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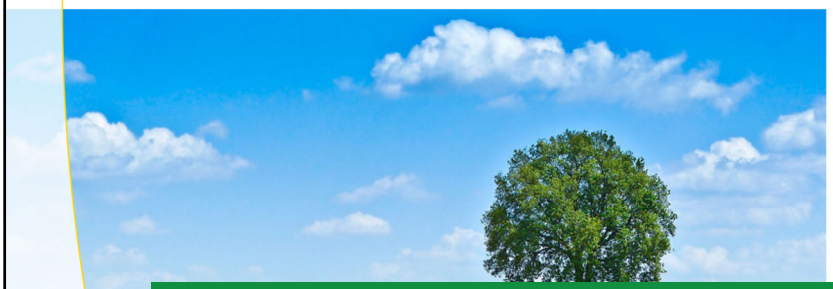

Measuring sustainable intensification: a framework of metrics combined with agricultural systems modelling

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The SUSTAg project

Aim: Identify sustainable intensification options for integrated food and non-food production to build a competitive and sustainable European bioeconomy.

- Project duration: April 2016 – July 2019
- Modelling at field, farm, regional, EU and global scales (three case studies, EU-global analysis)
- Development of generic SI metrics framework
- Stakeholder relevant SI options and metrics

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Background

- Sustainable Intensification (SI) is a promising strategy for satisfying growing demands, while reducing agriculture's environmental impacts and maximizing its resource use efficiency.
- The definition and quantification of SI and the identification of pathways to achieve it remain a challenge.

Achieving targets requires metrics to assess progress
(Garnett and Godfray, 2012)

SI sets major challenges, with consensus on sustainability issues at stake based on precise definitions and indicators being one of them
(Struik et al., 2014)

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Working premises

Holistic
- agronomic, ecological, socio-economic and cultural sustainability perspectives involved in SI (Gliessman, 2014)
- acknowledging complexity via systems perspective
- considering trade-offs across sustainability dimensions

Generic and flexible
- compatible with diverse agricultural contexts and definitions of SI
- applicable to various questions, assessment methods, and scales
- consistency, efficiency, and comparability across SI assessments

Policy-relevant
- better communication in the science-policy interface
- compatibility with changing policy goals
- consideration of key societal challenges

Operational for application by modelling
- modelling facilitates ex-ante assessment of policies, increasing their efficiency and effectiveness (van Ittersum et al., 2008)
- contribution to ex-ante evaluation of SI measures and policies

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Research Aim

- Present a holistic, generic, flexible, and policy-relevant SI Metrics framework (SIM framework)
- Propose and evaluate an approach for operationalising it for application by agricultural systems modelling

Not a blueprint for the complex problem of quantifying, assessing, and implementing SI, but rather one of many steps towards the quantification of SI and the ex-ante assessment of SI policies and measures.

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Overview of methodology

Definition of scope and domains of SI based on literature review	List of SI domains for structuring the SIM framework
Scientific workshop on SI metrics	Identification of priority indicators and suggestions for improvement
Review of the literature on indicators of SI and the Sustainable Development Goals (SDGs)	Integration of insights from academic literature, policy frameworks, SDGs
Operationalisation approach	Application by models and quantifiability of indicators

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Definition of domains of SI

Intensification

- Indirect Inputs
  - Knowledge
  - Markets
  - Management
  - Biophysical conditions, etc.
- Direct Inputs
  - Land
  - Fertilisers
  - Labour
  - Energy, etc…
- Outputs
  - Primary products
  - Secondary products
  - Economic output
  - Losses and waste, etc.
- Input-Output Relation
  - Yields
  - Productivity
  - Intensity
  - Efficiency

Sustainability

- Environ-ment
  - Climate
  - Water
  - Biodiversity
  - Land use, etc…
- Economy
  - Income
  - Compet/ness
  - Prices
  - Resilience, etc…
- Society
  - Equity
  - Human capital
  - Quality of life
  - Nutrition, etc…

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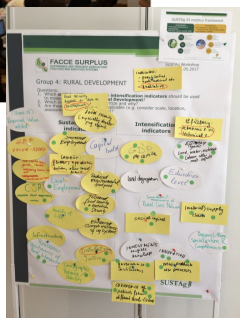
Scientific workshop

- Sustainability and intensification indicators for *food security*, *bioeconomy*, *environment*, *rural development*, and *climate resilience*

→ proposed indicators integrated into indicator list and suggestions for improvement taken on board



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Indicator frameworks selected for review

POLICY-RELEVANT	
Common Agricultural Policy (CAP) context indicators	Direct link to priorities associated with the CAP, the central instrument for European agricultural policy.
Ecosystem Services of the Millennium Ecosystems Assessment (ES-MEA)	Useful summary of ecosystem services and the benefits people can retrieve from them.
The agri-environmental indicators (AEIs) of Driver-Pressure-State-Impact-Response framework (DPSIR)	Known by policy makers at all scales and some of them used as part of other frameworks (CAP context indicators, SDGs)
Food System Dashboard (FSD)	Metrics list rom a project on meeting the challenges of producing more food more sustainably, commisioned by the British Government Office for Science
MODELLING-RELATED	
Goal-Oriented Framework (GOF)	Developed within the frame of the SEAMLESS project (van Ittersum et al., 2008) focusing on multi-scale modelling approaches.
Food and Nutrition Security metrics (FNS)	Developed under the SUSFANS project, with modelling at its core.
SI-FOCUSED	
Socio-Ecological Systems framework (SES)	One of the most comprehensive frameworks with a focus on SI.
Africa-focused SI Indicator List (ASIIL)	Composed via a comprehensive review of SI metrics
The Montpellier Panel's model of SI (MPM)	It highlights core aspects and principles of SI.
The BioSight decision support tool (BioSight)	A shortlist of SI indicators and metrics is proposed.
Land Use Policy Group SI measurement indicators (LUPG)	A selection of indicators and metrics measured to assess whether different farm types in the UK have achieved SI over a certain period of time.

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Comparison to SDGs

- Representation of international policy aims calling to action for achieving sustainable development

→ All indicators of Goal 2 and indicators relevant to SI for other Goals

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Operationalisation of SIM framework with modelling

- SUSTAg project case study: 8 agro-ecological and 5 agro-economic models at field-global scales.
- Identification of indicators that are quantifiable via modelling.

Scenario formulation
Scenarios can describe the boundary and underlying conditions within which agricultural systems operate and act as a means to formulate agricultural management practices towards SI. Scenarios can include dimensions such as socio-economic narratives, climate scenarios, water availability, etc. In the SIM framework, we are clustering potential boundary conditions and management attributes under the domain *indirect inputs*.
Simulation/optimisation
Scenarios are implemented into models which, via simulation or optimisation, aim at reproducing, and possibly projecting over time, their potential repercussions. Depending on model capabilities, the research question at hand, and the scale of analysis, the SI metrics that are more appropriate for the specific analysis are selected and then quantified via model simulation/optimisation. By design, the SIM framework provides a wide range of metrics, such that it can be utilized with different types of models, diverse research questions and at various scales.
Decision-support
The quantification of the SI metrics by the models aims ultimately at decision-support by quantifying the prospects for SI over time and across scenarios, as well as the involved trade-offs. The SI metrics can be presented in different ways (e.g. frontier curves, spider diagrams, combined into composite indicators) and combined with various decision-support tools (e.g. multi-criteria approaches, cost-effectiveness analysis). The presentation, aggregation, and weighing schemes can be tailored to the preferences and needs of potentially involved stakeholders.

Mouratiadou et al. (2019a)

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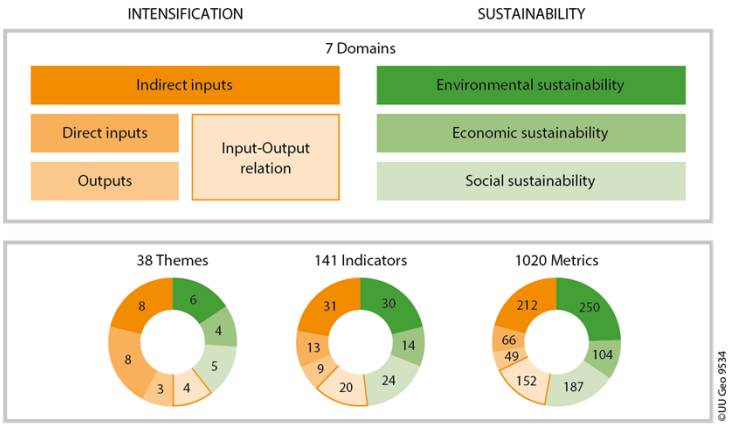
Overview of the SIM framework



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INPUT-OUTPUT RELATION

Productivity	Water productivity
	Nutrient and material productivity
	Labour productivity
	Capital productivity
	Partial factor productivity
	Total factor productivity
	General or aggregate productivity
Yields	Product yield
	Yield variability
	Yield gap
Intensity	Chemical input intensity
	Other input intensity
	Cropping density
	Livestock density
	Energy and emissions intensity
Efficiency	Nutrient efficiency
	Water efficiency
	Energy efficiency
	Feed efficiency
	Aggregate efficiency

● Indicator quantifiable by models as model output
○ Indicator considered by models as scenario attribute

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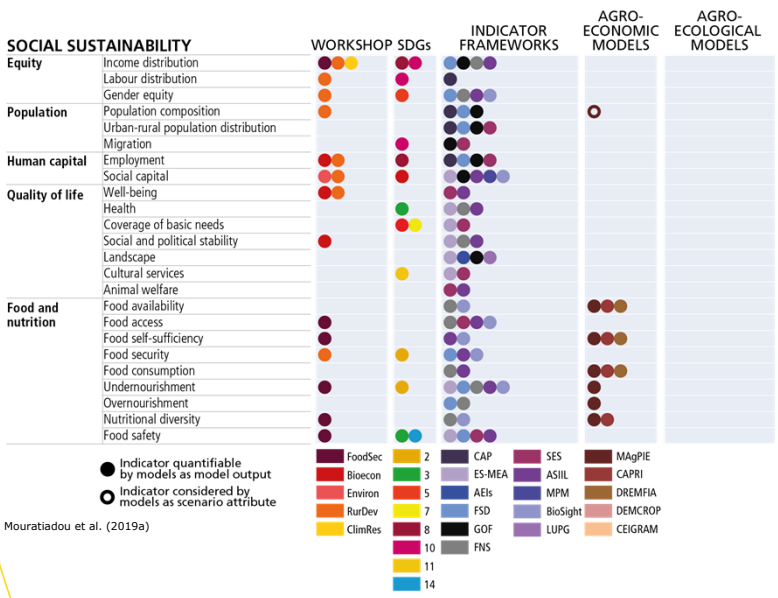

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Operationalizing approach

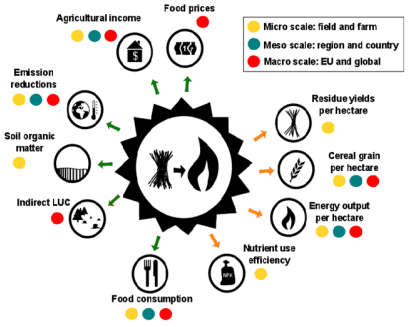
1. Scenario formulation

Scenario	Residue management	Mineral N fertilisation	Winter cover rate
Ref	Residue removal rate: 33%	Rule-based	25%
SI	Humus balance: 400 H_{eq}	Optimised	100%

HB-400 | Opt Fert | Full Cov

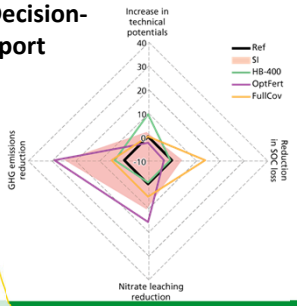
Mouratiadou et al. (2019b)

2. Simulation/optimisation



Mouratiadou et al. (2019a)

3. Decision-support



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Concluding remarks

SIM Framework

Flexible, generic, holistic, and policy-relevant approach for quantifying and assessing SI options.

Simple and transparent, yet follows systems approach capturing agro-ecosystems complexity.

Operational at different scales and combinable with integrated modelling of agricultural systems.

Agricultural systems modelling

Can inform evaluation of SI over time or across scenarios, SI measures and pathways.

Gaps remain in quantification of social sustainability aspects, biodiversity, markets (existence, innovation, preferences), losses and waste management, resilience.

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Thank you!

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