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Evaluating ecosystem services in the life cycle assessment framework

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Overview

- The concepts of ecosystem services (ESS) and life cycle assessment (LCA) within the sustainability framework
- Crossing ESS and LCA: overlaps and gaps
- Different approaches to address ESS within LCA: options and examples
- Challenges of combining ESS and LCA
- Conclusions

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Different approaches to assessing sustainability

- Both methodologies have similar goals:
  - To preserve an intact nature and environment, supporting human well-being
- Ecosystem services (ESS) assessment:
  - Quantifies **benefits** people obtain **from ecosystems** → **positive perception**
  - Processes having no benefit for humans are ignored
- Life cycle assessment (LCA):
  - Quantifies the **impacts** of human activities **on the environment** → **negative perception**

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Ecosystem services (ESS) in the sustainability framework

- Provisioning services → economic dimension
- Regulation and maintenance → environmental dimension
- Cultural services → social/societal dimension
- Addresses all three dimensions of sustainability, but only as related to the ecosystems; all other aspects of sustainability are ignored

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LCA in the sustainability framework and related to land use impacts

- Environmental impacts are referred to a functional unit, which usually represents the economic output
- «Classical» LCA studies do not cover many aspects of ESS
- Comprehensive LCA methods (current good practice) include an assessment of land use impacts, but general consensus on the methodology is lacking
- LCA has a global focus, but is increasingly including regional and local impacts
- Land occupation and land transformation impacts are distinguished
- Biodiversity in LCA: addresses mainly species diversity and not functional biodiversity
- Addressing ESS in LCA is a new topic under development

General approaches for the quantification of ESS

A. Economic valuation (Häyhä & Franzese, 2014):
   1. Market price method
   2. Productivity method
   3. Hedonic pricing method
   4. Travel cost method
   5. Damage costs avoided / Replacement costs / Substitute costs methods
   6. Contingent valuation method
   7. Contingent choice method
   8. Benefit transfer method

B. Thermodynamic approaches:
   A. exergy, emergy, NPP / HANPP

C. Ecological approaches:
   - Many different indicators

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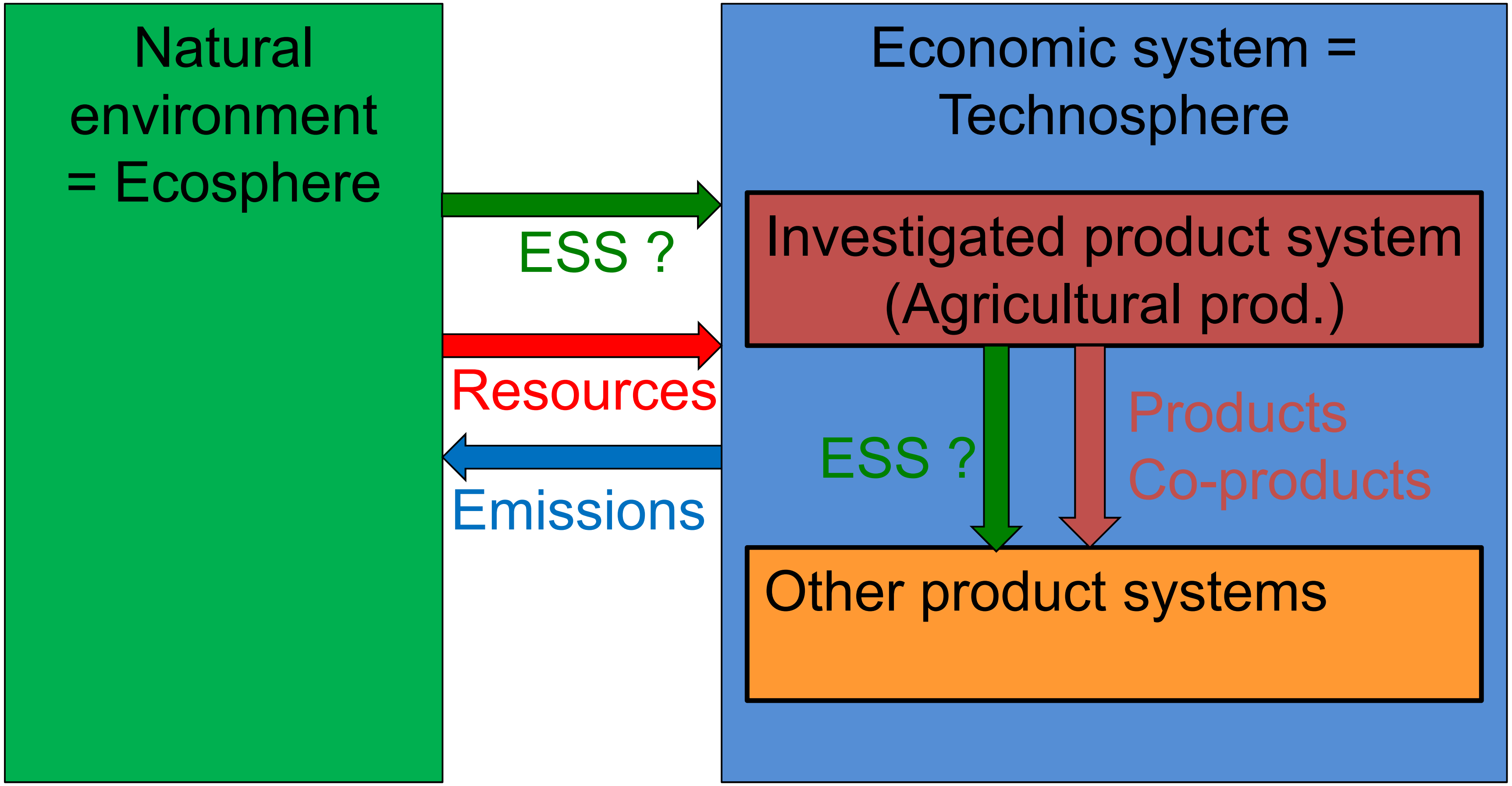
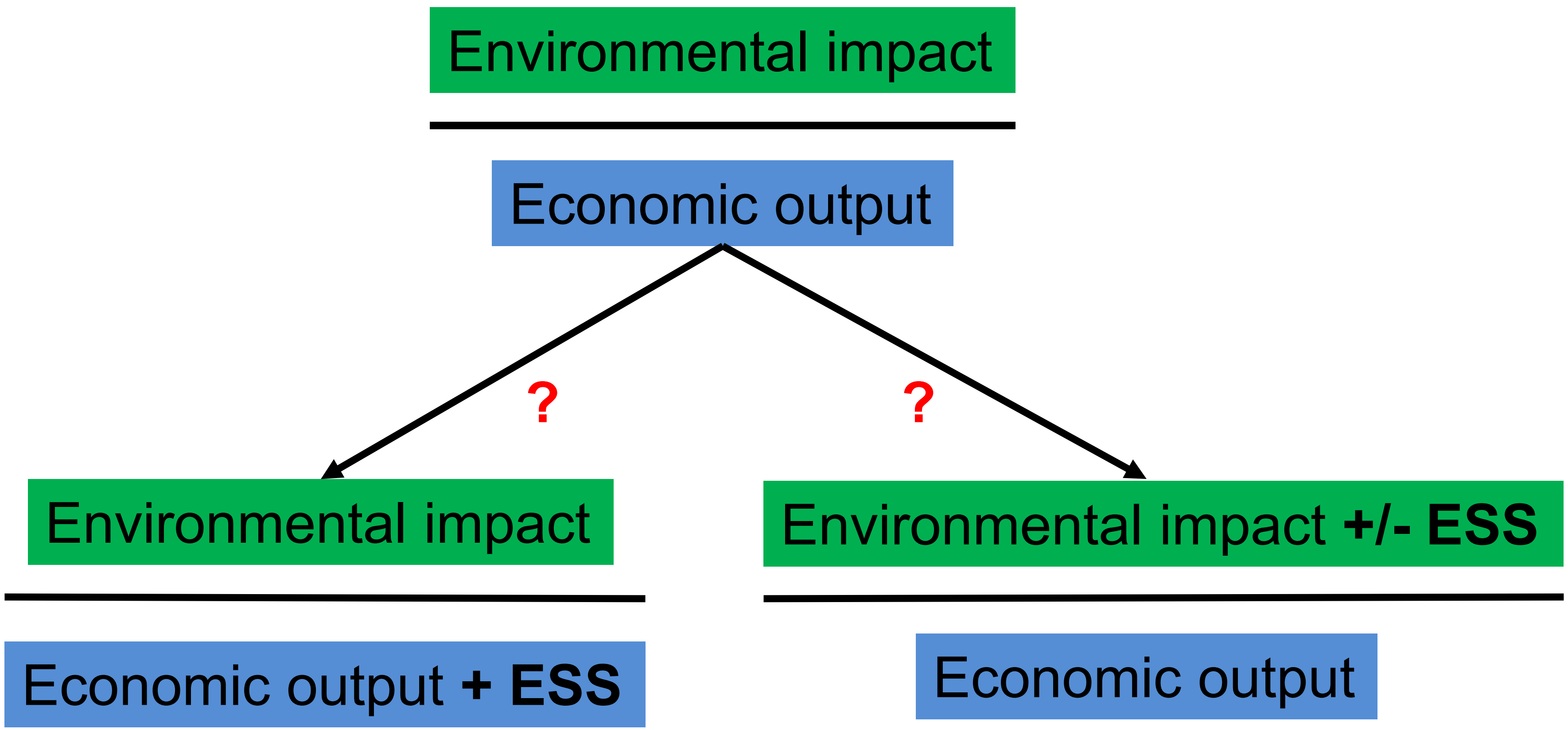
General LCA framework and positioning ESS



Where do we fit the ESS into LCA?



Crossing ecosystem services with LCA

Section	Division	Group	Consideration in LCA
Provisioning services	Nutrition	Biomass - Cultivated plants and animals	Functional unit
		Biomass - Wild plants and animals	Biotic resource depletion
		Water	nc
	Materials	Biomass	Functional unit
		Water	nc
	Energy	Biomass-based energy sources	Functional unit

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Crossing ecosystem services with LCA

Section	Division	Group	Consideration in LCA
Regulation & Maintenance services	Mediation of waste, toxics and other nuisances	Mediation by biota	nc
		Mediation by ecosystems	C sequestration
			Nutrient leaching Aq./Terr. Eutrophication
	Mediation of flows	Mass flows	Soil quality Soil erosion
		Liquid flows	Soil quality Soil erosion
		Gaseous / air flows	nc

Crossing ecosystem services with LCA

Section	Division	Group	Consideration in LCA
Regulation & Maintenance services	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Biodiversity Pollination
		Pest and disease control	Indirectly (e.g. reduced pesticide application) Biodiversity
		Soil formation and composition	Soil quality, Indirectly (N fixation)
		Water conditions	Aq. ecotoxicity Aq. eutrophication Aq. acidification
		Atmospheric composition and climate regulation	Global warming potential

Crossing ecosystem services with LCA

Section	Division	Group	Consideration in LCA
Cultural services	Physical and intellectual interactions with biota, ecosystems, and landscapes	Physical and experiential interactions	nc (social LCA)
		Intellectual and representative interactions	nc (social LCA)
	Spiritual, symbolic and other interactions with biota, ecosystems, and landcapes	Spiritual and/or emblematic	nc (social LCA)
		Other cultural outputs	Landscape aesthetics Conservation biodiversity

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Options to integrate ESS into LCA

Several options are available in LCA to address the multifunctionality of agricultural systems and to include ESS:

1. Using multiple functional units to account for the various functions of the agricultural system
2. Using allocation, by dividing the environmental impacts between the products and ESS.
3. Using system expansion, where an alternative provision of ESS is subtracted (avoided impacts).
4. Including ESS as additional indicators, considering the impacts on ESS.

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Option 1: Using multiple functional units in LCA

1. **Land management function**:
   agricultural use of an area
   ha*year
   Objective: reduce environmental intensity per area
2. **Productive function**: food, feed, fuel and fibre
   Examples: kg DM, MJ digestible energy (physical unit)
   Objective: Optimise productive eco-efficiency
3. **Financial function**: return
   Examples: Gross profit, gross margin, income (currency unit, €, £, $, …)
   Objective: Optimise financial eco-efficiency

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Option 1: Multiple functional units: introducing legumes into crop rotations

	CR2 in % of CR1	Saxony-Anhalt (D)			Barrois (F)			Vaud (CH)			Castilla y Leon (E)		
	Functional unit	ha	€	GJ	ha	€	GJ	ha	€	GJ	ha	€	GJ
Resource management	energy demand	86%	82%	92%	89%	86%	93%	69%	68%	85%	102%	101%	103%
	global warming potential	89%	85%	95%	92%	90%	97%	91%	89%	113%	110%	108%	111%
	ozone formation	90%	86%	96%	94%	92%	99%	85%	83%	105%	103%	102%	104%
Nutrient mana-gement	eutrophication	98%	94%	106%	94%	91%	98%	110%	107%	135%	114%	113%	116%
	acidification	83%	79%	89%	82%	80%	86%	86%	84%	106%	103%	102%	104%
Pollutant management	terrestrial ecotoxicity EDIP	63%	61%	68%	93%	90%	98%	118%	115%	145%	104%	103%	105%
	aquatic ecotoxicity EDIP	102%	97%	109%	87%	85%	91%	96%	94%	119%	75%	74%	75%
	terrestrial ecotoxicity CML	99%	95%	106%	80%	78%	84%	100%	98%	124%	135%	134%	137%
	aquatic ecotoxicity CML	96%	92%	103%	81%	79%	85%	113%	111%	140%	90%	89%	91%
	human toxicity CML	85%	81%	91%	87%	84%	91%	95%	92%	117%	103%	102%	104%

CR2 compared to CR1 is:

(dark green)	very favourable
(light green)	favourable
(white)	similar
(orange)	unfavourable
(magenta)	very unfavourable

CR1: crop rotation **without** grain legumes (standard).
CR2: crop rotation **with** grain legumes.

Source: Nemecek *et al*. (2008)

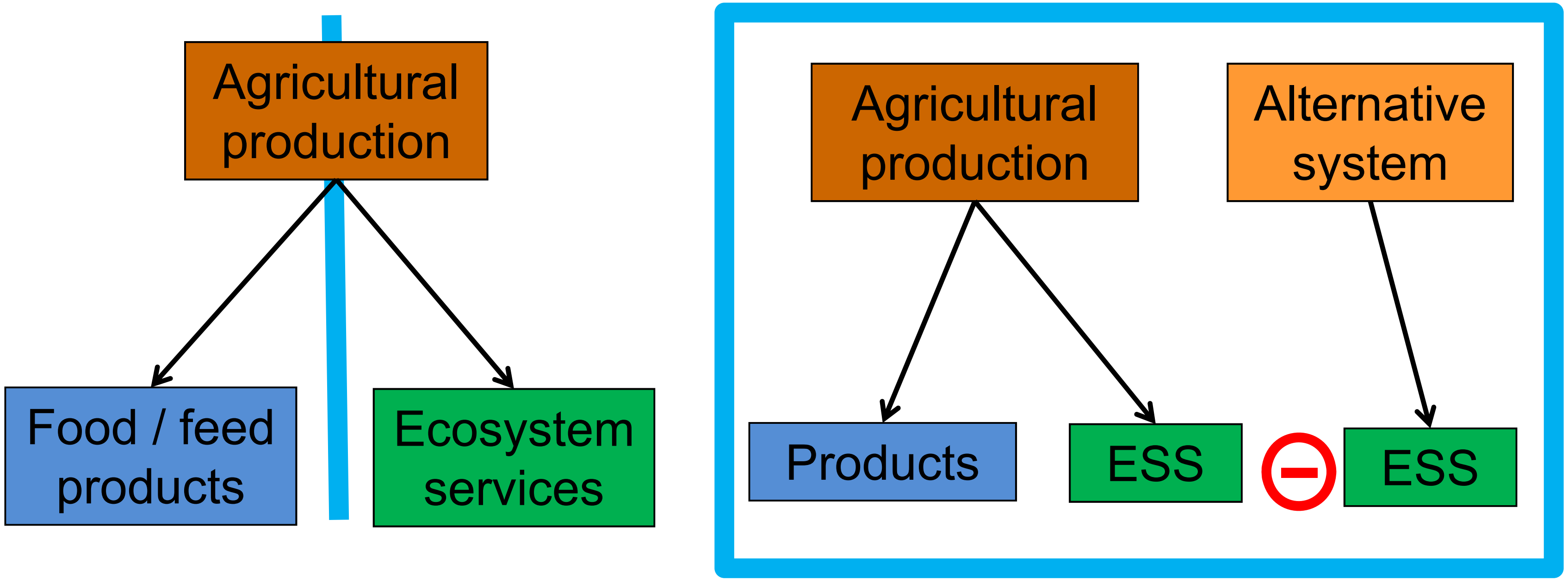
Option 1: Using multiple functional units in LCA

- Relatively simple implementation
- ESS can be covered only partly
- Interpretation and communication is challenging
- Trade-offs can be shown

Source: Nemecek *et al*. (2008)

Options 2 and 3: Allocation and system expansion

In both approaches, the ESS are considered as co-functions / co-products of the agricultural production



Allocation: Partitioning

System expansion: Subtraction

Option 2: Allocation

- The environmental impacts are partitioned according to a common property of the co-products
- Mostly this is the economic return → requires an economic valuation of ESS
- Many different options for economic valuation exist
- Product value and direct payments for ESS can be used as allocation key
- But: Are the direct payments a good proxy for ESS?
- Relatively simple, if ESS can be quantified

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Option 3: System expansion

- An alternative system delivering the requested ESS is subtracted
- Difficult to identify the alternative system
- Economic valuation is not needed
- Can become quite complex

- In both cases (allocation and system expansion) the ESS delivery has to bear a part of the environmental burden

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Option 4: Using specific additional indicators for impacts on ESS

- UNEP-SETAC guidelines: defining additional impact categories for the **damage to ESS**
  - Biodiversity damage potential
    - Species diversity
    - Functional diversity
  - Ecosystem services damage potential
    - Biotic production potential
    - Climate regulation potential
    - Freshwater regulation potential
    - Erosion regulation potential
    - Water purification potential
- See presentation of C. Cederberg
- Application in practice is not easy
- Other approaches: exergy, specific land-use related impact categories

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Thermodynamic approaches: Biomass production potential based on NPP in exergy units

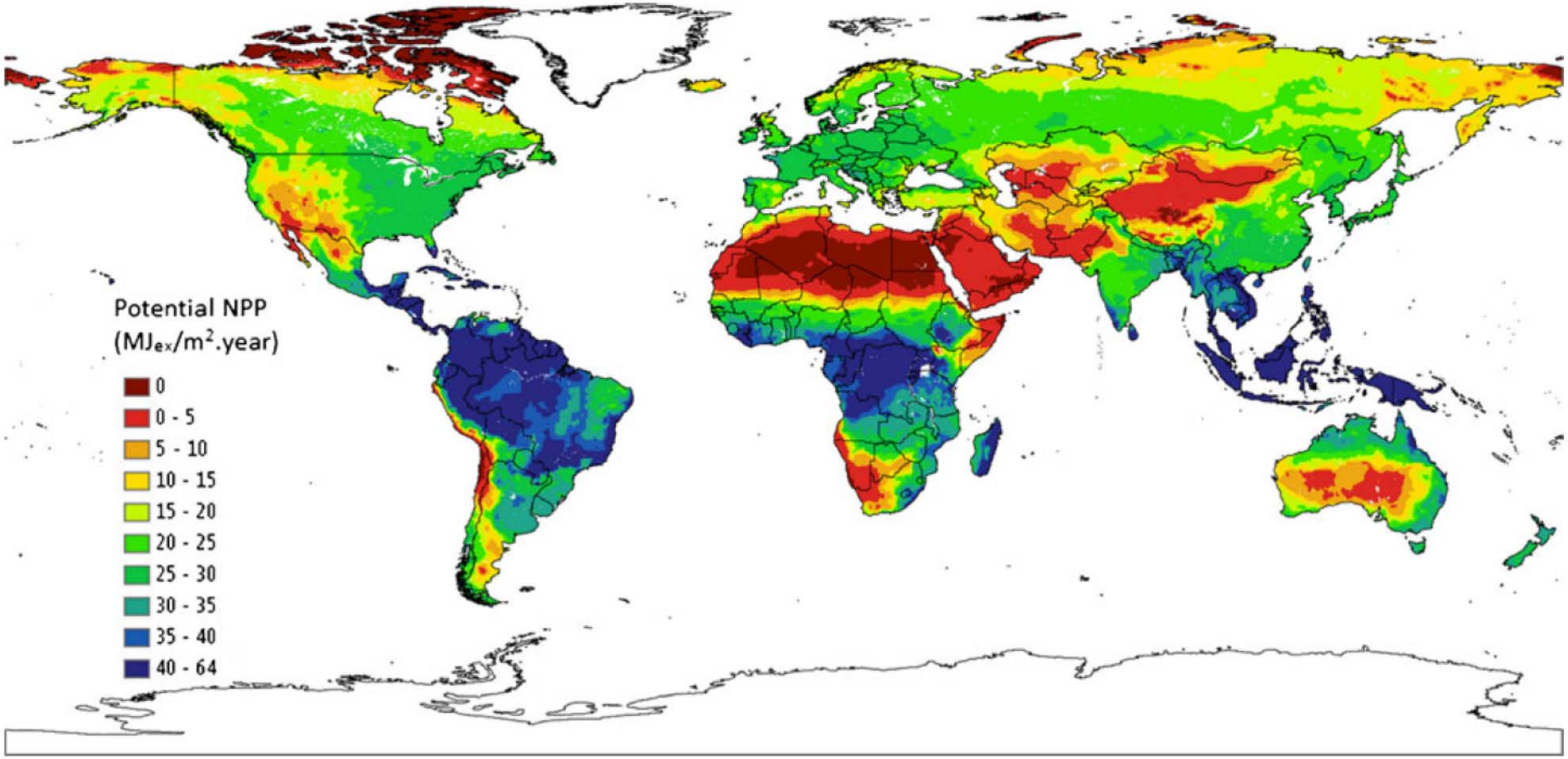


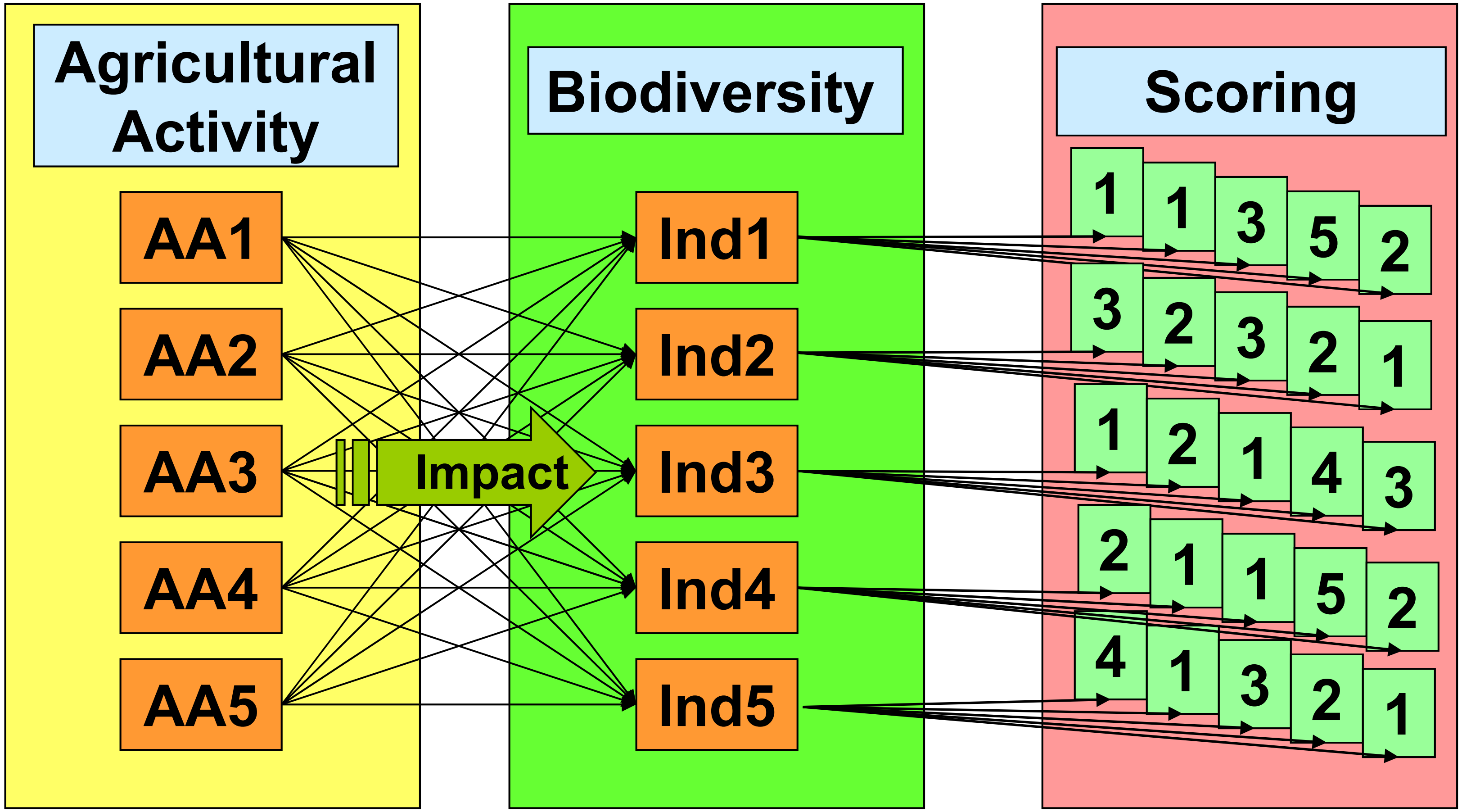
Fig. 2 World map of characterization factors of land resources in human-made systems, based on the potential availability of natural net primary production (in exergy units, MJ_{ex}/m^2year)

Quelle: Alvarenga *et al*. (2013)

SALCA biodiversity – framework
(SALCA = Swiss Agricultural Life Cycle Assessment)

- **11 Indicator species groups** were determined considering ecological and LCA criteria: flora, birds, mammals, amphibians, molluscs, spiders, carabids, butterflies, wild bees, and grasshoppers.
- Two characteristics: **overall species diversity** of the indicator species groups and **ecologically demanding species**
- Extensive **inventory data about agricultural practices**: occupation, emissions, farming intensity indicators (e.g. number of cuts) and process figures (e.g. herbicide type). Beside typical cultivated fields, semi-natural habitats were integrated.
- **Characterisation based on scoring system** was evolved to estimate every indicator species group's reaction to agricultural activities followed by an aggregation step resulting in **scores**.
- **Aggregation** and **normalisation** of scores: biodiversity value and biodiversity potential

SALCA methodology
Method for biodiversity - principle



SALCA methodology
Method for biodiversity – case study

Biodiversity scores

Production system	Grassland (A)	Grassland (B)	Grassland (C)	Grassland (D)	Winter Wheat (A)	Winter Wheat (B)	Winter Wheat (C)	Winter Wheat (D)
Overall species diversity	**6.2**	**6.4**	**13.8**	**21.3**	**7.7**	**7.5**	**8.4**	**8.7**
Grassland flora	3.7	3.9	11.4	18.5				
Crop flora					15.2	15.1	16.0	17.3
Birds	6.4	6.7	13.8	22.0	5.3	5.0	6.2	6.4
Mammals	7.3	7.3	11.1	11.1	4.6	4.6	4.6	4.6
Amphibians	2.1	2.1	5.2	9.5	1.7	1.7	1.8	1.8
Molluscs	5.4	5.6	5.8	11.3	2.2	2.2	2.2	2.2
Spiders	9.1	9.3	15.8	22.4	8.2	8.0	10.5	10.7
Carabid Beetles	7.0	7.4	13.6	21.0	10.9	10.6	11.7	11.9
Butterflies	6.8	7.0	20.0	36.0				
Wild Bees	7.4	7.6	18.6	23.0	5.2	4.9	5.0	4.8
Grasshoppers	6.9	6.9	19.4	33.1				
Species with high ecological requirements								
Amphibians	0.8	0.8	2.9	4.8	1.5	1.4	1.6	1.6
Spiders	8.9	9.0	15.3	21.6	8.0	7.8	10.3	10.5
Carabid Beetles	7.0	7.3	13.4	20.6	10.6	10.1	11.2	11.3
Butterflies	6.7	6.8	19.4	36.0				
Grasshoppers	6.8	6.8	19.3	32.9				

Source: Jeanneret et al. 2006

Results of SALCA-Biodiversity. Biodiversity scores are given per ha cultivated crop. A, B, C, D are management systems with main characteristics :

Grassland systems (hay production):

(A) 5 cuts/year, fertilised with slurry; 11t DM/ha

(B) 4 cuts/year, fertilised with slurry; 9t DM/ha

(C) 3 cuts/year, fertilised with solid manure; 5.6t DM/ha

(D) 1 cut/year, no fertilisation; 2.7t DM/ha

Winter wheat systems:

(A) Conventional production; 5.8t DM/ha

(B) Integrated production – intensive; 5.5t DM/ha

(C) Integrated production – extensive; 4.5t DM/ha

(D) Organic production; 3.5t DM/ha

Scores of grassland (A) and winter wheat (B) systems are set as **reference scores**. Color codes are given for rough comparison:

- similar to the reference (95%<score<104%)
- better than the reference (105%<score<114%)
- much better than the reference (score >115%)
- no relevance for the considered system

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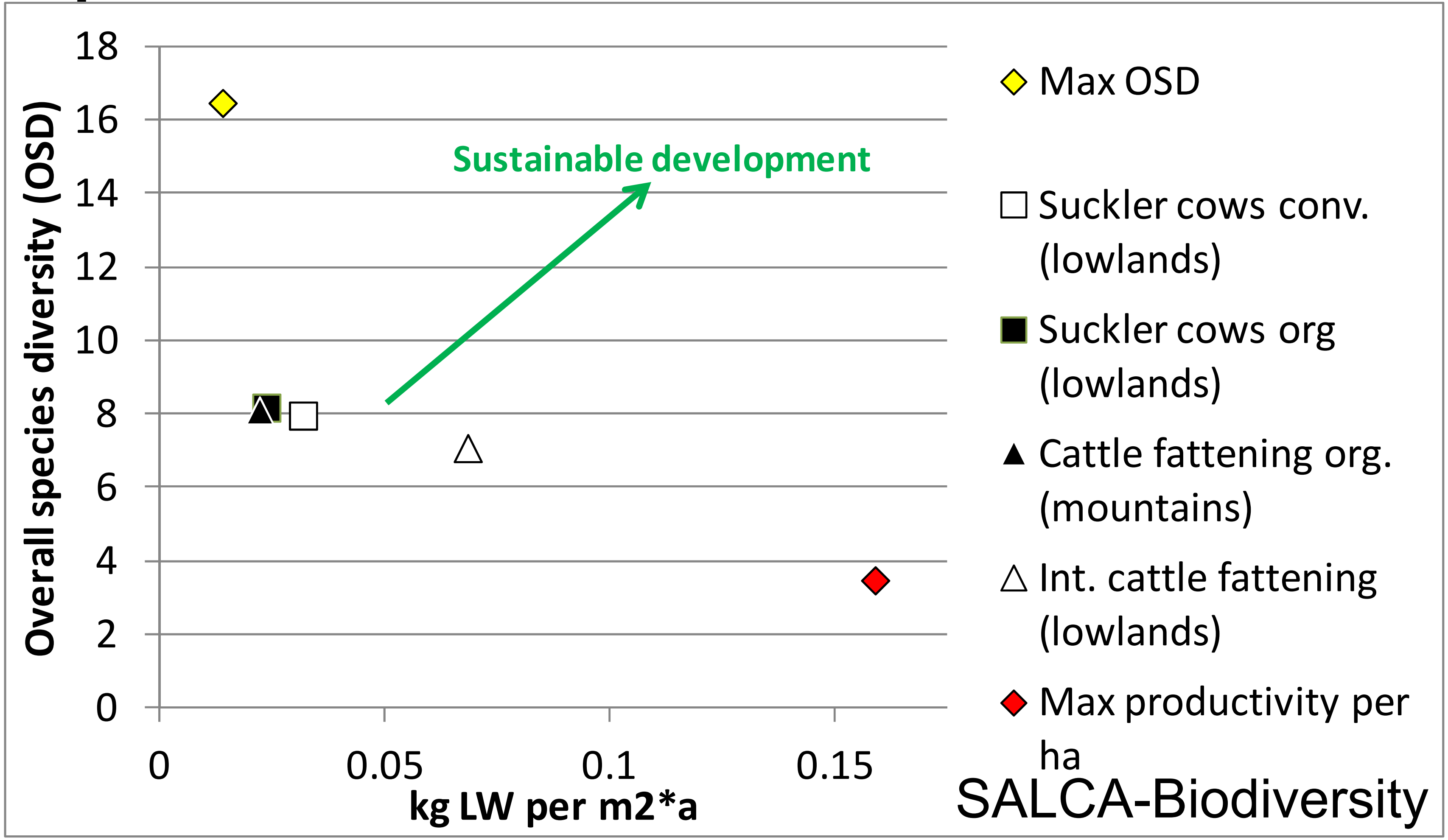
Trade-off between productivity and biodiversity: intensive and extensive beef production



SALCA soil quality - framework

- Spatial system boundary = farm;
- Temporal system boundary = crop rotation period (6-8 years)
- Management data of all plots of a farm in a single year are considered as representative for a whole crop rotation
- Only influences of agricultural management practices are included, not immissions
- The development trend of soil properties is assessed, not absolute values

Soil properties
Physical
Chemical
Biological

Criteria
According to ISO 14040 and ISO 14042
Depending on the needs of Life Cycle Assessment

9 Direct Indicators = measurable soil properties

Physical	Rooting depth of soil
	Macropore volume
	Aggregate stability
Chemical	Soil organic matter
	Inorganic pollutants
	Organic pollutants
Biological	Earthworm biomass
	Microbial biomass
	Microbial activity

Source: Oberholzer et al. (2006)

SALCA soil quality – impact assessment

Example: slurry application

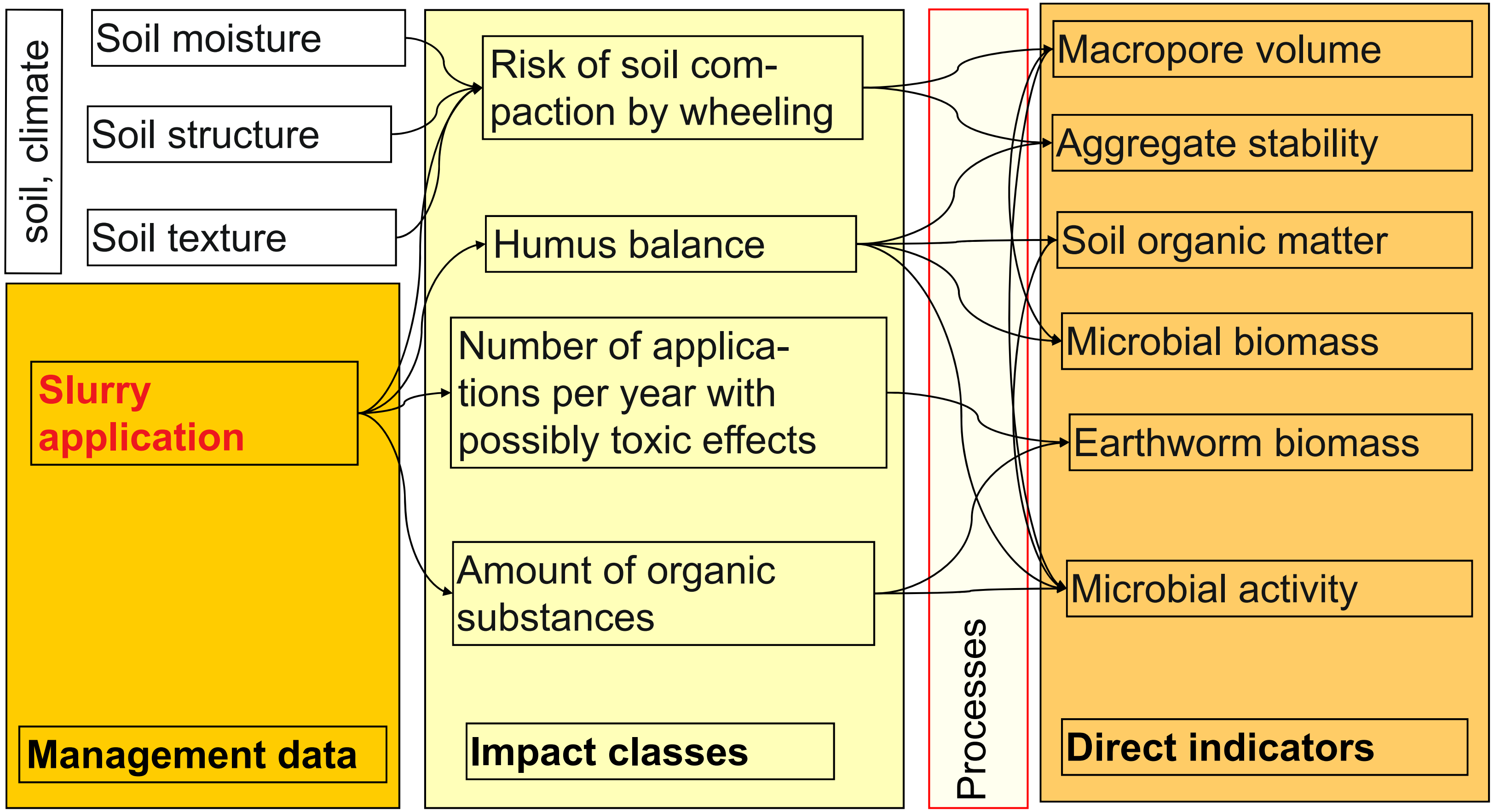


Figure 1: Example of impact assessment of a slurry application

SALCA soil quality – Results DOK trial

Results of SALCA-Soil Quality for the five treatments

	Direct Indicators for soil quality	D0	D2	O2	K2	M
Physical	Rooting depth of soil	0	0	0	0	0
	Macropore volume	0	0	+	+	0
	Aggregate stability	-	+	+	+	-
Chemical	Corg content	--	+	+	+	--
	Heavy metal content	0	0	0	0	0
	Organic pollutants	0	0	0	0	0
Biological	Eathworm biomass	0	0	0	+	0
	Microbial biomass	-	0	+	+	-
	Microbial activity	-	0	+	+	-

- **Minor differences between the three farming systems** because most management practices are similar or equal regarding soil quality. Some indicators do not show a positive effect in D2 because of slightly less organic input compared to O2 and K2.
- **D0 and M:** Impacts on soil quality because of insufficient organic carbon supply without organic fertilisers and removal of crop residues.
- **O2 and K2:** Positive effect of crop rotation on macropore volume is not negated by a high compaction risk.

Cultural ESS: Landscape Aesthetics

Goal

Estimate the contribution of a farm to a **diverse and / or nice landscape**.

Theoretical framework

Based on framework of Tveit et al. (2006)

- **Complexity** (**diversity**)
- **Naturalness**
- Ephemera (weather phenomena, **season**)

Computation

- Diversity -> Shannon-Index $H = \sum_{i=1}^{n} -p_i \cdot \ln(p_i)$
- Naturalness -> Preference values
- Season -> accumulated seasonal diversity

Source: A. Roesch, Agroscope (2016)

Challenges for integrating ESS into LCA

- Spatial differentiation: global coverage needed with generic CFs for the background system, specific CFs for the foreground system
- Relation to functional unit
- Time horizon / regeneration time
- Different options of inclusion
- Defining the reference situation
- Aggregation of many different impacts / services

- Assessment of ESS more challenging for animal production systems, due to feedstuffs and animals brought on the farm
- Integrate ESS into LCA or combine the two methods?

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Conclusions

- Both methodologies have fundamentally the same goals
- LCA and ESS assessment have overlaps and complementarities; their combination provides a more complete picture of environmental sustainability
- Provisioning services can be considered in the functional unit
- Regulation and maintenance services can be included by specific indicators
- Cultural services can be covered by social LCA and landscape aesthetics
- Substantial developments of methods, databases and tools are needed to allow a systematic assessment of ESS

Thank you for your attention

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