Multiobjective feed formulation for swine - economic and environmental aspects

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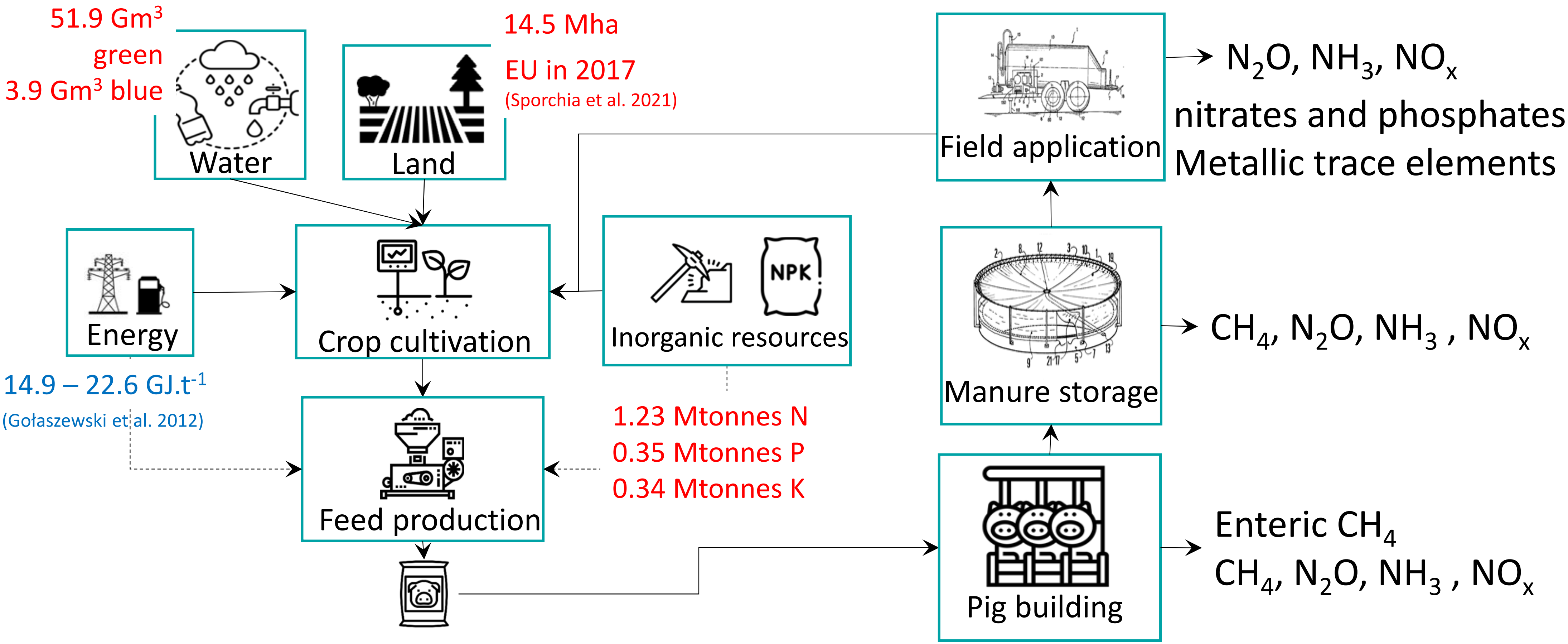
Swine production systems (SPS) and the environment



Feed production and manure emissions are major contributors to most environmental impacts

Life Cycle Assessment framework into 4 steps

Goal and scope definition

- Product labelling Eco-design…
- Functionnal unit
- System boundaries
- Multifunctionality

Inventory analysis

- Foreground/ background data
- Surveys, experiments, models
- Databases

Life Cycle Impact Assessment

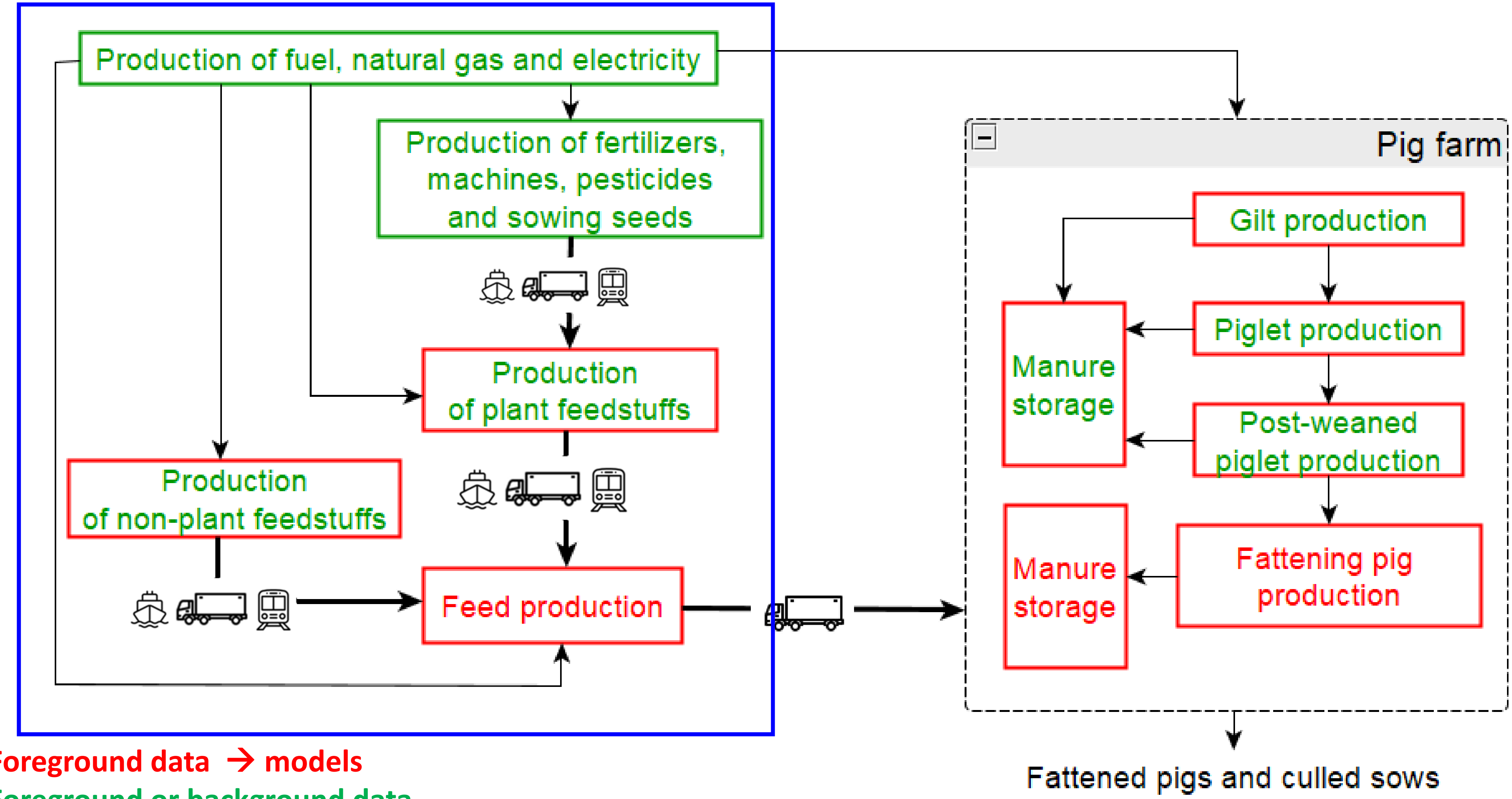
- Impact categories
- Characterization factors
- Normalization

Interpretation

- Scenario analysis
- Contribution analysis
- Uncertainty analysis

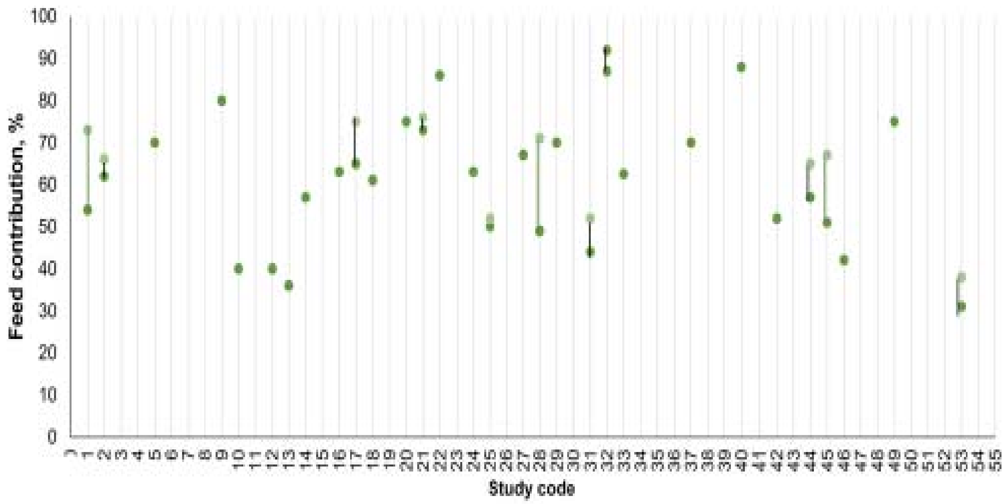
LCA offers a comprehensive framework to support eco-design in many areas, including swine production

Goal and scope in Swine Production Systems (SPS) LCAs

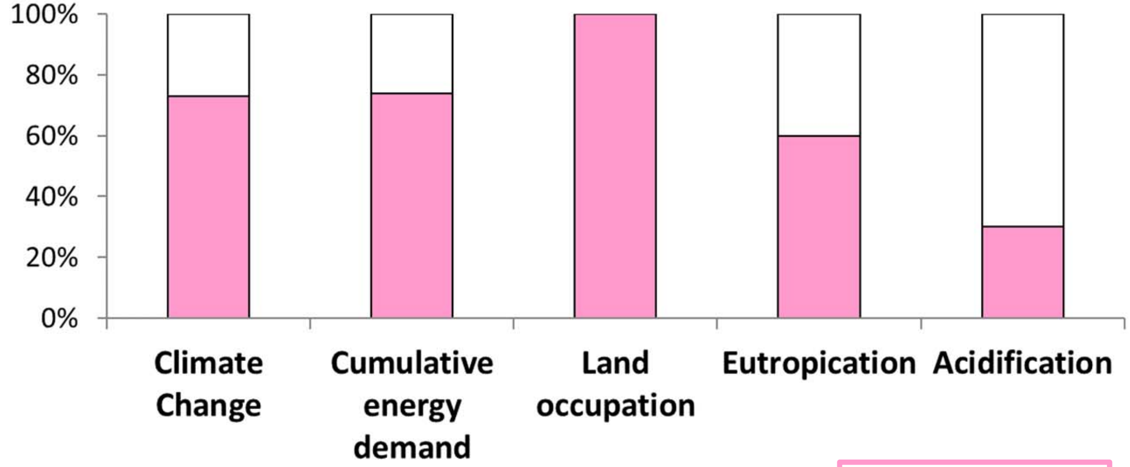


Contribution of feed production to most environmental impacts

PIG Contribution to climate change



Andretta et al. 2021



Basset-Mens & van der Werf, 2005
Dourmad et al. 2014

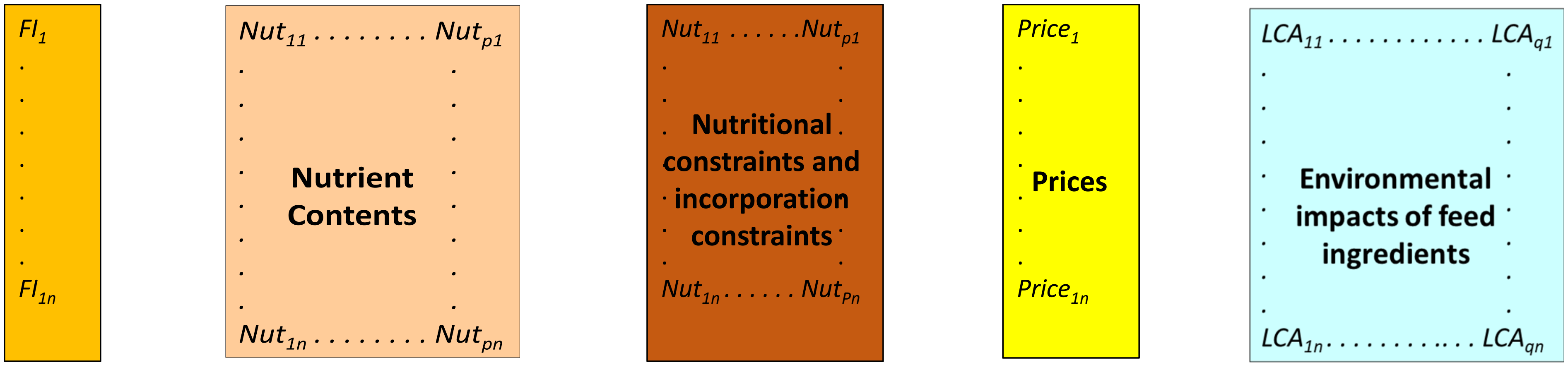
Decreasing the environmental impacts of pig feeds is potentially an interesting lever of mitigation

Associating LCA to feed formulation for swine production systems should contribute to mitigate the environmental impacts of swine production while addressing the best trade-off with feed cost

The story of multiobjective feed formulation

1. **First story - Dealing with multiple objectives to overcome potential transfer of impacts**
2. Second story - Dealing with multiple objectives to overcome potential transfer of impacts
3. Supporting decision with multiobjective feed formulation
4. Conclusions and implications

Multiobjective feed formulation – what are we talking about?



Environmental impacts at feed factory gate

Garcia-Launay et al. 2018 - https://doi.org/10.1017/S0007114518002672

Step 1 : traditional least-cost feed formulation

$$\begin{cases} \min \mathbf{c}^t\mathbf{x} \\ \begin{pmatrix} \mathbf{q_{min}} \\ \mathbf{n_{min}} \\ 1 \end{pmatrix} \leq \begin{pmatrix} \mathbf{Q} \\ \mathbf{N} \\ \mathbf{1}^t \end{pmatrix} \mathbf{x} \leq \begin{pmatrix} \mathbf{q_{max}} \\ \mathbf{n_{max}} \\ 1 \end{pmatrix} \\ 0 \leq \mathbf{x} \leq 1 \end{cases}$$

In this first step, we produce a reference least-cost feed

I := set of feed ingredients

J := set of nutrients

$\mathbf{x} = (x_i)_{i \in I}$

Ingredient **incorporation rate** decision vector

$\mathbf{c} = (c_i)_{i \in I}$

Ingredient cost vector

$\mathbf{Q} = Id * 1000$

$\mathbf{q_{min}} = \left(q_{min_i}\right)_{i \in I}$, $\mathbf{q_{max}} = \left(q_{max_i}\right)_{i \in I}$

vectors of ingredient incorporation constraints

$\mathbf{N} = \left(n_{ij}\right)_{i \in I, j \in J}$ matrix of nutritional values

$\mathbf{n_{min}} = \left(n_{min_j}\right)_{j \in J}$, $\mathbf{n_{max}} = \left(n_{max_j}\right)_{j \in J}$

Vectors of nutritional constraints

Garcia-Launay et al. 2018 - https://doi.org/10.1017/S0007114518002672

Step 2 : multiobjective feed formulation

$$\begin{cases} \min\ (1-\alpha)\dfrac{\mathbf{c}^t\mathbf{x}}{\mathrm{Cost}_{ref}} + \alpha \times \displaystyle\sum_{i\in I} \mathrm{coef}_i \dfrac{\mathbf{impact_i}^t\mathbf{x}}{\mathrm{impact}_{ref_i}} \\ \begin{pmatrix} \mathbf{q_{min}} \\ \mathbf{n_{min}} \\ 1 \end{pmatrix} \leq \begin{pmatrix} \mathbf{Q} \\ \mathbf{N} \\ \mathbf{1}^t \end{pmatrix} \mathbf{x} \leq \begin{pmatrix} \mathbf{q_{max}} \\ \mathbf{n_{max}} \\ 1 \end{pmatrix} \\ 0 \leq \mathbf{x} \leq 1 \\ \begin{pmatrix} \mathbf{impact_1}^t \\ \mathbf{impact_2}^t \\ \vdots \\ \mathbf{impact_m}^t \end{pmatrix} \mathbf{x} \leq \begin{pmatrix} 1{,}05 * \mathrm{impact}_{1_{ref}} \\ 1{,}05 * \mathrm{impact}_{2_{ref}} \\ \vdots \\ 1{,}05 * \mathrm{impact}_{m_{ref}} \end{pmatrix} \end{cases}$$

Impacts: climate change, non-renewable energy demand, land occupation, phosphorus demand

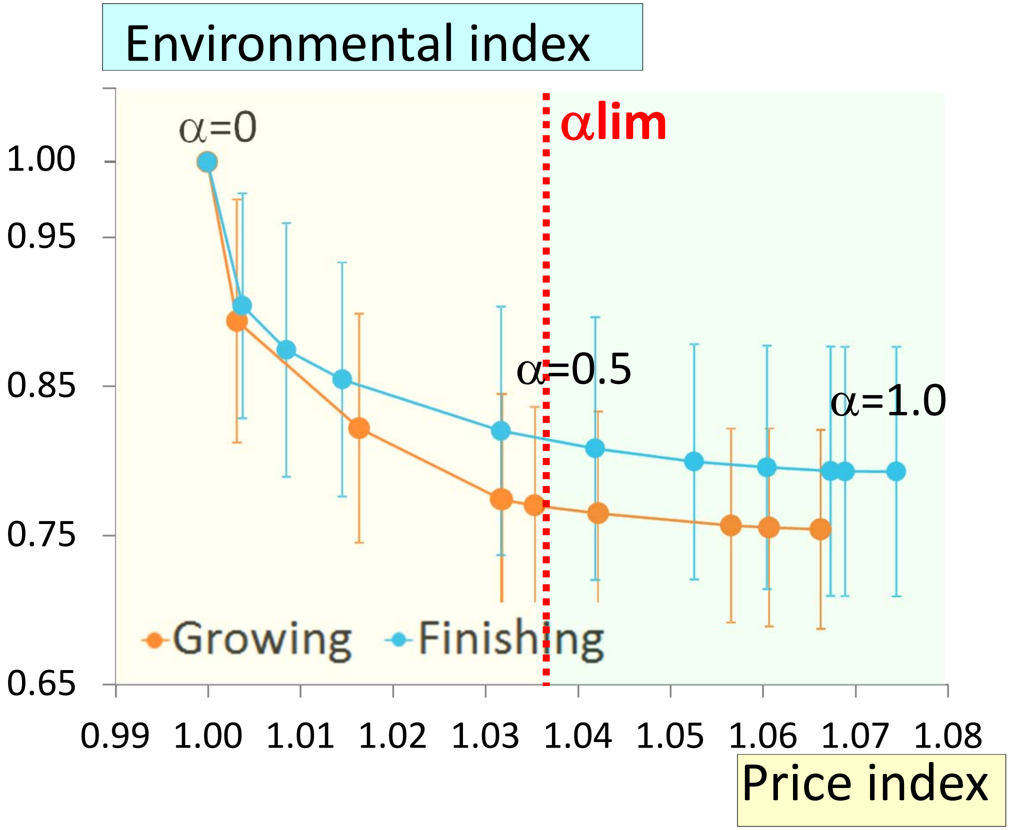
$\mathbf{impact_i}$ → vector of impact values i for feed ingredients

Variables with subscript "ref" → values obtained for the reference feed from least cost feed formulation

α is the weighting factor between cost index and environment index

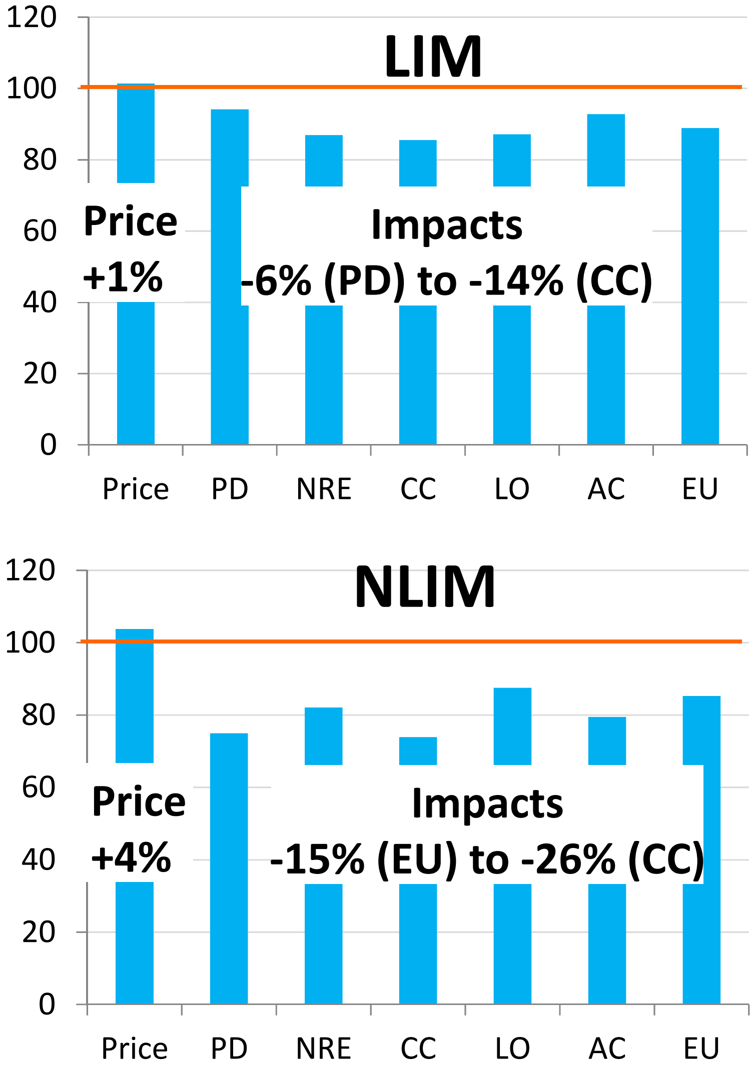
Garcia-Launay et al. 2018 - https://doi.org/10.1017/S0007114518002672

Trade-off economy | environment



Feed formulas and mitigation of impacts calculated at αlim

Mitigation of environmental impacts

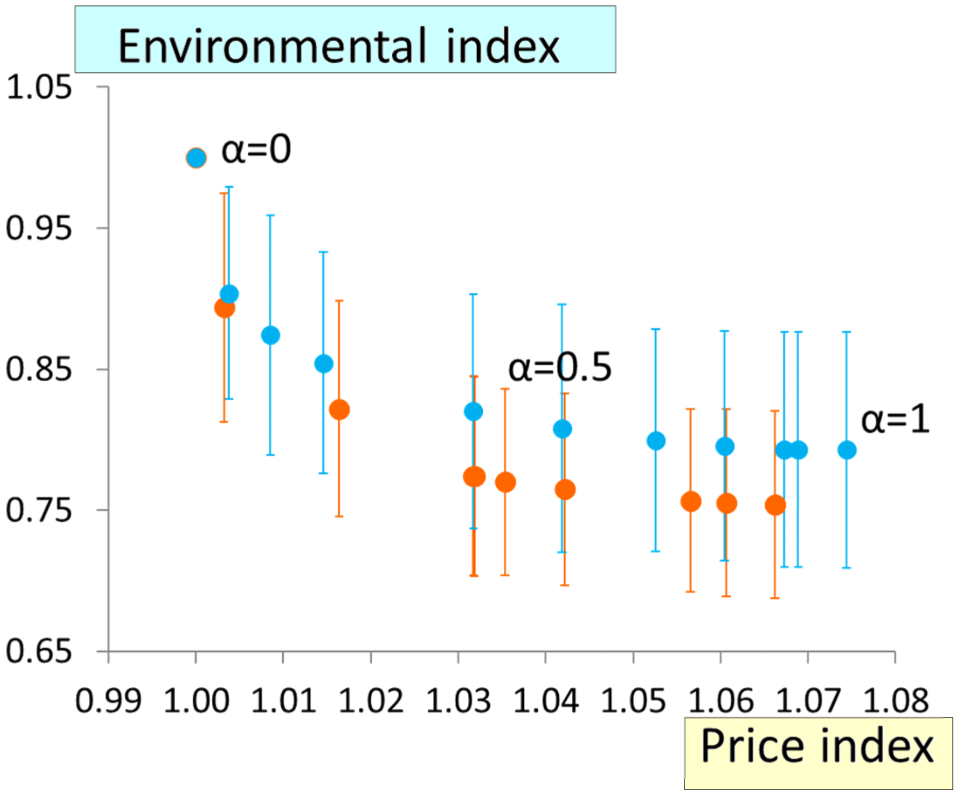


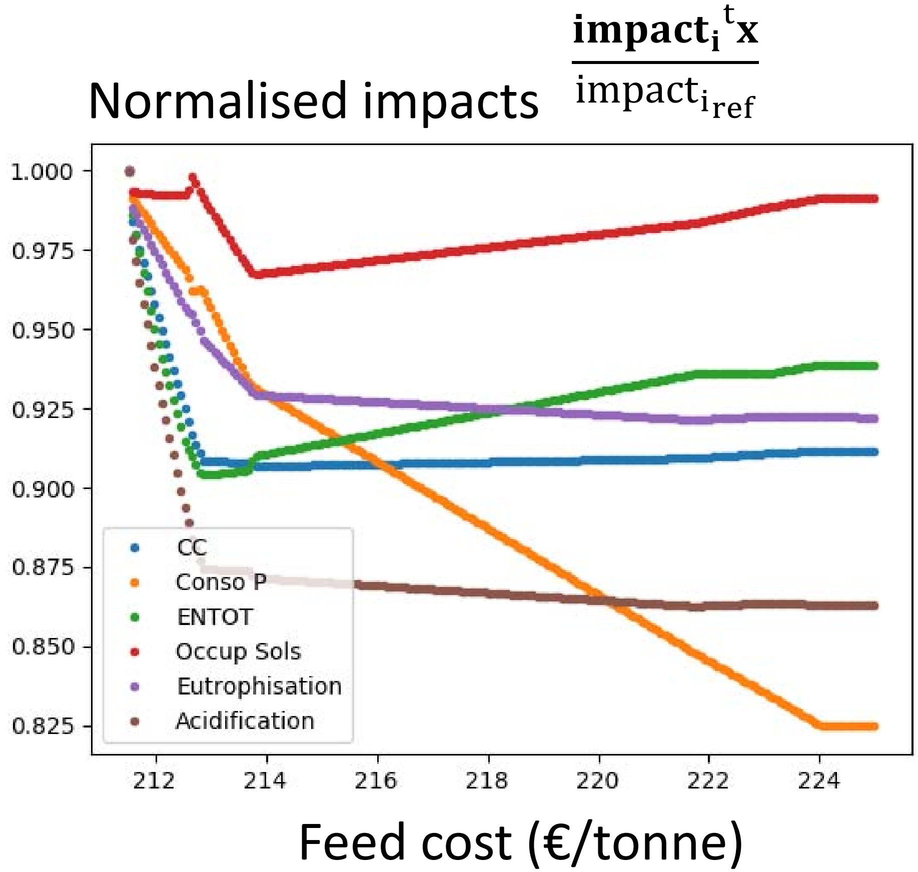
Current limited availability of feed ingredients (LIM)
Increased potential availability of some feed ingredients such as protein seeds and co-products (NLIM)

PD: phosphorus demand
NRE: non-renewable energy demand
CC: climate change
LO: land occupation
AC: acidification
EU: eutrophication

No transfer of impacts

However ! Remaining problems…





The story of multiobjective feed formulation

1. First story - Dealing with multiple objectives to overcome potential transfer of impacts
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Resolving the remaining problems

$$
\begin{cases}
\min \sum_{i \in I} \mathrm{coef}_i \dfrac{\mathbf{impact_i}^t\mathbf{x} - \mathbf{Min_i}}{\mathrm{impact}_{\mathrm{ref}_i} - \mathrm{Min_i}} \\
\mathbf{c}^t\mathbf{x} \leq \epsilon \\
\begin{pmatrix} \mathbf{q_{min}} \\ \mathbf{n_{min}} \\ 1 \end{pmatrix} \leq \begin{pmatrix} \mathbf{Q} \\ \mathbf{N} \\ \mathbf{1}^t \end{pmatrix} \mathbf{x} \leq \begin{pmatrix} \mathbf{q_{max}} \\ \mathbf{n_{max}} \\ 1 \end{pmatrix} \\
0 \leq \mathbf{x} \leq 1 \\
\begin{pmatrix} \mathbf{impact_1}^t \\ \mathbf{impact_2}^t \\ \vdots \\ \mathbf{impact_m}^t \end{pmatrix} \mathbf{x} \leq \begin{pmatrix} 1{,}05 * \mathrm{impact}_{1_{\mathrm{ref}}} \\ 1{,}05 * \mathrm{impact}_{2_{\mathrm{ref}}} \\ \vdots \\ 1{,}05 * \mathrm{impact}_{m_{\mathrm{ref}}} \end{pmatrix}
\end{cases}
$$

ϵ − constraint method

$\epsilon = \{\mathrm{Cost}_{\mathrm{ref}}, \dots, \mathrm{Cost}_{\mathrm{max}}\}$

$\mathbf{impact_i}$ → vector of impact values i for feed ingredients

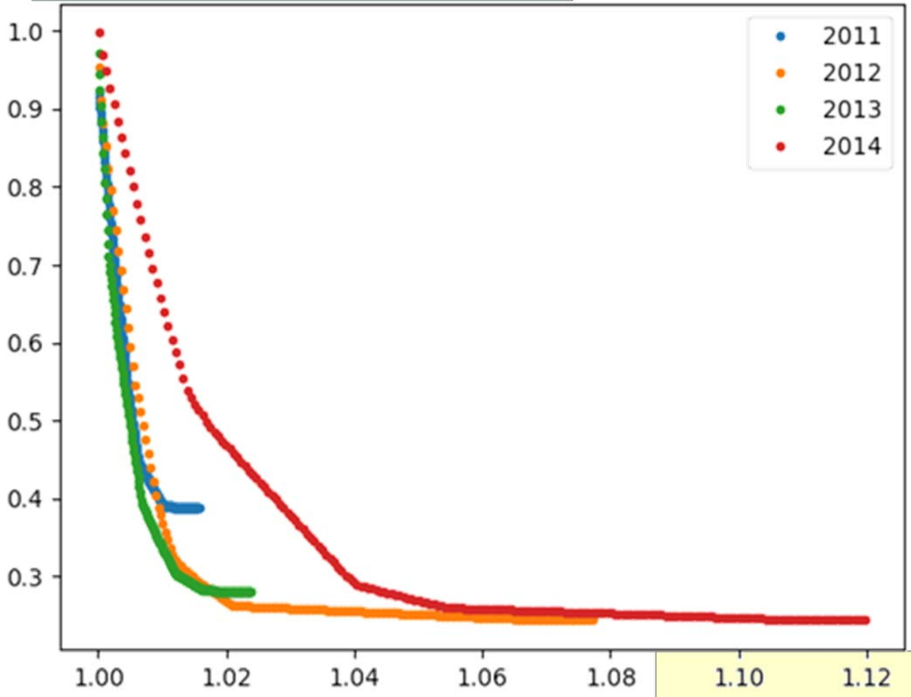
$\mathrm{Cost}_{\mathrm{max}}$: price of feed when formulating without ϵ-constraint

$\mathrm{Min_i}$: level of impact i when formulating at lowest impact i

De Quelen et al. 2021 - https://doi.org/10.3389/fvets.2021.689012
Wilfart et al. 2022 - https://doi.org/10.1016/j.aquaculture.2022.738826

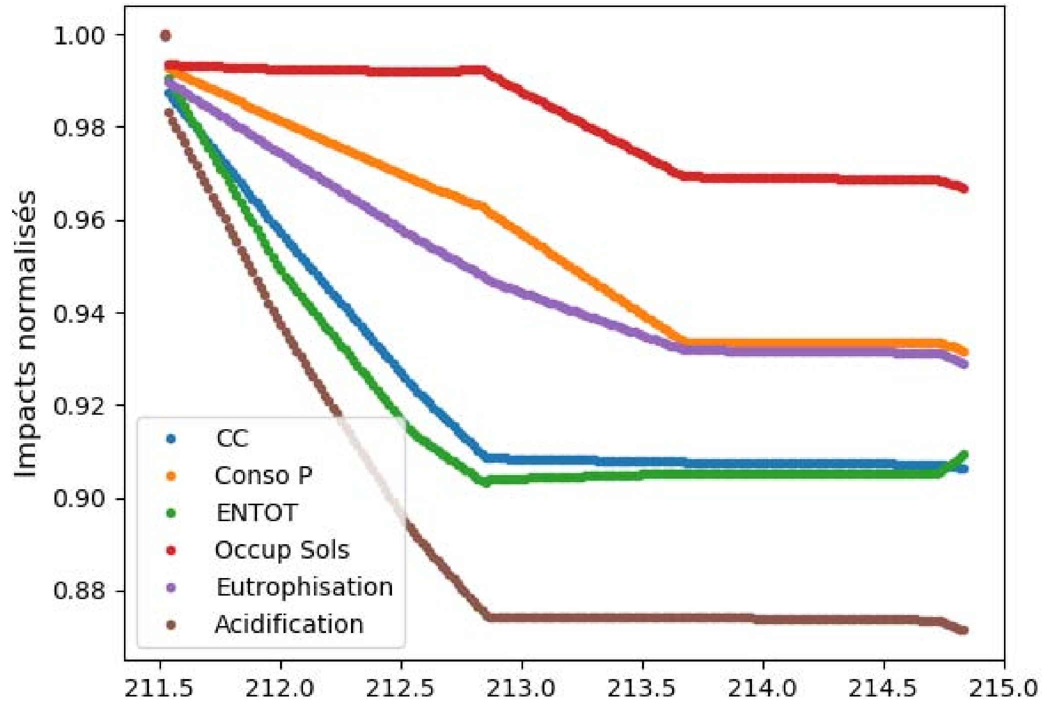
Resolving the remaining problems !

Environmental index



Price index

Normalised impacts $\frac{\mathbf{impact_i}^t\mathbf{x}}{\text{impact}_{i_{ref}}}$



Feed cost (€/tonne)

De Quelen et al. 2021 - https://doi.org/10.3389/fvets.2021.689012
Wilfart et al. 2022 - https://doi.org/10.1016/j.aquaculture.2022.738826

Application to swine production

❖ **Formulation considers animal requirements, feed cost and different environmental impacts by Life Cycle Assessment (LCA) approach**

❖ **3 different formulation approaches :**

- **Control diet** = least-cost formulation in accordance with practices in commercial farms
- **Ecodiet** = multiobjective formulation considering feed cost and environmental impacts calculated by Life Cycle Assessment (LCA) (Ecoalim)
- **Local diet** = multiobjective formulation using feed ingredients locally produced by farmers to reduce the impact of feed transport

De Quelen et al. 2021 - https://doi.org/10.3389/fvets.2021.689012

Environmental impacts of diets calculated through LCA (per kg average feed)

	Control diet	Ecodiet	Local diet	Control diet to Ecodiet	Control diet to Local diet	Ecodiet to Local diet
CC (kg CO_2 eq)	485	342	376	↓ 29.5%	↓ 22.5%	↑ 9.9%
CED (MJ)	4073	3486	3286	↓ 14.4%	↓ 19.3%	↓ 5.7%
Acidification (molc H^+ eq)	9.39	7.65	7.76	↓ 18.5%	↓ 17.3%	↑ 1.4%
Eutrophication (kg PO_4^{3-} eq)	3.68	3.22	3.79	↓ 12.5%	↑3%	↑ 17.7%
Land occupation (m^2.y)	1412	1374	1674	↓ 2.7%	↑18.5%	↑ 21.8%

CC (climate change (kg CO_2 eq)) = global warming potential; CED = non-renewable and fossil energy demand (MJ); AC = acidification (molc H+ eq); EU = eutrophication (kg PO_4^{3-} eq); LO (land occupation (m^2/y)) = area of the land required to produce one kg of feed.

De Quelen et al. 2021 - https://doi.org/10.3389/fvets.2021.689012

Environmental impacts at farm gate (per kg of live pig)

- **Animals : 96 Pietrain x (Large White x Landrace) pigs**
- **Daily individual recording of animal performance from 40 to 115kg: live weight, feed consumption, water consumption**
- **Slaughterage at 115kg : carcass weight, lean meat percentage**

	Control diet	Ecodiet	Local diet	RSD	Statistics
CC (kg CO_2 eq)	2.50[a]	2.06[b]	2.20[c]	0.13	G**, S***, A***
CED (MJ)	14.58[a]	12.47[b]	12.43[b]	0.12	G**, S***, A***
AC (molc H^+eq)	0.155[a]	0.144[b]	0.154[a]	0.108	G**, S***, A**
EU (kg PO_4^{3-}eq)	0.295[a]	0.273[b]	0.308[a]	0.113	G**, S***, A***
LO (m^2.y)	4.63[a]	4.45[a]	5.69[b]	0.15	G**, S***, A***

CC (climate change (kg CO_2 eq)) = global warming potential; CED = non-renewable and fossil energy demand (MJ); AC = acidification (molc H+ eq); EU = eutrophication (kg PO_4^{3-} eq); LO (land occupation (m^2/y)) = area of the land required to produce one kg of feed.

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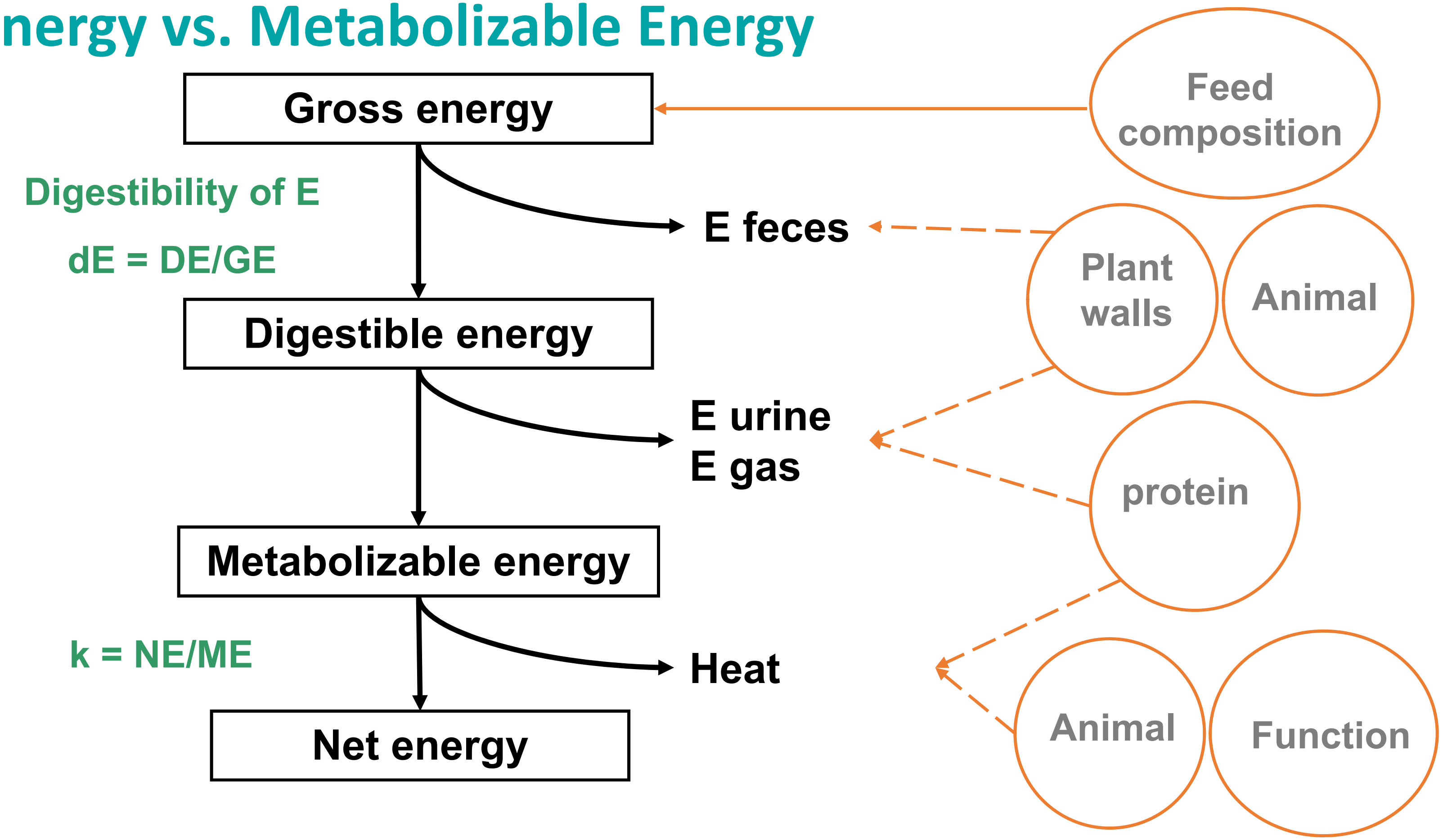
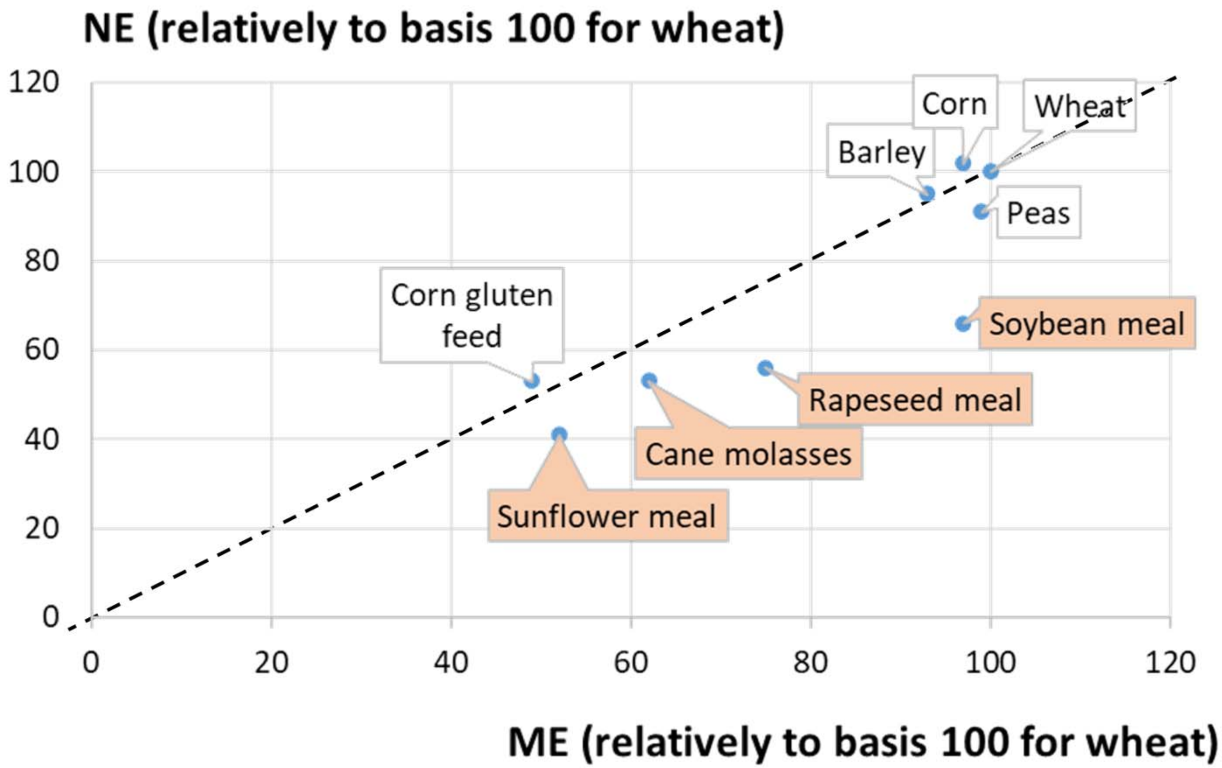
Performing multiobjective feed formulation based on Net Energy vs. Metabolizable Energy



NE provides the true energetic value of feed ingredients, which is the energy really available for maintenance, growth…

Performing multiobjective feed formulation based on Net Energy vs. Metabolizable Energy

Noblet 2015 - https://hal.inrae.fr/hal-02742572

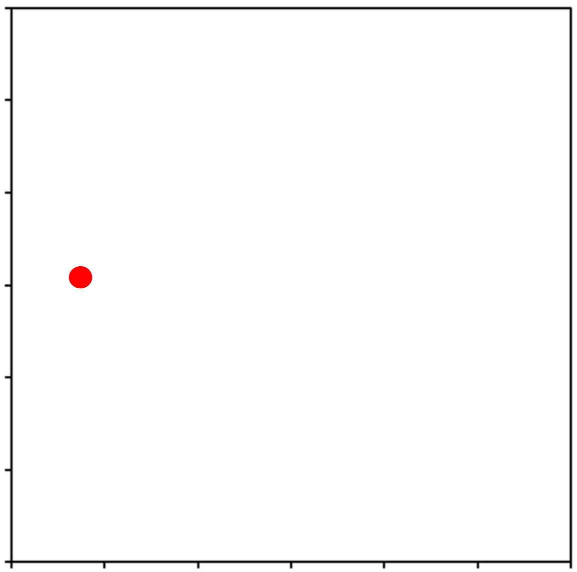


In practice, the efficiency NE/ME varies between the different feed ingredients, because this efficiency depends on the origin of ME (fat, starch, protein, fibres)
→ the energy value of protein-rich or fibruous feeds is overestimated when expressed on a ME basis.

Multiobjective optimization may produce ecofeeds with different NE/ME ratios than leas-cost formulated feeds → necessary to formulate on NE basis

It is necessary to build the Pareto front!

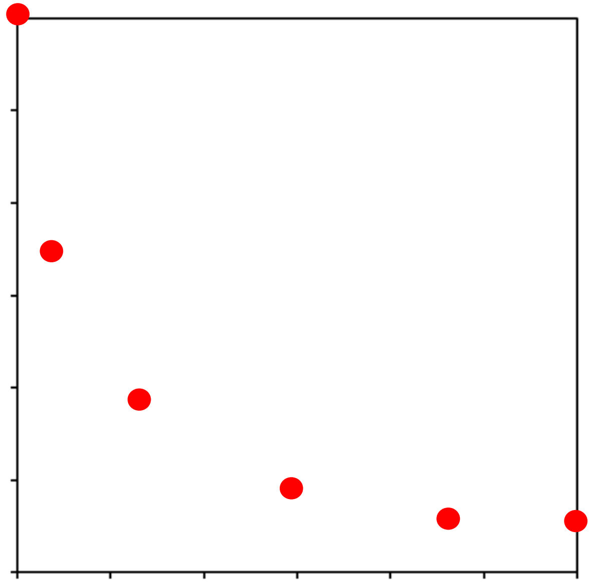
Cost index – α = 0.3



Environmental Index weight (0.7)

Fixed weighting factors

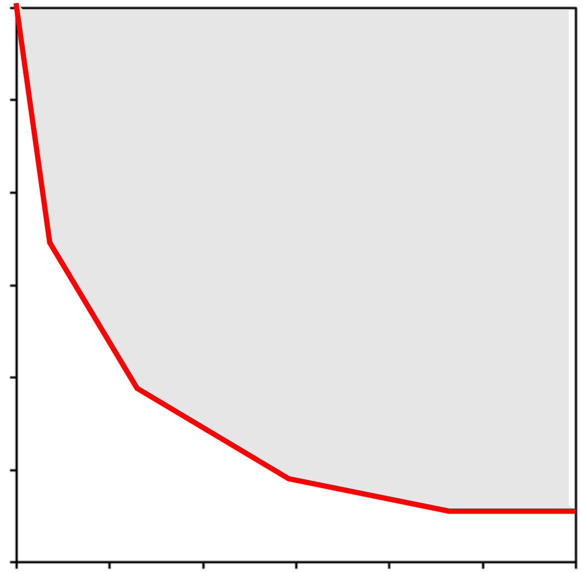
Cost index – weight α



Environmental Index weight (1-α)

Weighted sum

Feed cost – ε-constraint



Environmental Index

ε-constraint

Necessary to get all the Pareto front before choosing a trade-off

Erghott – Multicriteria Optimization 2nd Edition - 2005

Multiobjective feed formulation with average values for environmental impacts of feed ingredients?

Feed formulation using average values of feedstuffs impacts in France

Ecofeeds

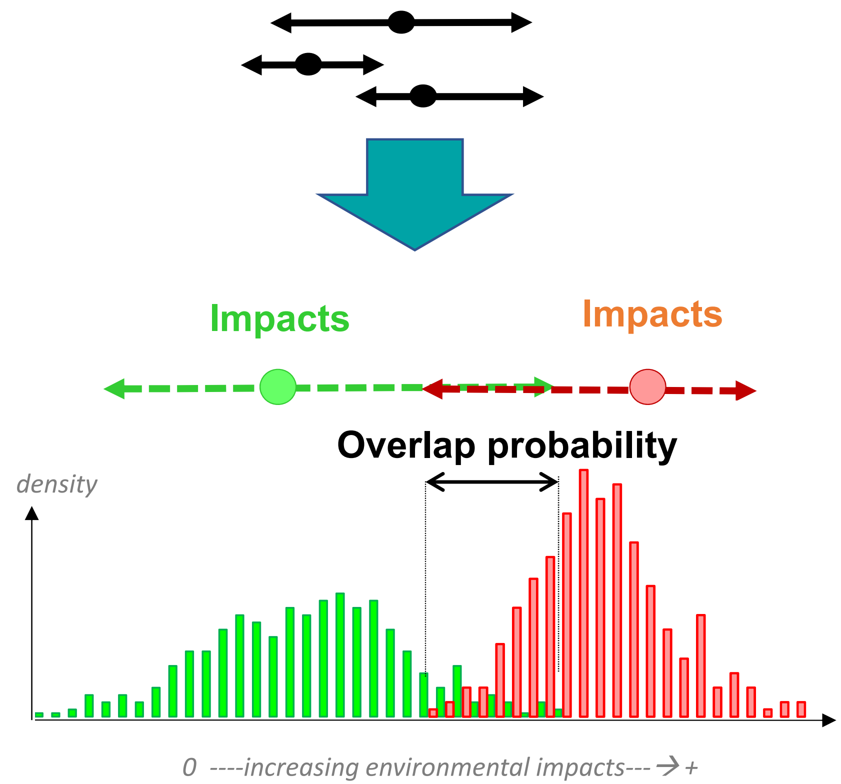
Multiobjective formulation

Standard feeds

Least-cost formulation

Profile of the feeds in terms of feedstuffs incorporations

Variability of the feedstuffs impacts in France



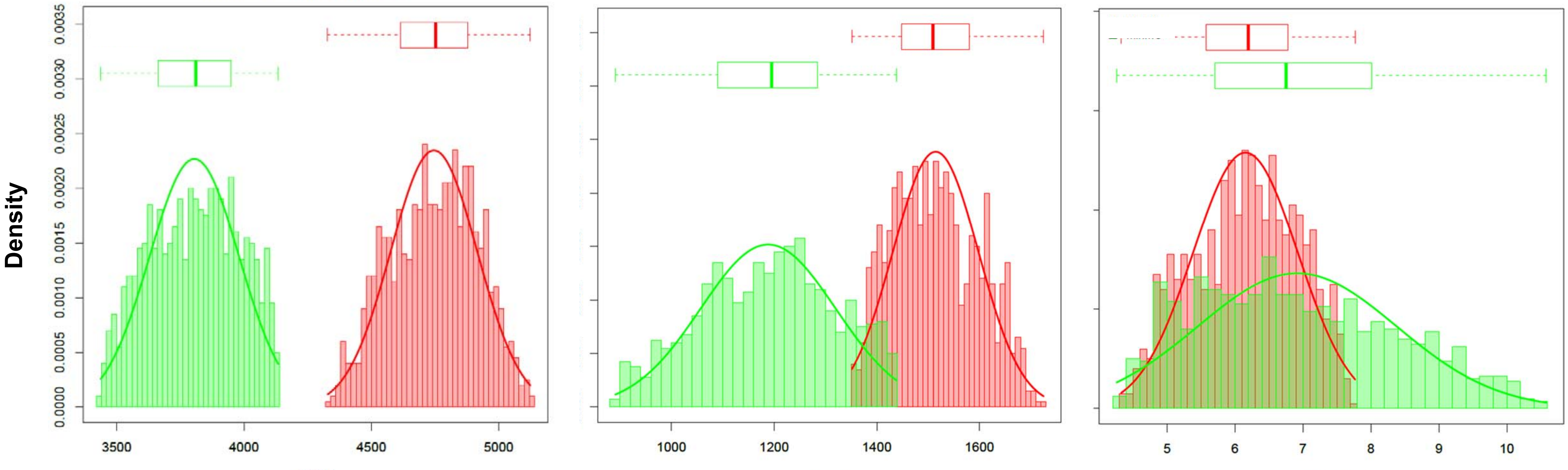
Espagnol et al. LCA Foods 2018

Multiobjective feed formulation with average values for environmental impacts of feed ingredients?

Ecofeed

Sandard feed

Non renewable energy consumption | **Land occupation** | **Acidification**



Overlap probability = 0 | **Overlap probability = 13%** | **Overlap probability = 99%**

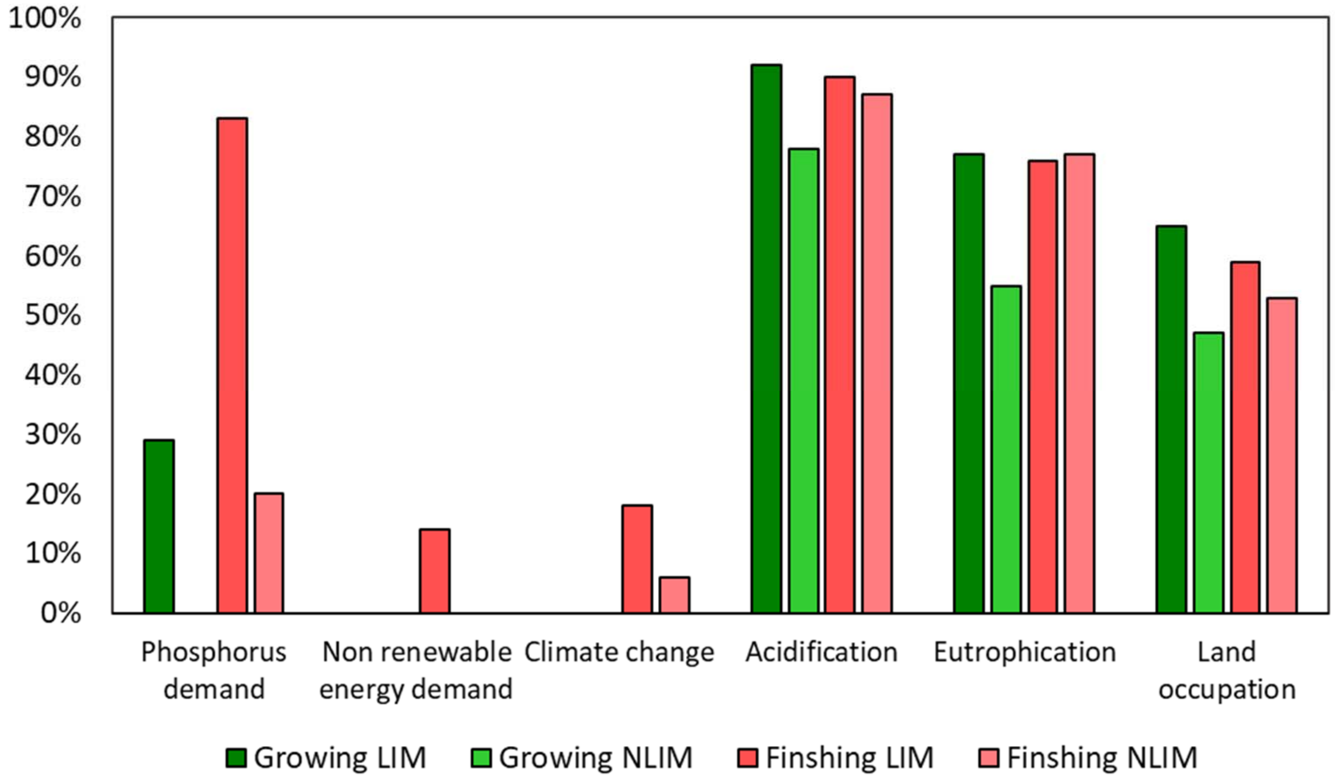
Espagnol et al. LCA Foods 2018

Multiobjective feed formulation with average values for environmental impacts of feed ingredients?

Espagnol et al. LCA Foods 2018

16 situations

- 2 feeds of the fattening period (growing and finishing)
- 4 contrasted economic contexts (2011, 2012, 2013 and 2014)
- 2 levels of feedstuff availability



LCA data on available feedstuffs should be as precise as much as possible

Robustness to variability for climate change and non renewable energy demand

Eco-design in pig production supported by multiobjective feed formulation and LCA

Feed factory gate

- Various studies – models proposed – minimizing a single impact (Nguyen et al. 2011 in broilers)
- Methodology accounting for 4 global environmental impacts and feed cost (Garcia-Launay et al. 2018) – updated (de Quelen et al. 2021)

Pig farm gate

- Diet formulation tool that seeks for the feed formula and the levels of net energy, CP and AA that minimize a composite function including environmental impacts (McKenzie et al. 2016)

One should be careful when applying multiobjective optimization that the excretion of nutrients, in particular N & P, is not increased

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Multiobjective optimization to support eco-design in pig production

- Multiobjective optimization of pig feeds is efficient for reducing environmental impacts which are included in the objective-function

- Caution should be taken when applying feed formulation :
  - Formulating on a Net Energy basis
  - Making sure excretion of N & P are not increased
  - Looking at the whole Pareto front
  - Checking for effects of uncertainty in the impacts of feed ingredients

Perspectives

- Optimizing of both feed formulas and feeding program
- Multiobjective optimization based on the environmental impacts of pig at farm gate.

- Decision support tools to make it easily available for feed producers, and for teaching purpose

Thank you for your attention

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