e.g. CH_4/head/year). The second tier uses more complex methodologies which try to capture unique national circumstances (e.g. levels of productivity, feeding regimes, etc). Within the resources of the SMILE project it was possible to implement a Tier 1 approach. While noting that there would be benefits from the more sophisticated Tier 2 approach the reliability of the additional data could not be determined so the simpler approach was preferred. The elements of the Tier 1 IPCC approach used are briefly set out below.

2.2.1 Livestock populations

The livestock populations reported in the June Agricultural Census and/or December Survey (i.e. those currently used in the SUMMA case study) are suitable inputs for the calculation of emissions; however, if appropriate, some adjustment should be made for animals that are alive for periods shorter than a year. In these cases the (Total Annual) Population should be adjusted as follows, to give (Average Annual) Population:

(

2.2.2 Emissions of methane (CH_4)

Methane emissions are a by-product of both Enteric Fermentation (a digestive process by which carbohydrates are broken down) and Manure Management (the decomposition of dung and urine).

The formula for the calculation of methane emissions from Enteric Fermentation (kg/year) is:

Similarly the formula for the calculation of emissions from Manure Management (kg/year) is:

Where:

- P_T is the livestock population for livestock type T
- EF_{ET} is the *enteric fermentation* emissions factor for livestock type T (kg CH_4/head/year)
- EF_{MT} is the *manure management* emissions factor for livestock type T (kg CH_4/head/year)

The IPCC Guidelines propose that the following CH_4 emissions factors are appropriate for Scotland:

Table 1: Methane Emissions Factors (kg CH4/head/year)

Classification	EF_{ET} (Enteric Fermentation)	EF_{MM} (Manure Management[10])	IPCC 2006 Ref
Dairy Cattle	117.0	21.00	Tables 10.11, 10.14
Other Cattle	57.0	6.00	Tables 10.11, 10.14
Sheep	8.0	0.19	Tables 10.10, 10.15
Goats	5.0	0.13	Tables 10.10, 10.15
Horses	18.0	1.56	Tables 10.10, 10.15
Deer	20.0	0.22	Tables 10.10, 10.16
Pigs	1.5	6.00 – 9.00	Tables 10.10, 10.14
Market Swine (90%)	1.5	6.00	Tables 10.10, 10.14
Breeding Swine (10%)	1.5	9.00	Tables 10.10, 10.14
Poultry	N/A	0.02 – 1.20	Tables 10.10, 10.15
Layers (dry)	N/A	0.03	Tables 10.10, 10.15
Layers (wet)	N/A	1.20	Tables 10.10, 10.15
Broilers	N/A	0.02	Tables 10.10, 10.15
Turkeys	N/A	0.09	Tables 10.10, 10.15
Duck	N/A	0.02	Tables 10.10, 10.15

2.2.3 Emissions of nitrous oxide (N_2O)

Nitrous oxide emissions from Manure Management refer to the estimation of the N_2O produced during the storage and treatment of both dung and urine. The IPCC equations for the calculation of N_2O are set out in Appendix 1. For the $Scot_{AG}$ and CNP_{AG} analyses the MLURI team used a second software tool (Feliciano 2011) that implements the IPCC equations and included the outputs from this tool as additional sources of N_2O within SUMMA. These additional livestock sources of emissions are added to the other emissions of N_2O estimated for other processes within SUMMA.

2.3 Other Issues Addressed

Other minor issues with data quality were addressed in the revised analysis. These mainly related to improvements in how to estimate values of parameters for the CNP when only Scotland level analyses were represented. The key improvement here is in the use of JAC data rather than IACS data since this gives a more comprehensive coverage of the CNP area particularly for the earlier time periods (1991 and 2001). Efforts to improve the estimation of materials data were partially successful, particularly with the inclusion of plastics, through reinterpreting JAC data.

[10] Assumes Scotland has an average annual temperature of <= 10^{o}C and follows the classification for Western European Developed Countries (i.e. liquid/slurry and pit storage systems are commonly used for cattle and swine manure. Limited cropland is available for spreading manure)

3 Findings

The findings from the $Scot_{AG}$ and CNP_{AG} SUMMA analyses are presented as time series for the three periods chosen (1991, 2001 and 2007). The analyses are presented as tables (to provide the numerical values and native units) and as multi-metric spider plots (to allow comparison between metrics and to provide the means of making and an overall assessment). Given the greatly different magnitudes of the individual indicators it is necessary to use some form of normalisation to make the spider plots comparable. Two forms of normalisation have been used

1. within series normalisation – relative to 1991 (i.e. 1991 = 1.0), and
2. between scale normalisation – comparing CNP with Scotland.

In some cases the normalised indicators are "inverted" so that for example an increasing value for all indicators means an increased impact on the environment. Where this occurs it is noted in the text for ease of interpretation. In all cases there is considerable need for care in interpreting the normalised indicators as the significance of, for example, a doubling will depend on the basis of normalisation (e.g. doubling of a small undesirable affect may be less significant than a 10% increase in a large undesirable effect). As with MuSIASEM in D28, the stakeholders note that there are significant conceptual and practical challenges to the communication of SUMMA outputs.

The $Scot_{AG}$ and CNP_{AG} SUMMA findings are grouped for ease of interpretation into themes

1. Emissions
2. Environmental Impacts
3. Emergy

3.1 SUMMA Theme 1 – Emissions

The emissions analysis is presented as both extents and intensities.

3.1.1 Emissions Extents

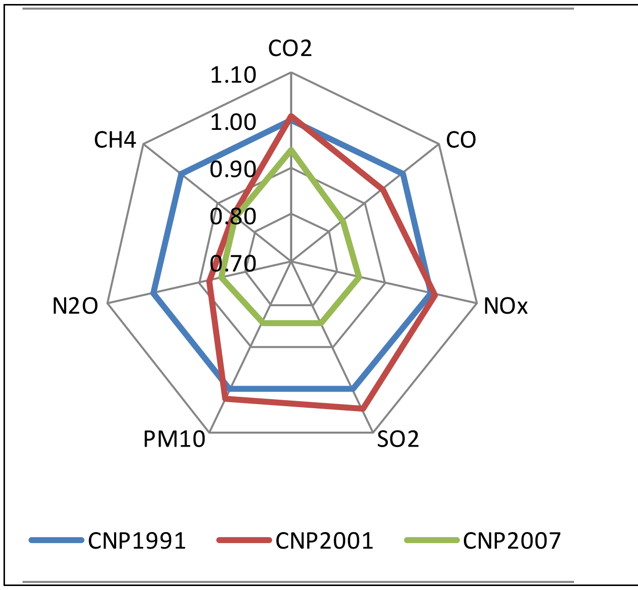
The emissions tonnages for $Scot_{AG}$ and CNP_{AG} are presented in Table 1 with emissions for CNP and Scotland relative to the baseline year (1991) presented in Figure 3. Note that to asses the GHG potential for each of the tonnages presented they need to be converted to tonnes of CO_2 equivalent see Section 3.2.

In terms of CO_2 it can be seen that for both the CNP and Scotland there is an increase in the emissions from 1991 to 2001 followed by a decrease to below 1991 values by 2007. This reflects a process of intensification based on the structure of agricultural subsidies that was reversed after 2003. For methane and nitrous oxide the pattern is of a reduction from 1991 but with less reduction after 2001.

Table 2: Emissions extents for CNP and Scotland for 1991, 2001 and 2007

Emissions (t/yr)	CNP1991	CNP2001	CNP2007	Sco1991	Sco2001	Sco2007
CO_2	63,794	64,365	59,742	3,271,818	3,401,176	2,921,718
CO	15	14	12	1,712	1,621	1,429
NOx	86	87	73	8,205	8,492	6,853
SO_2	128	133	107	10,617	11,685	8,784
PM_{10}	6	6	5	535	567	445
N_2O released	77	67	65	6,768	6,194	5,941
CH_4 released	3,300	2,833	2,814	240,989	211,932	206,513

The relative pattern of emissions for CNP_{AG} and $Scot_{AG}$ have strong similarities in terms of the overall shape of the spider plots. Scotland has a stronger increase by 2001 in CO_2, Nox, SO_2 and PM10's associated with more mechanised sectors of agriculture, but also a greater reduction (by 2007), perhaps reflecting a greater reduction in intensity in more remote rural areas pulling down the overall Scotland totals.



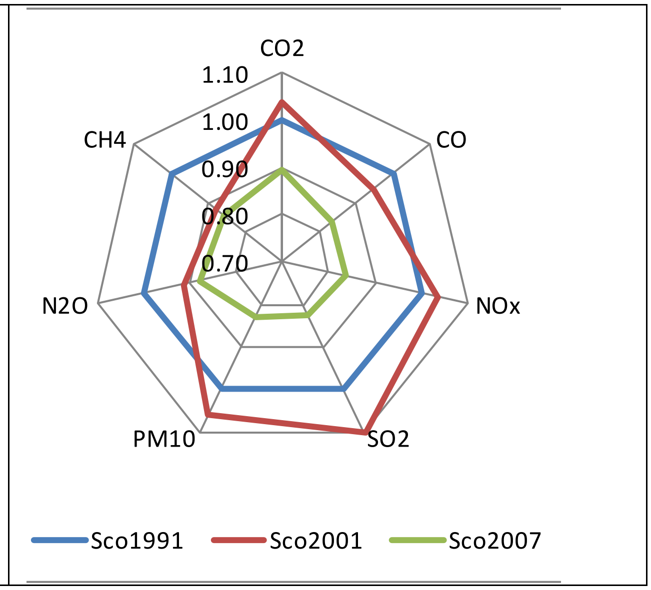
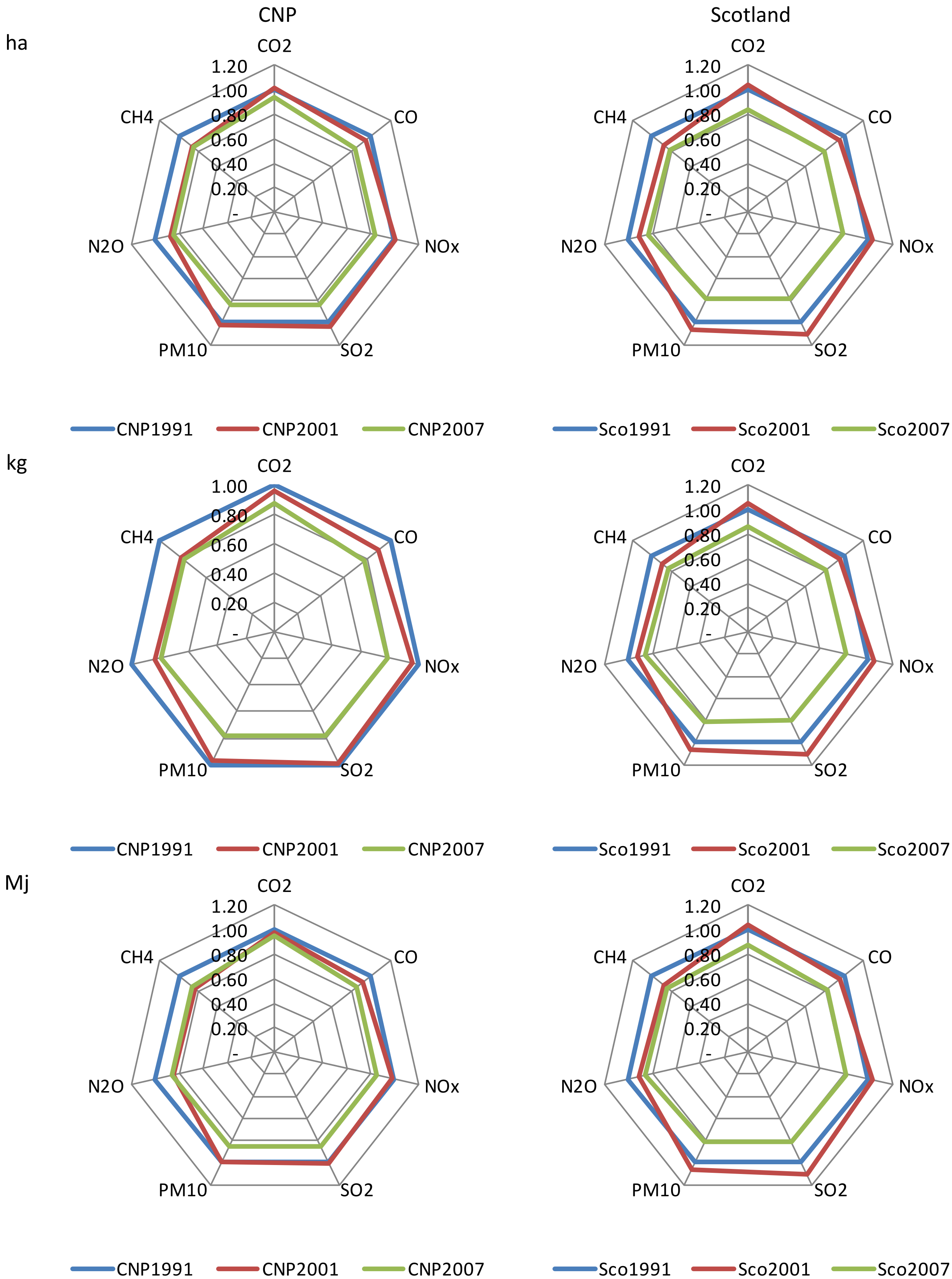


Figure 3: Total Emissions from $Scot_{AG}$ and CNP_{AG} 1991-2007

3.1.2 Emissions Intensities

Emissions intensities are estimated by SUMMA per ha, per kg of dry matter produced, per Mj of energy and per € of value for the production. Figure 4 presents the intensity measures for CNP_{AG} and Scots $_{AG}$ for 2001 and 2007 relative to the base year 1991.


CNP
Scotland
ha
kg
Mj
CO2
CO
NOx
SO2
PM10
N2O
CH4
1.20
1.00
0.80
0.60
0.40
0.20
-
CNP1991
CNP2001
CNP2007
Sco1991
Sco2001
Sco2007

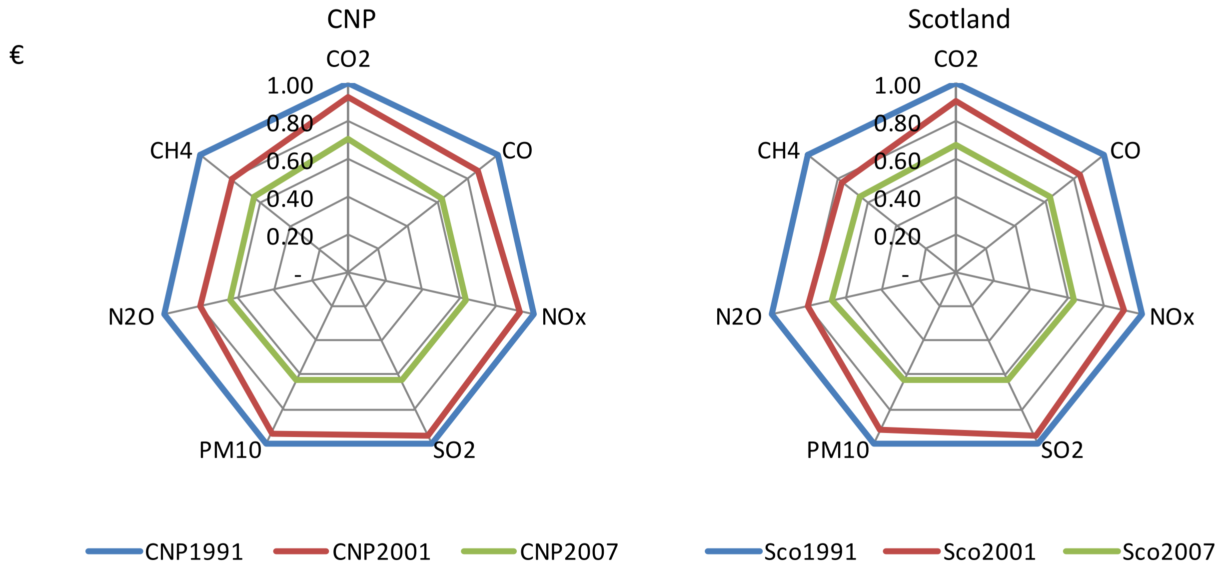


Figure 4: Emissions intensity for CNP_{AG} and $Scot_{AG}$ 1991-2007

Using intensity measures does reveal more about the nature of the changes experienced by CNP_{AG} and $Scot_{AG}$. In terms of per ha values both CNP_{AG} and $Scot_{AG}$ see some increase in intensity for indicators associated with mechanised agriculture in 2001 falling back in 2007. Both see reduction in intensity of emissions associated with livestock (N2O and CH4). Per kg and per Mj sees the CNP consistently increasing in efficiency while Scotland dips and then recovers. For € the results show an overall reduction in emissions per €. This positive €/unit of emissions analysis is limited by using current price values for each of the time steps without adjusting the € value in terms of purchasing power. A further limitation is the lack of availability of local price premium value for products generated within the CNP and/or the extra costs of doing business in a more remote rural setting.

Comparing CNP_{AG} and $Scot_{AG}$ also provides useful information about the different nature of their production systems. Figure 5 presents the relative emissions intensities for CNP_{AG} and $Scot_{AG}$ for each of the indicators for 2007 (earlier patterns are consistent but with minor variations). The emissions per ha shows the CNP_{AG} as a very low intensity system (less so in terms of CO_2 but still low) compared with an overall $Scot_{AG}$ average. In terms of emissions per kg of dry matter and per Mj of embodied energy the CNP_{AG} system can be seen to be relatively inefficient since it requires up to six times emissions to generate a comparable output. This reflects the marginal nature of the bio-physical resource available to land managers within the park (in terms of production). This lack of efficiency is though offset by the higher value per unit of production so that emission per € are three rather than six times the $Scot_{AG}$ average.

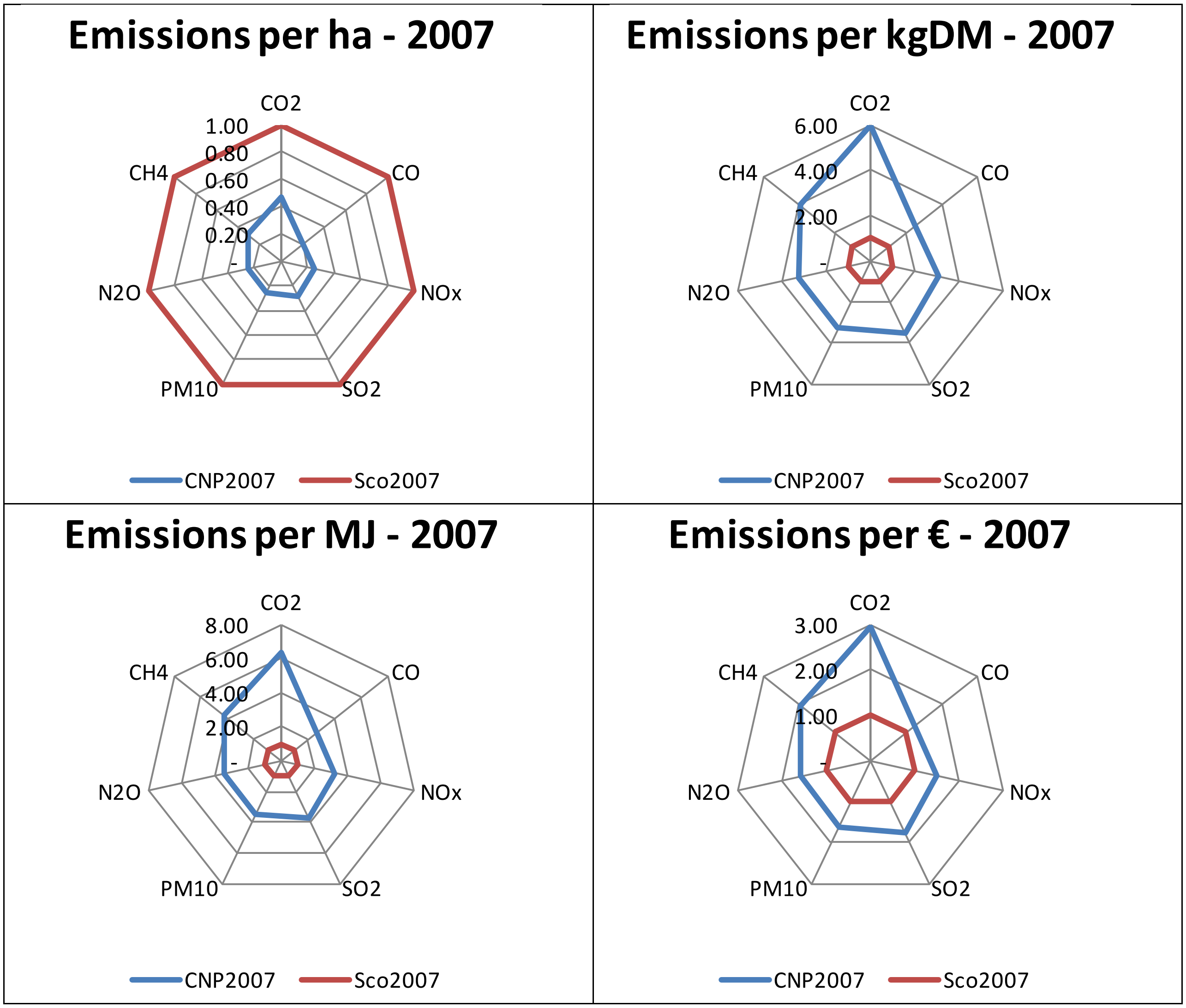


Figure 5: Emissions intensities for CNP_{AG} relative to $Scot_{AG}$ in 2007

3.2 Environmental Impacts

This theme seeks to summarise the environmental consequences of production systems in terms of:

1. Global Warming Potential (100yr) - (t CO_2 eq.)
2. Human Toxicity - (t 1.4-dchlorobenzene eq.)
3. Photochemical Oxidation - (t ethylene eq.)
4. Acidification - (t SO_2 eq.)
5. Eutrophication - (t PO_4 eq.)

3.2.1 Extents of impact

The extents of the environmental impacts estimated by SUMMA for CNP_{AG} and $Scot_{AG}$ are presented in Table 3. In Figure 6 the relative change in these values for the two cases are also presented. While over the period there has been some reduction in the extent of environmental impacts of both CNP_{AG} and $Scot_{AG}$ this reduction has not been dramatic and has in the main occurred since 2001.

Table 3: Environmental impacts of CNP_{AG} and $Scot_{AG}$ 1991-2001

Indicator/unit	CNP1991	CNP2001	CNP2007	Sco1991	Sco2001	Sco2007
Global Warming Potential 100yr - t CO_2 eq.	169,118	155,276	149,596	11,313,280	10,545,324	9,855,086
Human Toxicity t 1.4-dchlorobenzene eq.	115	117	97	10,865	11,312	9,067
Photochemical Oxidation t ethylene eq.	32	30	27	2,647	2,508	2,238
Acidification t SO_2 eq	196	203	165	16,843	18,268	13,967
Eutrophication t PO_4 eq.	32	29	27	2,894	2,776	2,495

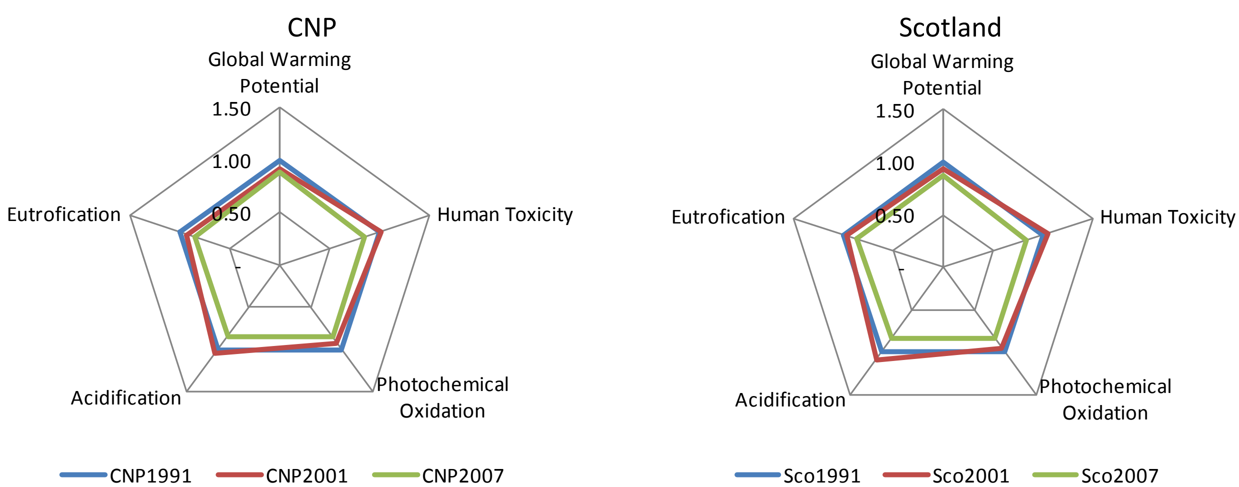
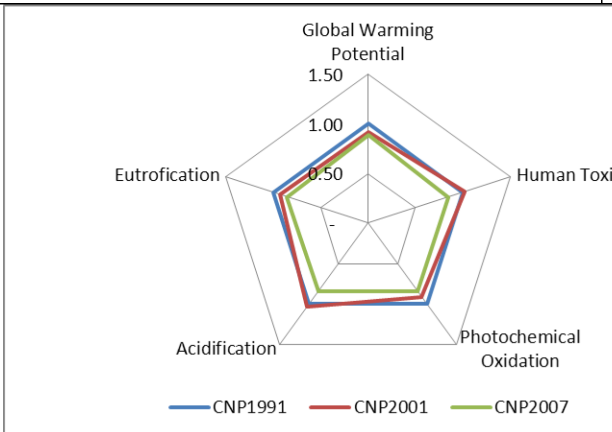
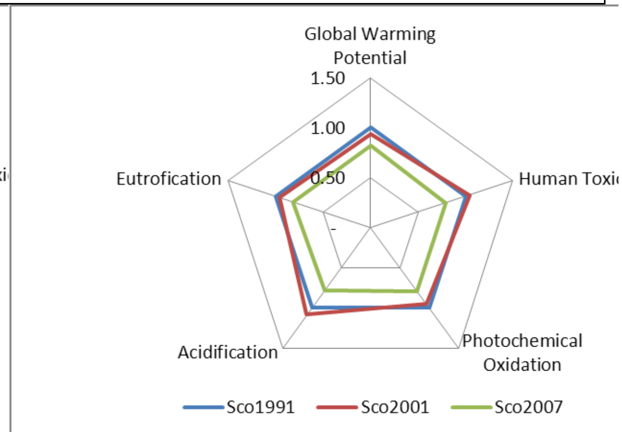
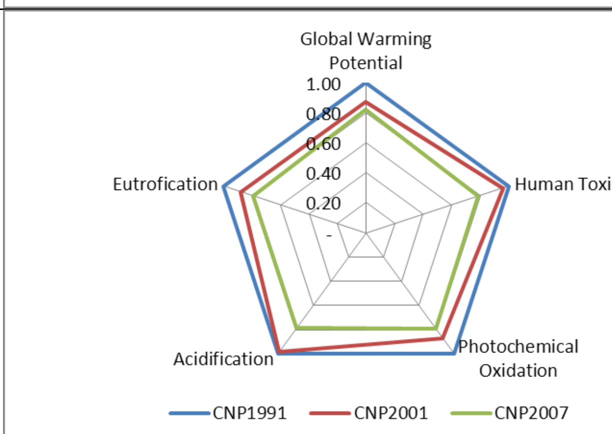
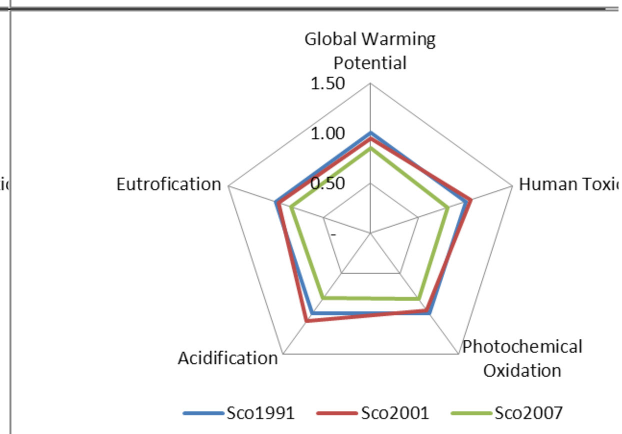
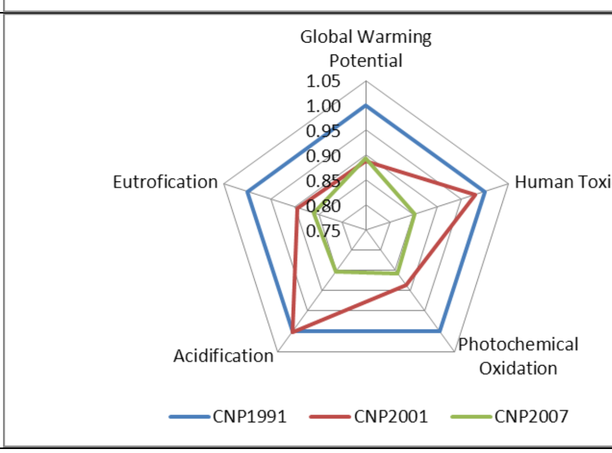
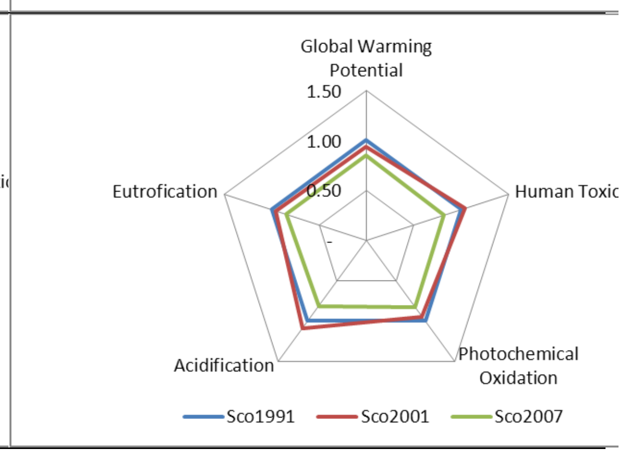


Figure 6: Change in extent of environmental impacts of CNP_{AG} and $Scot_{AG}$

3.2.2 Intensity of environmental impact

As with the emissions it is possible to assess the environmental impacts in terms of their intensity: per unit of land, per unit of production (kg of dry matter or Mj of energy) or in terms of impacts per € of value for the production. As with the previous emissions analysis the intensity can be presented as a time series for both CNP_{AG} and $Scot_{AG}$ and as their relative levels of intensity for comparison. Figure 7 presents the time series of intensity values and Figure 8 the relative values. As with the emissions intensities, the environmental impacts intensities in general show an overall pattern of marginal increase from 1991 to 2001 and then a decrease to 2007 for both cases. The pattern per Mj is unusual showing much smaller than expected reductions in Human Toxicity, Photochemical Oxidation and Acidification. The relative patterns for the two cases are also similar in form to the emission intensities. There is marginally less difference in terms of impacts per kgDM and per Mj, but a similar difference between these indicators and the impact per €.

	CNP_{AG}	$Scot_{AG}$
ha		
kg		
Mj		

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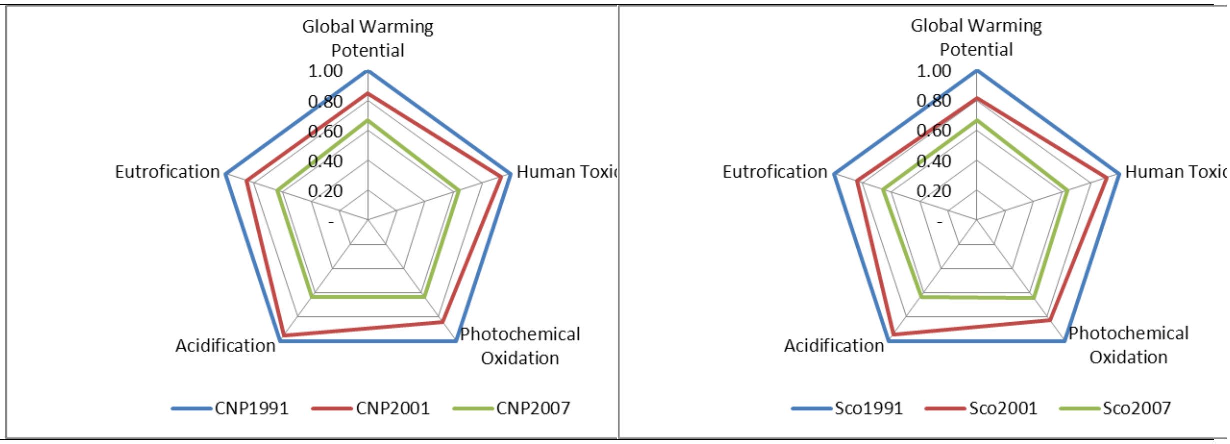


Figure 7: Environmental impacts intensity for CNP_{AG} and $Scot_{AG}$ 1991-2007

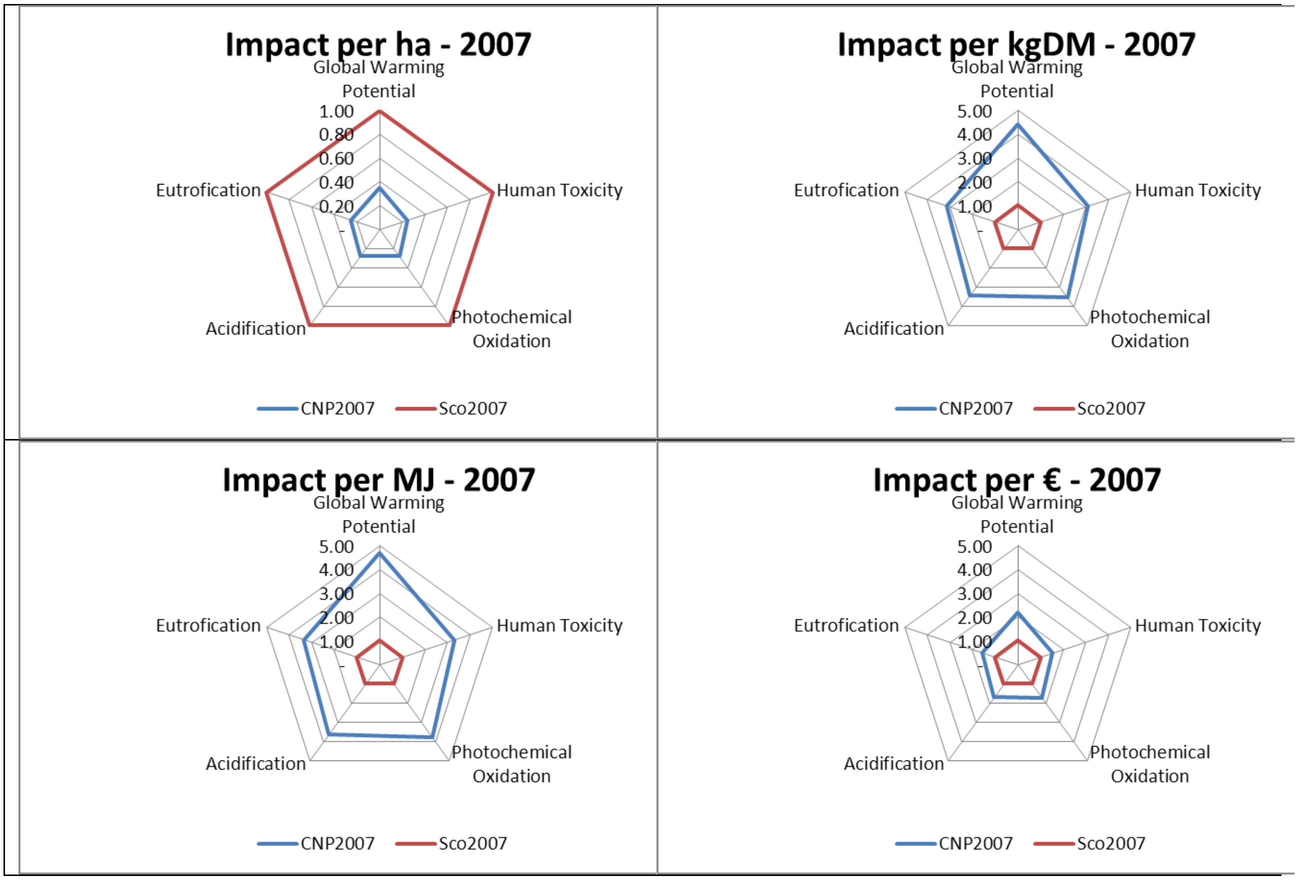
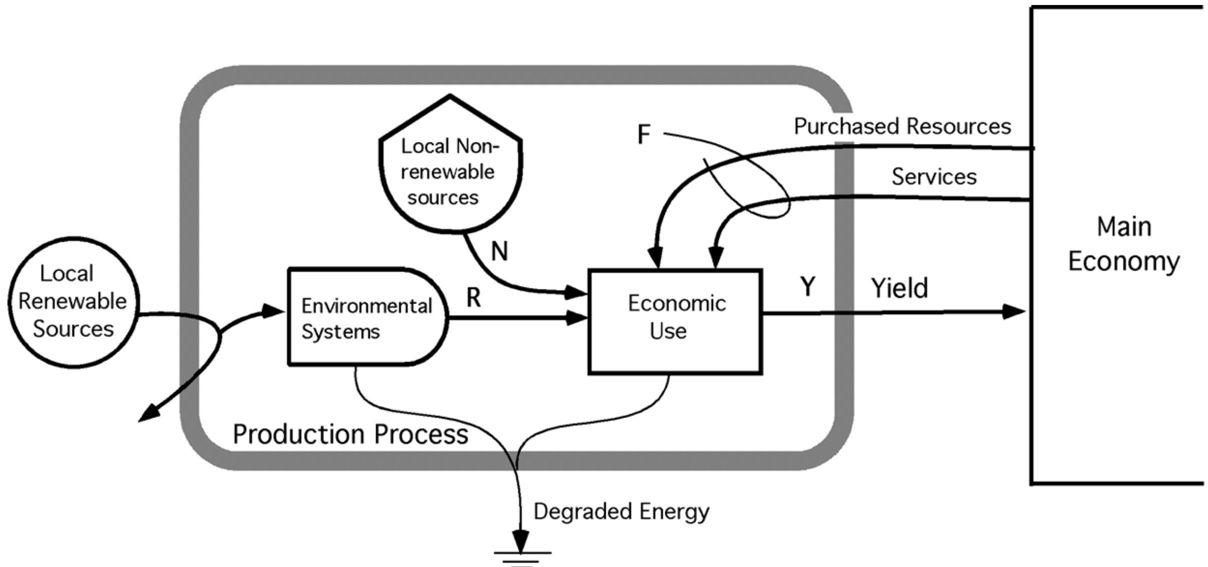


Figure 8: Environmental impact intensities for CNP_{AG} relative to $Scot_{AG}$ in 2007

3.3 Emergy Analysis

One of the key features of the SUMMA analysis is the support for emergy analysis. Emergy is the available energy of one form that is used up in transformations directly and indirectly to make a product or service. The forms of emergy and their relationships are illustrated in Figure 9.



R: local renewables (e.g. solar, wind); N: local non-renewables (e.g. soil, oil);
F: total emergy imported from outside the system (e.g. fuels, machinery);
L: labour, S: services (usually embodied); Y = total emergy yield

Figure 9: Forms of emergy and their relationships

Emergy analysis provides a sophisticated means of conducting an integrated impact assessment using a single unit of measure – solar equivalent joules (seJ), providing a consistent basis on which to make assessments of the sustainability of the system being investigated. The forms of emergy also provide useful information on the degree of dependence on non-renewable resources or on resources from out with the system boundary.

As with the previous SUMMA analyses it is possible to generate both extents and intensities of emergy use.

3.3.1 Emergy extents

Table 4 shows the magnitudes of the emergy extents for CNPAG and ScoptAG in 1991, 2001, and 2007. The table is colour coded to show where there have been improvements in sustainability (more local and more renewable). Green is improved, red less sustainable.

Table 4: Emergy extents for CNP_{AG} and $Scot_{AG}$ 1991 to 2007

Emergy Extensive Indicators - all seJ/yr	CNP 1991	CNP 2001	CNP 2007	Sco 1991	Sco 2001	Sco 2007
Locally renewable inputs, R	9.55E+19	9.85E+19	9.66E+19	3.31E+21	3.08E+21	3.69E+21
Locally non-renewable inputs, N	6.45E+19	6.45E+19	6.45E+19	1.41E+21	1.41E+21	1.49E+21
Purchased inputs to agricultural phase, F (exc L&S)	3.97E+19	4.03E+19	3.42E+19	3.65E+21	3.90E+21	3.13E+21
Indirect Labour, L	2.24E+19	3.42E+19	3.46E+19	2.37E+21	3.61E+21	3.65E+21
Indirect labour (services), S	2.82E+19	2.73E+19	3.73E+19	5.80E+21	5.98E+21	5.57E+21
Total emergy inputs, U= (R+N+F+L+S)	2.50E+20	2.65E+20	2.67E+20	1.65E+22	1.80E+22	1.75E+22

From Table 4 it can be seen that for CNP_{AG} there is a consistent increase in the use of local renewable emergy, whereas $Scot_{AG}$ experienced a reduction to 2001 and then a recovery to 2007, though not to 1991 levels. For local non-renewable inputs the CNP_{AG} experiences no change and $Scot_{AG}$ see increases from 2001 (note that in this case the 1991 inputs affecting local non-renewables will have used the 2001 values). For purchased inputs both cases see increases for 2001 followed by reductions by 2007, this is consistent with the general trend to reduced intensity of production in response to changes in subsidy regimens and increased input prices. Indirect labour follows the same pattern of increase for both cases but there is a contrast in indirect labour (services) with the CNP_{AG} seeing a reduction in 2001 followed by increase while $Scot_{AG}$ sees the reverse. In terms of total emergy inputs to the system both systems continue to grow but with CNP_{AG} plateauing while $Scot_{AG}$ peaked in 2001 and has seen some reduction to 2007. These emergy extents are presented in graphical form in Figure 10. The figures show the relative importance of the changes highlighting the increased use of indirect labour (that is labour embodied in purchased products) and for the CNP an increase in indirect labour in the form of services. In neither case is there a dramatic improvement in sustainability.

CNP_{AG}	$Scot_{AG}$

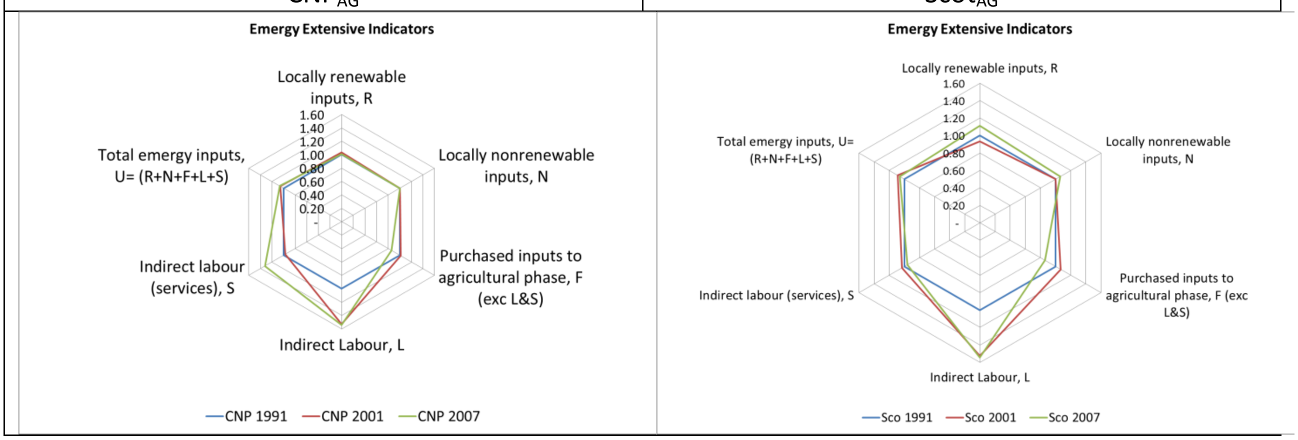


Figure 10: Emergy extents for CNP_{AG} and $Scot_{AG}$ 1991-2007

3.3.2 Emergy intensity

SUMMA provides several emergy intensity indicators and these were used to assess the performance over time of CNP_{AG} and $Scot_{AG}$ and their relative performance. The indicators are set out in Table 5, with both intensities in terms of area, weight, energy and value of production but also a series of summary indicators presenting the balance between different types of emergy. These latter are particularly useful in comparing system with significantly different magnitudes.

Table 5: Definitions of emergy intensity indicators

Indicator	Abrv	Definition	Units
Material Intensities			
Area	n/a	seJ per unit of area	seJ/ha
Weight	n/a	seJ per unit of weigh	seJ/g
Energy	n/a	seJ per unit of energy	seJ/J
Value	n/a	seJ per unit of value	seJ/€
Emergy Yield Ratio	EYR	the ratio of the total emergy yield (local and external) to the emergy invested (external). Y/F where F includes L&S. The lowest possible value of EYR is 1.0, which indicates no local resources are mobilised. Higher values are normally better **– this is not used in later figures except as part of ESI (see below)**	n/a
Emergy Investment Ratio	EIR	compares the imported emergy to the yield of local emergy. So F/Y. Where F includes L&S, and Y = N+R. Lower values indicate that larger investments of external resources are needed to exploit one unit of local resource – the complement of EYR.	n/a
Environmental Loading Ratio	ELR	compares the amount of local non-renewable emergy (N) and purchased emergy (F) to the amount of locally renewable emergy (R). Lower value means more renewable. (N+F)/R.	n/a
Renewable Energy Requirement	%REN	R/Y where Y = (F+L+S+N+R). Higher value is more renewable. Inverted for figures (**Non-Renewable Emergy Req.**) lower is better.	n/a
Emergy Sustainability Index	ESI	the ratio of EYR per ELR can be used to compare how sustainable one or more systems are at a point in time. Higher is better so inverted for figures.	n/a

The values for the emergy intensity indicators are presented in Table 6, again colour coded for improvement (green) or worsening (red).

Table 6 Emergy intensity indicators (including inversions) for CNP_{AG} and $Scot_{AG}$ (1991-2007)

	CNP1991	CNP2001	CNP2007	Sco1991	Sco2001	Sco2007
Specific Emergy (seJ/€)	1.94E+13	1.89E+13	1.56E+13	8.84E+12	8.41E+12	7.15E+12
Specific Emergy (seJ/gDM)	2.44E+10	2.46E+10	2.43E+10	5.32E+09	5.85E+09	5.48E+09
Transformity (seJ/J)	1.67E+06	1.70E+06	1.80E+06	3.67E+05	4.00E+05	3.82E+05
Specific Emergy(seJ/Ha)	1.39E+15	1.48E+15	1.49E+15	4.22E+15	4.59E+15	4.23E+15
Emergy Investment Ratio (EIR) = (F+L+S)/(R+N)	0.56	0.62	0.66	2.51	3.01	2.39
Environmental Loading Ratio (ELR) = (N+F+L+S)/R	1.62	1.69	1.77	4.00	4.83	3.75
Non-renewable Emergy Requirement (%nREN) = 1 - (R/(R+N+F+L+S))	0.62	0.63	0.64	0.80	0.83	0.79
Emergy Unsustainability Index (EuSI) = 1 / (EYR/ELR)	0.58	0.65	0.70	2.86	3.63	2.64

The material intensity values for emergy show that in terms of emergy per unit of value both systems are increasingly efficient. For emergy per unit of dry matter CNP_{AG} declined and recovered to make a marginal gain over 1991 levels. $Scot_{AG}$ saw a similar pattern but has not recovered to 1991 levels of efficiency. In terms of transformativity CNP_{AG} has seen continuous improvement whereas $Scot_{AG}$ has seen the characteristic decline and then recovery. Emergy per ha has seen both systems intensify, with CNP_{AG} level from 2001 and $Scot_{AG}$ seeing some reduction but not back to 1991 levels.

Whereas with the material intensity values all that can be compared is the trend values, with the emergy intensity indices it is possible to make more direct comparisons both of the magnitudes and trends. The key results here are that that the CNP_{AG} system can be seen to be considerably more efficient in emergy terms than $Scot_{AG}$ (in all but non-renewable emergy resource requirements). CNP_{AG} requires less investment of external resources (a lower EIR), has a lower environmental loading (ELR), comparable requirements for non-renewable emergy and overall a lower emergy un-sustainability index. That said the trends for CNP_{AG} while not dramatic are all towards reduced performance. $Scot_{AG}$, while performing more poorly, has seen improvements since 2001.

Figure 11 illustrates the emergy intensity indicators for CNP_{AG} and $Scot_{AG}$ for 1991, 2001 and 2007. From this figure it is clear that between 1991 and 2001 there was a significant worsening of the sustainability of the $Scot_{AG}$, but that from 2001 to 2007 the system has returned to (or in some cases made gains over) the 1991 values. For CNP_{AG} the time series shows a gradual worsening for the emergy intensity indicators and all but the emergy per € material emergy intensities. This latter is most likely the result in increasing prices rather than efficiency gains.

Figure 12 shows the relative performance of the two systems and is useful in contrasting the characteristics of the two systems. CNP_{AG} can be seen to be a lower intensity system (lower seJ/ha values) but to be a less efficient one in terms of the emergy resources required to generate kg of dry matter, energy embodied in products or value (€). Conversely the CNP_{AG} is much more sustainable in terms of the sources of emergy on which it draws, with even its worst performing metric (non-renewable emergy requirements) still outperforming $Scot_{AG}$.

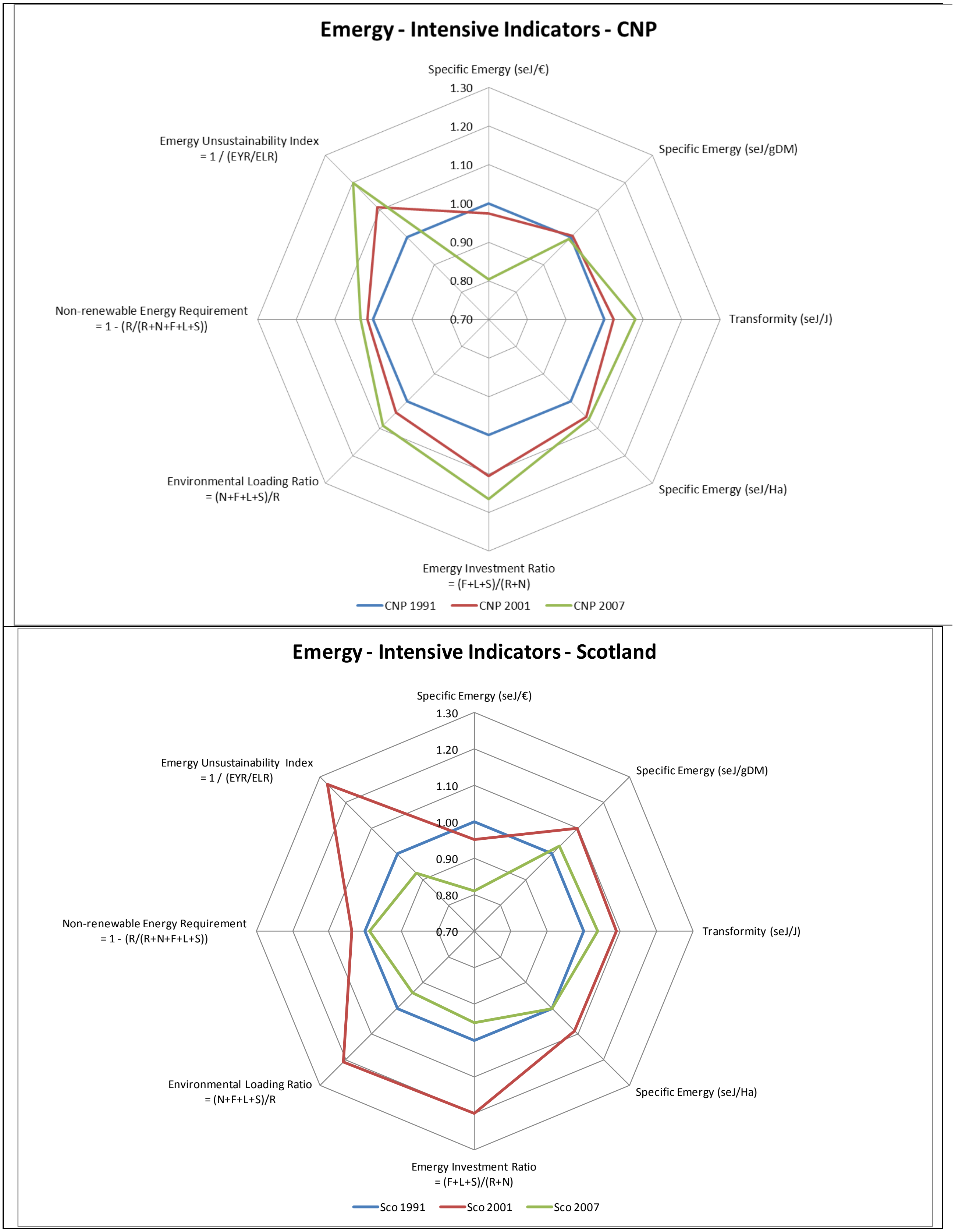
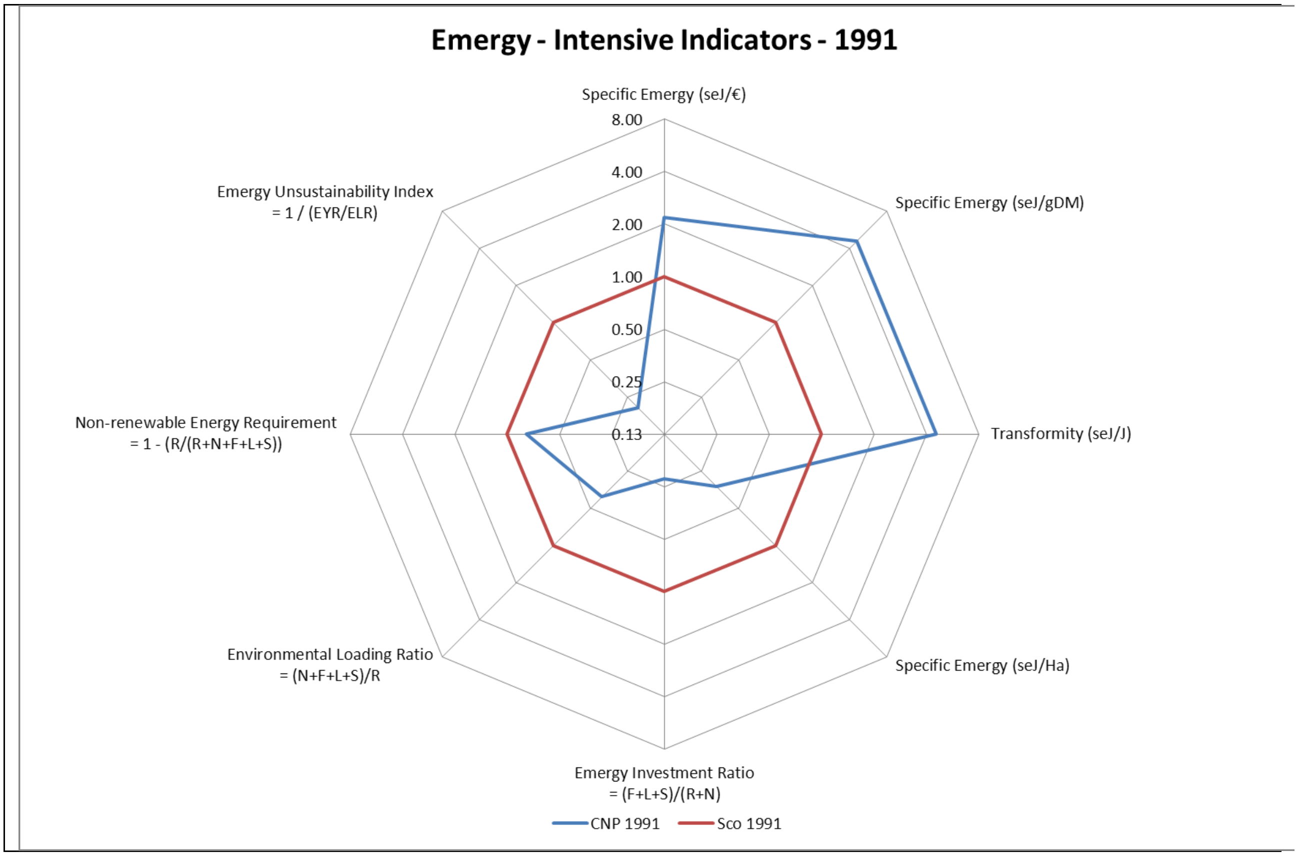
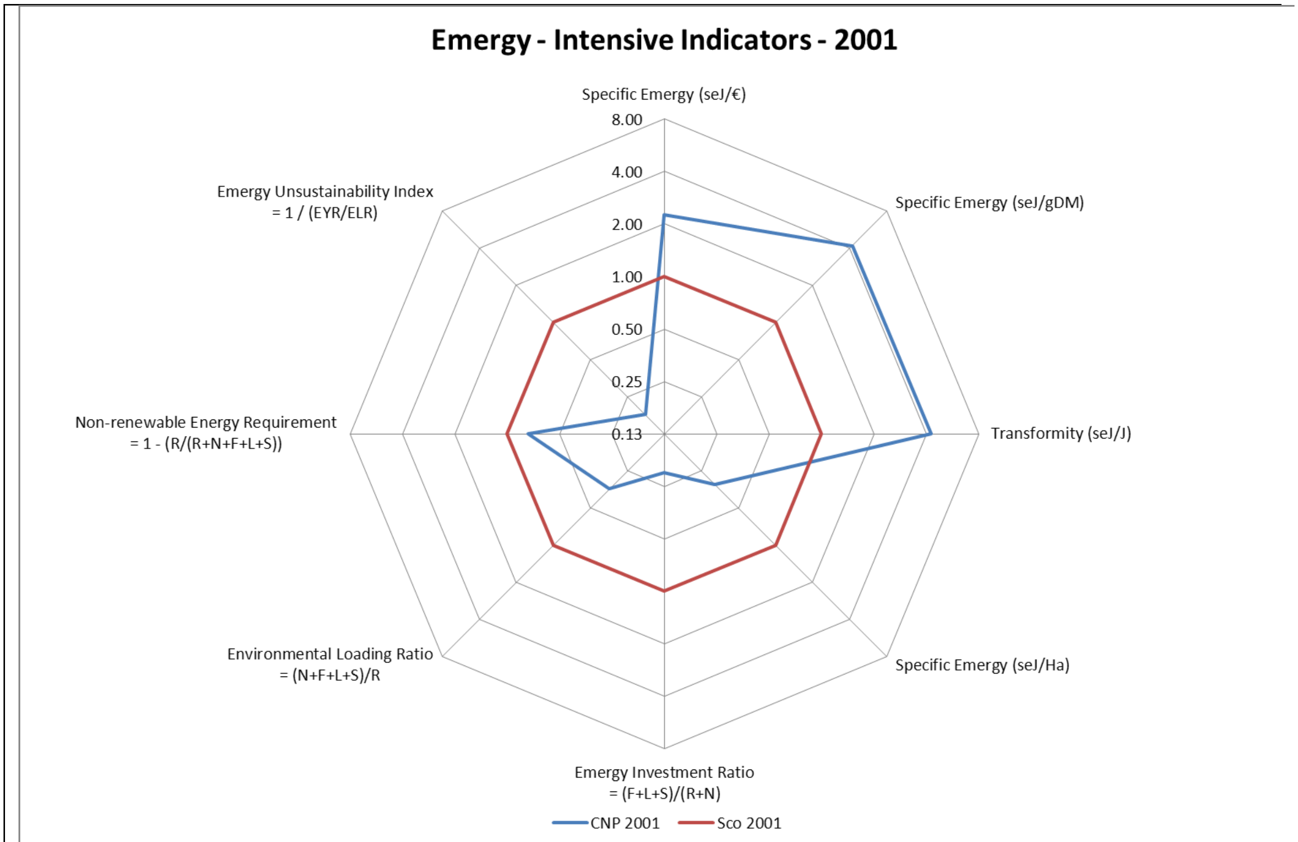


Figure 11: Emergy intensity indicators for CNP_{AG} and $Scot_{AG}$ - 1991-2007


Emergy - Intensive Indicators - 1991
Specific Emergy (seJ/€)
8.00
4.00
2.00
1.00
0.50
0.25
0.13
Specific Emergy (seJ/gDM)
Transformity (seJ/J)
Specific Emergy (seJ/Ha)
Emergy Investment Ratio
= (F+L+S)/(R+N)
Environmental Loading Ratio
= (N+F+L+S)/R
Non-renewable Energy Requirement
= 1 - (R/(R+N+F+L+S))
Emergy Unsustainability Index
= 1 / (EYR/ELR)
CNP 1991
Sco 1991



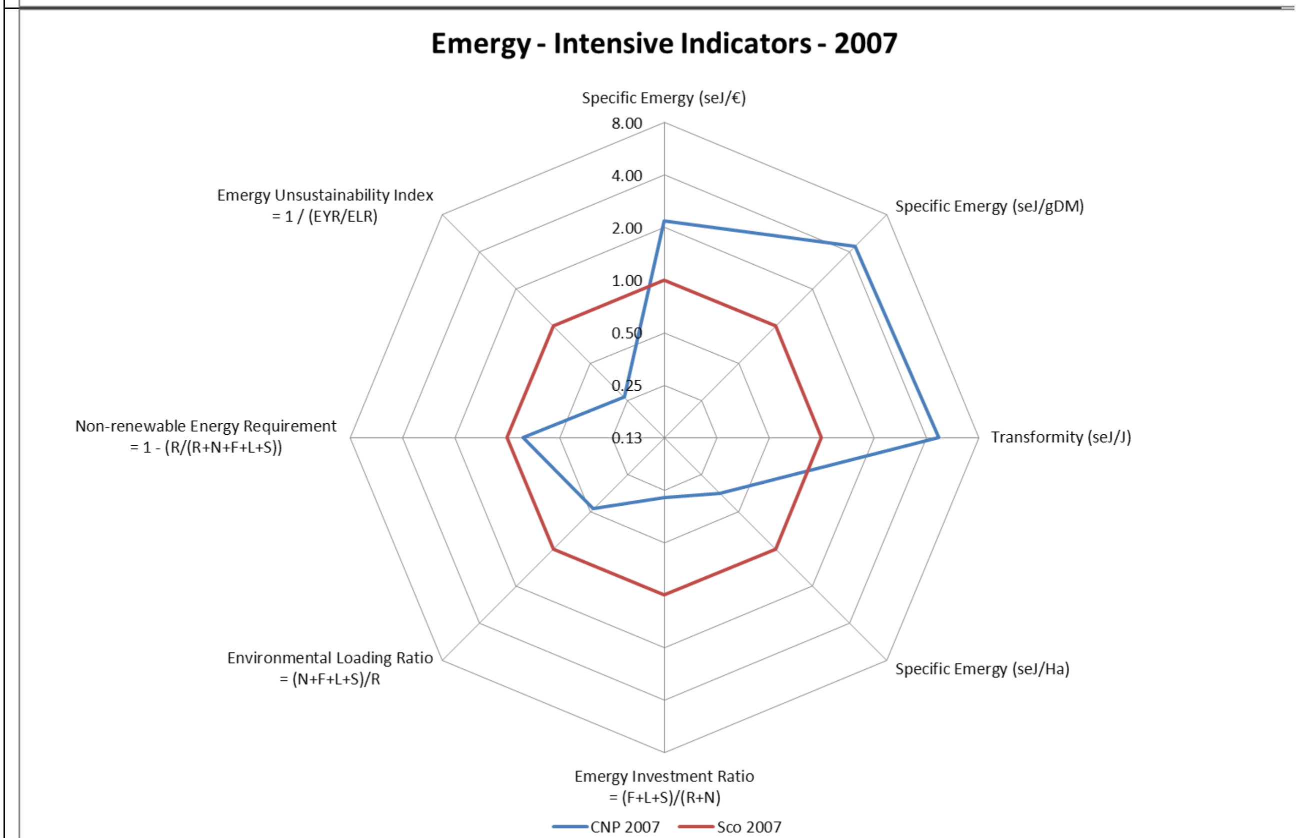


Figure 12: Intensity of emergy use CNP_{AG} relative to $Scot_{AG}$ - 1991-2007

4 Discussion

4.1 Trade-offs and synergies

This report has used a SUMMA analysis of the agricultural sector at two scales (Scotland and CNP) to look at the trade-offs and synergies. The findings of the analysis are broadly that over the period examined 1991 to 2007 there have been significant changes in the extent and intensity of agricultural production and its environmental impacts. Our conclusion is that for the agricultural sector as a whole (or regionally) there are unavoidable trade-offs between production and environmental impacts and little or no evidence of synergies, win-wins, dematerialisation or sustainable growth. For many of the extent and intensity indicators there is a pattern of increasing resource use and impact from 1991 to 2001 and a subsequent reduction back to 1991 levels by 2007. This fits well with the overall understanding of the effect of agricultural policy change over the period 1991 to 2007. The high water mark of intensification, particularly in extensive upland systems, was pre the 2003 CAP reforms. These reforms have been widely criticised as leading to land abandonment and "subsidy farming". Whatever the failings of the policy regime, however, it does at least appear that in terms of its environmental consequences the industry is now more efficient (compared with 2001) as well as being more market oriented. It would perhaps be useful to add to the time series for more recent years so that the effects of changes in EU regulations (such as removal of set aside) and higher input prices and more volatile commodity returns can be seen. In any event there is little to suggest fundamental changes in the relationships between resource inputs, the outputs from the system and the environmental load.

The emergy analysis points to changes in the sources and forms of resources used and the continuing and in some case increasing dependence on non-renewable resources. While systems can be quite different in their profiles there is little to suggest win-win synergies such as increased production with reduced impact are possible. The analysis perhaps even indicates that for the agriculture sector at least only trade-offs are possible. The CNP_{AG} system is low intensity and has a low impact but is also fundamentally less efficient in production terms. The authors anticipate that adding the other land based industry elements (such as hunting and fishing) to the SUMMA CNP_{AG} will see the overall efficiency of the system increase since these generate high value products without requiring intensive land management. Set against this would be the dependence of such industries on external resources in terms of a supporting infrastructure beyond the land holding.

4.2 Strengths and weaknesses of the analysis

From the perspective of the MLURI team developing the SUMMA application for CNP_{AG} and $Scot_{AG}$ it is possible to draw several conclusions on the strengths and weaknesses of the SUMMA tools. The key strength is in the rigour that SUMMA brings to sustainability assessment. It recognises the importance of both the extents and intensity of resource use, and looks both upstream at the effect of inputs drawn into the system and downstream to the outputs and wastes. In quantifying the intensities in terms of land area, physical quantities of materials derived (kg of dry matter) and the energy embodied in outputs, and their financial value its is possible to make explicit judgements on the costs and benefits of a system as it is configured. The emergy analysis, particularly intensity ratios, is particularly effective in providing a high level summary of the balance of resource use. With time series of such data it is possible to make assessments of trends and recognise the impacts of key drivers on system performance. Comparison between systems or scales provides an external referent against which to objectively judge system performance. In other milieus the publication of comparable system performance data has led to "levelling up" with innovation and good-practice copied and learned from. Perhaps the CNP_{AG} and $Scot_{AG}$ analyses could serve as a template for such an audit?

In terms of sustainability assessment SUMMA is strongest in analysing the links between environment and economics. It addresses key policy concerns of emissions, environmental loadings and the balance in the use of renewable and non-renewable resources. It makes these analyses in a scientifically coherent fashion, rather than through the use of ad hoc or arbitrarily chosen indicators. This coherence is a key factor in being able to take a truly systematic approach to the analysis of trends and trade-offs in system performance. Where SUMMA (and indeed most tools of this sort), performs less well is in including the social and cultural dimension of sustainability. While these aspects have been debated within the SMILE consortium (non-use and existence values etc) there still remains a significant intellectual challenge in defining, measuring and integrating analyses that are salient, credible and legitimate. Indeed it may be that such social aspects are inherently not suitable for computer-based modelling and quantification and that sustainability analysis that wish to include social aspects need to use mixed methods (incorporating qualitative analysis and participatory research processes).

SUMMA has the advantage of having data structures into which case-study data can be added and has embedded functions that perform the calculations and structured outputs. It is thus more of a software tool than MuSIASEM which is an approach with a "grammar" that defines how data is organised and manipulated, leaving the users to choose, structure and organise the data. At one level this means that where there is an existing SUMMA tool the process of using the tool is simpler. Yet this strength is a weakness when modifications need to be made to a SUMMA application. SUMMA is a complicated system of equations and other data manipulations that cannot easily be modified by non-experts. This implies a dependence on the SUMMA developers that can be difficult for them to service (given their primary role as a research team). Consideration should be given to investing in the development of a more modular SUMMA system that is suited to supporting the development of new applications by third parties and it thus more reusable.

4.3 Implications for mainstreaming the use of SUMMA

No matter how the tool is developed it will still remain demanding in terms of its input data requirements. This means that it will be initially very challenging for SUMMA to be used beyond a research/consulting environment. That said, if managers through collaboration with research teams become convinced of the value of the outputs, then the ideas within SUMMA will become more mainstream and processes put in place that mean the required information is collected and collated and resources will be invested in developing easier to use and modify versions of the software tools. Given the reservations expressed by the CNP stakeholders in D23 there remains several significant challenges in mainstreaming SUMMA. The first is making transparent the assumptions within the input data. The second is in demonstrating how the calculations of the indicators are made (not in detail but enough so that black-box can be opened if necessary). Third the communication of the outputs from SUMMA is a challenge as they are demanding conceptually and are numerous. Experience of the MLURI team in the field of climate change indicators has been that these barriers can be overcome through ongoing process of stakeholder engagement and social leaning backed by improvements to the modelling and software aspects (Matthews et al. 2008;McCrum et al. 2009). There is a significant opportunity to build on the investment in SUMMA within FP7 and elsewhere and to see the methods and tools used in mainstream policy and management contexts but the investment needs to be focused on using the tools with stakeholders rather than on further increasing the sophistication of the analysis.

5 Further developments

As noted in the text and in D23 and this report there are several developments that would improve the SUMMA analysis both for the agriculture sector but also potential applications to other sectors. These options will be discussed with the CNP stakeholders in a further meeting scheduled to occur before the conclusion of SMILE in June 2011. Some of the future developments have been incorporated within the new programme of research funded by the Scottish Government, “A rural economy resilient to global and local change”. The further developments from D23 are tabulated here with commentary based on the further experience of developing this deliverable.

SUMMA Scotland analysis next steps	Commentary
1. Differentiate between land that is stocked with domestic livestock and land managed for hunting/conservation. This differentiates rough grazing based on altitude and makes per ha intensities for farming more realistic (higher).	The technical issues of how this can be accomplished have been solved and this improvement will be incorporated into the next version of the SUMMA analyses of CNP_{AG} and $Scot_{AG}$
2. The SUMMA emissions analysis does not include those direct from livestock. This can be easily rectified using IPCC Tier 1 GHG emissions per head and it may be possible to use more sophisticated analyses that distinguish based on breed and diet since these are known for the Scotland/CNP systems.	Tier 1 IPCC methods in place. Tier 2 methods look to be too complex at present for national scale analysis.
3. Another key GHG emission source in the CNP is seen as the emissions from peatlands. This respiration is not included in the current SUMMA model but the MLURI team have access to models of soil carbon fluxes for all soils in the Park under cultivation or semi-natural coverage so these can be included and their relative importance judged.	The soils emissions maps are now available at 100m grid scale, the fluxes can be estimated and added to the SUMMA analysis. This need to be consulted on with the SUMMA developers.
4. Materials usage (steel, concrete and plastic) has yet to be quantified. Volumes of intermediate consumption of such products are present in the national accounts but only as expenditure not as physical quantities. Other physical accounts sources will be investigated.	Volumes of plastic have been estimated but not incorporated into the SUMMA analysis. Other sources of information on materials e.g. for steel and concrete have been examined and found to be inadequate..
5. Currently only average national prices are used for both inputs and outputs. The realism of this was queried and efforts will be made to assess if there is a premium for produce from the Park and whether this offsets higher input	None

prices.	
6. Forestry is a significant land use in the CNP but data on felling volumes and use is difficult to determine (particularly for private rather than state-owned forests). New data sources are becoming available but it remains unlikely that conservation forestry practice will be easy to identify/quantify. This may perhaps be done for small areas via interview. Use data is unlikely to be possible to determine within the scope of SMILE.	None
7. The SUMMA analysis needs to include the management of land for sport/hunting. In physical terms the numbers of red deer are the most significant but grouse are also a significant income stream. Deer numbers (population) and culls (stag and hind numbers) are available but the value of the physical products is small relative to the payment for shooting rights. How best to represent such as system within SUMMA needs to be carefully considered particularly the infrastructure required, seasonal use of labour and the impacts of vegetation management which can include burning to encourage regeneration but which could have implications for net GHG emissions. Validation of the SUMMA model may be possible against existing audits of exemplar Estates.	None

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McCrum, G., Blackstock, K. L., Matthews, K. B., Rivington, M., Miller, D. G., & Buchan, K. 2009, Adapting to climate change in land management: the role of deliberative workshops in enhancing social learning., *Environmental Policy and Governance*, vol. 19, pp. 413-426.

Appendix One: IPCC N_2O Emissions Tier 1 Method

Nitrous oxide emissions from Manure Management refer to the estimation of the N_2O produced during the storage and treatment of both dung and urine. The calculation is split in two parts: *direct* emissions and *indirect* emissions.

The formula for the calculation of *direct* nitrous oxide emissions from Manure Management (kg/year) is:

The formula for the calculation of *indirect* nitrous oxide emissions due to volatilization of N from Manure Management (kg/year) is:

The average annual N excretion per head of population (NE_T) is calculated:

Where:

- P_T is the livestock population for livestock type T
- NE_T is the average annual N excretion per head of population (kgN/head/year)
- MS_T is the fraction of total N for livestock type T managed in manure management system (IPCC tables 10A-4 to 10A-9)
- EF_3 is the emissions factor for direct N_2O from manure management system S (IPCC table 10.21)
- V_T is the % of managed manure N for livestock type T that volatilizes as NH_3 and NO_X in S (IPCC table 10.22)
- EF_4 is the emissions factor for N2O emissions from atmospheric deposition of N on soils and water surfaces, default value is 0.01 (IPCC table 11.3)
- 44/28 is the conversion of N_2O-N emissions to N_2O emissions
- NR_T is the default N excretion rate, kg N per 1000g animal mass per day (IPCC table 10.19)
- TAM_T is the typical animal mass for livestock type T (kg) (IPCC tables 10A-4 to 10A-9)