Differences in LCA impact between meat types are reduced when ecosystem services related to their production are accounted for

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Rationale and objective of the work

The negative environmental impacts of meat production assessed from LCA (further LCA impacts), is highly dependent on the concerned livestock species. To produce one kilo of meat, LCA assessments indicate that energy consumption and greenhouse gas emissions (GHG) increase from chicken to pork, and from pork to beef (de Vries and de Boer, 2010; Flachowsky et al., 2017).

However, LCA has been criticized for its inability to account for the positive aspects of certain forms of extensive farming, such as organic and agro-ecological farming (van der Werf et al., 2020). This is a limit as this type of farming, such as grass-based beef production, can deliver multiple benefits and ecosystem services (ES) (Dumont et al., 2018; Ryschawy et al., 2019). The permanent grasslands involved in such system can indeed provide, for example, ES of pollination, carbon storage, erosion prevention or recreation (Schils et al., 2022). The LCA impacts of meat of chicken, pork and cattle may therefore differ, or be nuanced, if positive impacts were accounted.

To solve this issue, a new method has been proposed to allocate LCA impacts to the strictly productive services and to other types of services (Boone et al., 2019). For a given production system, productive aspects are assessed according to their relative level of provisioning ES (PES), e.g. ES producing physical goods like grain, wood or meat, and other services are assessed based on their level of regulating ES (RES), e.g. ES contributing to stabilize biophysical processes like climate. This method proposes allocation factors based on the capacity of systems to supply the two types of ES and it has been applied to compare LCA impacts of organic and conventional crop productions. Here we apply the method to the production of chicken, pork and beef.

Approach and Methodology

The allocation factors $f_{prov,s}$ and $f_{reg,s}$ of the production system of livestock species s, are calculated based on the capacity of this system to deliver PES and RES. This capacity is itself quantified according to scores we calculated, and denoted $PES_{sys,s}^{score}$ and $RES_{sys,s}^{score}$, respectively (Eq. (1)-(2)). These scores are normalized and take values ranging from 0 to 5, referring to no capacity to very high capacity of the system to supply a particular ES. This scoring approach is based on the ES score matrix framework proposed by Burkhard et al. (2012).

$$f_{prov,s} = PES_{sys,s}^{score} / (PES_{sys,s}^{score} + RES_{sys,s}^{score}) \quad \text{Eq. 1}$$

$$f_{reg,s} = RES_{sys,s}^{score} / (PES_{sys,s}^{score} + RES_{sys,s}^{score}) \quad \text{Eq. 2}$$

The factors initially concern arable land only (Boone et al. 2019), but livestock production systems involves feeding systems with specific land use profiles. We therefore expressed PES_{sys}^{score} and RES_{sys}^{score} based on the scores of each land use (grasslands and croplands). The score of the whole feeding system is then assessed through a weighted average, calculated by weighing grassland and cropland scores by the areas used to produce one kilo of meat (Eq. (3)-(4)).

$$PES_{sys,s}^{score} = (a_{crop,s} \cdot PES_{crop,s}^{score} + a_{grass,s} \cdot PES_{grass,s}^{score})/(a_{crop,s} + a_{grass,s}) \quad \text{Eq. 3}$$

$$RES_{sys,s}^{score} = (a_{crop,s} \cdot RES_{crop,s}^{score} + a_{grass,s} \cdot RES_{grass,s}^{score})/(a_{crop,s} + a_{grass,s}) \quad \text{Eq. 4}$$

Where, for livestock species s, $a_{crop,s}$ and $a_{grass,s}$ are the area of croplands and grasslands, respectively. $PES_{crop,s}^{score}$ and $PES_{grass,s}^{score}$ are PES score of croplands and grasslands, respectively; and $RES_{crop,s}^{score}$ and $RES_{grass,s}^{score}$ are RES score of croplands and grasslands, respectively.

To assess PES scores we used the areas of grasslands and croplands used to produce one kg of chicken, pork and beef (based on Fischer et al. (2014)). We used in this aim an intermediate variable OP, quantifying the overall productive performances. We quantified it considering that the system requiring the less surfaces would be the most efficient, from a productive viewpoint. We derived from cropland and grassland areas an overall productive score to the feeding system OP, by attributing an overall score of 5 (maximum) to chicken systems, as a reference, as they are the most efficient (less area used). We normalized this way our score on a scale of 0 to 5. The scores of our three studied species are expressed by Eq. (5)-(7).

$$OP_{chicken} = 5 \quad \text{Eq. 5}$$

$$OP_{pork} = 5 \cdot (a_{crop,chicken} + a_{grass,chicken})/(a_{crop,pork} + a_{grass,pork}) \quad \text{Eq. 6}$$

$$OP_{cattle} = 5 \cdot (a_{crop,chicken} + a_{grass,chicken})/(a_{crop,cattle} + a_{grass,cattle}) \quad \text{Eq. 7}$$

We finally calculated $PES_{crop,s}^{score}$ and $PES_{grass,s}^{score}$ by breaking down OP_s according to the area of crops and grassland in the feeding system of the concerned species s (Eq. (8)-(9)).

$$PES_{crop,s}^{score} = OP_s \cdot a_{crop,s}/(a_{crop,s} + a_{grass,s}) \quad \text{Eq. 8}$$

$$PES_{grass,s}^{score} = OP_s \cdot a_{grass,s}/(a_{crop,s} + a_{grass,s}) \quad \text{Eq. 9}$$

The values of $a_{crop,s}$ and $a_{grass,s}$ were derived from Flachowsky et al. (2017), who give reference values for systems of different levels of productivity. We chose systems of intermediate productivity for the three species, as our purpose was to account for the differences of species only, without biases that could be induced by management intensity. We then obtained $RES_{crop,s}^{score}$ and $RES_{grass,s}^{score}$ from the matrix of score of Stoll et al. (2015), and considered the scores independent of the livestock species, as we focused on systems of similar management intensity. We finally collected the LCA impacts from de Vries and de Boer (2010), and broke them down according to the allocation factors we calculated.

Main results and discussion

Our calculations of PES scores in croplands returned important differences according to species, with PES score being lower for beef, followed by pork and then chicken (Tab. 1). This gradient is consistent with the feed efficiency of these animals. PES score for grassland is higher for beef than pork and chicken, which is consistent as well, as pork and chicken are not able to digest the forage cellulose (access to grassland is often more justified by animal welfare than productive purposes for these two species). The RES scores are identical according to species, as we chose, and are logically higher for grassland than crops, as they are less transformed habitats.

The overall scores $PES_{av,s}^{score}$ and $RES_{av,s}^{score}$ of the feeding systems, calculated from weighed averages accounting for the relative areas of cropland and grassland (Eq. 3 and 4.), follow opposite gradients. PES increases from chicken to pork, and pork to cattle, whereas RES increases inversely. As a result allocation factors follow gradients where $f_{prov,s}$ increases from chicken to pork, and pork to cattle.

$f_{prov,chicken}$ is 0.84, indicating that the bundle of ES that can be provided by the chicken livestock system considered is mostly of PES type. In other terms, $f_{prov,chicken}$ indicates that this system mostly contributes to the human well-being through meat production. Oppositely $f_{prov,cattle}$ is 0.26, i.e. below 0.5, indicating that the bundle of ES that can be provided by the cattle livestock system considered is mostly of RES type. In other terms, $f_{prov,cattle}$ indicates that this system mostly contributes to the human well-being through its regulating ecosystem services. $f_{prov,pork}$ is also above 0.5 (0.66) indicating that its contribution to human well-being is mostly made through the PES provision. It is however less skewed towards PES that the chicken system.

Table 1: Areas used to produce 1 kg of meat and scores of provisioning ecosystem services (PES) and regulating ecosystem services (RES) related to production system of different livestock species

	Areas used for 1 kg of meat (m^2)			Overall productive score	PES score		RES score		Overall score	
	grassland	cropland	Total		grassland	cropland	grassland	cropland	PES	RES
Beef	25.81	2.98	28.78	0.99	0.89	0.10	2.27	0.73	0.81	2.11
Pork	1.48	11.99	13.47	2.12	0.23	1.89	2.27	0.73	1.71	0.90
Chicken	0.42	5.30	5.72	5.00	0.37	4.63	2.27	0.73	4.31	0.84

The differences of LCA impact along the chicken-beef gradient is two and a half higher for chicken than beef for energy, and six times higher for CO_2-eq. When these differences are reallocated according to the f_{prov} factor, the LCA energy impact gradient is modified with beef having the lower impact, and pork the highest. The LCA CO_2-eq gradient is not modified but the differences of impact that was six fold between chicken and beef, is now reduced to twofold.

Table 2: Allocation factors and LCA impacts allocated and not allocated

Livestock system	Allocation factors		LCA impacts per kg - not allocated		LCA impacts per kg - allocated according to f_{prov}	
	f_{prov}	f_{reg}	MJ	CO_2-eq	MJ	CO_2-eq
Beef	0.28	0.72	50.00	30.00	13.86	8.31
Pork	0.66	0.34	30.00	10.00	19.68	6.56
Chicken	0.84	0.16	20.00	5.00	16.73	4.18

These calculations indicate that depending on the species bred, the production of one kilo of meat induces different bundles of ecosystem services. They show in particular that an important share of the LCA impacts of beef benefits to the delivery of RES. That does not mean that the impact energy or CO_2-eq of kilo of beef should be considered lower than currently assessed, but that this production system also contributes to the delivery of other ES than just PES, such as meat production services.

Integrating LCA and ES frameworks has received significant interest for almost a decade (Brandão and i Canals, 2013; de Baan et al., 2013), and it is still considered incomplete (De Luca Peña et al., 2022; VanderWilde and Newell, 2021). To complete LCA assessments, some authors proposed an additional type of assessment to the usual list of LCA variables (emissions of CO_2-eq, energy consumption, eutrophication, etc…). This proposed additional assessment aims at expressing the damage to ecosystem quality over specific durations and areas, through dedicated equations (Koellner et al., 2013). We used another approach aiming at allocating existing usual LCA impacts according to the contribution of livestock systems to distinct ES. To do this we used allocating factors that describes how balanced are the bundles of ES, between PES and RES.

Our approach contributes to the debate about the impacts of livestock farming in the global food system, which is criticized for its impact on ecosystems, climate and biodiversity. Monogastric animals (chicken and pork) have low CO_2-eq emissions compared to cattle, which is highly penalized by its methane emissions, due grass digestion processes (rumination). Oppositely, cattle and other ruminants can use a significant share of grasslands that are semi-natural habitats that provide interesting levels of RES. These habitats can also be used as refuges of biodiversity. Depending on where society is going to put the priority in addressing climate change or biodiversity crisis, the source of protein and other animal products may differ. As both issues must be addressed simultaneously, a trade-off approach is required, and we think that methods such as the one we present here can help quantifying these trade-offs.

Conclusion

By applying an allocation method, we allocated the usual LCA impacts between those contributing to productive activities of meat, and those contributing to the delivery of other ES of interest. Our approach thus shows how some positive impacts of meat production could be integrated in LCA methods. This approach can describe how balanced are the bundles of ES provided by livestock farming and assess their negative or positive impacts on climate change and ES. We think that such method able to give nuanced assessments and a trade-off vision is important to address the immense sustainability challenges that society and decision-makers are facing.

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