Compared life cycle assessments of biomass feedstocks at sub-regional scale

Projet ECOBIOM - Livrable L7 - Résultats

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Ce document, écrit sous forme de manuscrit comme projet d'article pour une revue scientifique, présente la méthodologie employée pour l'analyse de cycle de vie dans le projet ECOBIOM, et les résultats obtenus.

Résumé

Un approvisionnement fiable et optimal de biomasse lignocellulosique pour des unités de conversion en bioénergie à grande échelle ne peut être assuré qu'à partir d'une large gamme des espèces candidates. Ceci exige une évaluation précise des potentiels de production et des impacts sur l'environnement, particulière au bassin d'approvisionnement envisagé, pour être en mesure de choisir les scénarios qui réduisent au minimum les coûts environnementaux et économiques. Dans cette étude, nous avons comparé la performance environnemenale de 5 espèces candidates dans la région de Champagne-Ardenne, dans le nord de la France: triticale, miscanthus, sorgho, blé (en plante entière), et peuplier en taillis à courte rotation. Deux co-produits agricole et sylvicole (pailles de blé et rémanents forestiers) ont également été analysés. L'impact environnemental de la production de biomasse (rendue bord de champ ou bord de route) a été évalué au moyen de l'analyse de cycle de vie dans diverses petites zones agricoles de Champagne Ardenne, pour lesquelles des données de rendements et les itinéraires techniques ont été collectées. Les espèces pérennes (miscanthus ou peuplier) ont les impacts les plus bas par MJ de biomasse produite, tandis que les impacts du blé sont jusqu'à deux fois plus élevés en raison de ses besoins en intrants. Des variations assez marquées entre zones agricoles sont apparues, principalement dues aux différences de rendement en biomasse et des apports d'engrais. Ceci met en évidence des marges de manoeuvre pour une optimisation géographique de l'emplacement des unités de transformation de biomasse, qui pourrait également inclure des critères sociaux et économiques élaborés au sein du projet ECOBIOM.

Abstract

Securing and optimizing the supply of lignocellulosic feedstock to bioenergy conversion units with potentially large capacity may be achieved by relying on a range of candidate species rather than only one or two types. This requires careful assessment within a given supply area where bioenergy projects are considered of both productivity potentials and environmental impacts, to select supply scenarios which minimize production and environmental costs.

Here, we compared the environmenal performance of six candidate energy crops in the Champagne-Ardenne region in northern France: triticale, miscanthus, sugar beet, sorghum, wheat (whole plant), and poplar tree. Two agricultural and forestry co-products (wheat straw and forest residues) were also analysed. Life-cycle assessment was used to evaluate the environmental impacts of crop production (up to farm gate or edge of road) in various small agro-ecological zones of Champagne Ardenne, for which specific yield and crop management data were available. The perennial grass species (miscanthus) had the lowest impacts per MJ of biomass produced, whereas wheat had up to twice higher impacts due to its high input requirements. There were also variations across agricultural regions, mainly due to discrepancies in yield potentials and fertilizer rates. This leaves room for a geographical optimization of the biomass plant location, which could also include the social and economic criteria developed for this region within the broader research project ECOBIOM.

1 Introduction

Bioenergy has recently come into sharp focus as part of policies aiming at curbing climate changes and reducing the use of fossil fuels. From the point of view of their environmental impacts, some concerns have also emerged regarding the production of agricultural feedstocks, associated with a variety of issues including enhanced eutrophication of ecosystems, acidification, human toxicity or ecotoxicity (17; 5). In developed countries, the agricultural sector is the main source for some of the air and water pollutants responsible for these impacts. In France for instance, agriculture contributes 95% of the anthropogenic emissions of ammonia (NH_3), and 70% of the methane emissions (3). From a life-cycle perspective, feedstock production also contributes a significant share of the overall impacts of bioenergy chains (13). Because the use and fate of cultivation inputs, along with biomass production yields vary widely depending on soil and climate conditions, the overall performance of bioenergy chains are higly dependent on the corresponding data and hypotheses (9). For instance, the the selection of emission factor used to convert fertilizer N inputs to nitrous oxide (N_2O) emissions was shown to alter the GHG savings by up to 41% for rapeseed methyl ester (7). An accurate description of the agricultural production system is therefore a major priority, taking national and regional characteristics into account (21; 10).

This paper reports results obtained in the course of the ECOBIOM research project, funded under the French national program of research on bioenergy (PNRB), which aims at developing generic tools to identify economically-viable and sustainable pathways to supply bioenergy units.

The originality of this study lied in its taking into account a range of possible lignocellulosic resources (from agriculture and forestry) in the distribution of the biomass supply at county[1] scale. An estimation of the most advantageous resources on a local scale will help optimize the location of a particular bioenergy production unit.

Here, we assessed the environmental impacts of a set of energy crops using the life cycle assessment methodology (LCA), which has been widely used in the field of energy and agricultural production (23), as a first step in the evaluation of feedstock supply scenarios. LCA quantifies the environmental impacts resulting from the provision of a particular good or service by a product system (12), and expresses them relative to a unit measure reflecting the usefulness of this system (the 'functional unit'). Its principle may be summarized by the 'cradle to grave' approach, according to which all flows of matter and energy into and out of the product system are inventoried. In the case of energy crop cultivation, the system extends from the supply of agricultural inputs (seeds, fertilizers, farm machinery, fuels,...) to the harvest and handling of biomass. Direct emissions related to the biogeochemical transformations of inputs (especially fertilizer N) in the field should also be considered.
Here, we used the framework, calculation methods and databases provided by the BioFit project (21), supplemented with more recent information sources and crop management data collected specifically for the purpose of this study. The following candidate species were analysed: wheat (whole crop), sugar beet (as a reference arable crop and 1st generation ethanol feedstock), miscanthus, triticale, sorghum, poplar tree in short-rotation coppice (SRC), along with two co-products (wheat straw and forest residues). The species selected were deemed suitable for biomass production under the prevailing climate and soil conditions of the region of interest, Champagne-Ardenne (Northeastern France). Its climate is temperate and mild, with marine influence. The analysis was carried out at two geographical levels: the whole region and sub-regional agro-ecological zones (SAZ) within that region, ie zones that were delineated as homogenous from the point of view of agronomic and pedoclimatic conditions. The regional and SAZ-scale data were obtained from census and survey data, together with expert knowledge provided by regional extension services.

2 Materials and methods

LCA comprises the following steps (12), which are detailed below:

- Goal and scope definition
- Inventory analysis
- Impact assessment
- Interpretation

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[1] Administrative entity ('canton'), covering from 10 to 200 km^2 in area.

2.1 Goal and scope definition

This first step states the objectives and target group of the LCA, and accordingly lays out the major assumptions necessary to carry out the LCA: the functional unit of the system considered, its boundaries (geographical and temporal), the targeted impact categories and the methodology used to characterize them.
Here, the goal of the LCA was to evaluate the environmental performance of a range of energy crop species potentially available in the Champagne Ardenne region. We focused on the production of biomass, and transport to farm gate (for arable feedstocks) or edge of road (for forest feedstocks), regardless of the conversion chain downstream. The functional unit (FU) expresses the performance of a system and serves as a reference unit for environmental impacts. Here, the main function of our system was the provision of lignocellulosic biomass for use in a generic bioenergy chain, so we selected 'one MJ of lower heating value (LHV)' for the biomass. Since the yields per unit area varied across species, we also retained 'one hectare' of area dedicated to energy crops as FU. The latter is relevant to characterize the impacts incurred by a bioenergy unit at the supply area level. It is also a convenient unit to collect and present management data in the inventory phase.
The system considered included the production and supply of agricultural inputs (seeds, fertilizers, farm machinery, fuels), and all management operations from seed bed preparation to harvest, handling and transport of biomass to farm gate or edge of road (for forest products). In the case of co-products (wheat straw and forest residues), only the technical operations specific to their collection and handling were considered. For wheat straw, the consequences on soil carbon (C) and nutrient depletion were also taken into account (the latter being compensated for by synthetic fertilizers application). Wheat straw was assumed to be baled and transported to an on-farm storage site by tractor. The tree residues corresponded to fine branches obtained as a co-product of a final cutting of deciduous trees, and were transported to the edge of the road for collection by trucks. They were crushed on-site to produce wood chips.
Emissions resulting from the application of inputs to the cultivation field were calculated assuming they occured up to one year after application (ie in particular during the winter drainage period following the harvest of annual crops for nitrate leaching). The timeframe was extended to sixteen consecutive years for miscanthus (perennial), and 30 years for poplar SRC (ie a total of 3 cuttings). Emissions were subsequently averaged over these growing cycles on a yearly basis.

2.2 Inventory analysis

This step inventories all inputs to and outputs occuring at the various steps of the product system, quantifies and expresses them relative to the various functional units selected. As far as the emissions (outputs) were concerned, emissions are termed either direct (occuring in the cultivated field) or indirect (upstream or downstream of field). Direct emissions are a result of biogeochemical transformations and transport of inputs, and include nitrate leaching, gaseous N emissions (as N_2O, NH_3 or NO), or soil-atmosphere CO_2 exchanges.
Direct emissions of N compounds were expressed as a fixed fraction of fertilizer N inputs (Nf), following the 'emission factor' approach (25). We used generic values obtained at country- to

Table 1: Emission factors used to calculate N losses. They are expressed as a fraction of fertilizer N (Nf) inputs.

Compound —	Emission factors kg N kg^{-1} N input	Reference
N_2O	0.0133 (fertilizer inputs)	(22; 16)
	0.01 (residue N inputs)	(16)
NO	0.01 (winter crops)	(19)
	0.02 (spring crops)	(19)
NH_3	0.03	(6)
NO_3^-	0.30	(16)

global-scale, which are listed in Table 2 together with the literature references from which they were extracted.

Agricultural management and yield data were obtained from surveys carried out by regional extension services for species that are currently grown within the area (wheat, sugar beet), even if marginal (triticale, sorghum, poplar-SRC)[2]. Data for miscanthus, which was only grown in experimental stations at the time of study, was obtained from a detailed field trial in the neighbouring Picardie region (S. Cadoux, INRA Laon/Mons, pers. comm.), and adapted to SAZ level based on a network of local trials. The data on forest residues were taken from a study under average forest management conditions in France (1). Missing data were completed with a variey of literature sources for France or European conditions (21; 2; 18; 4). For some species/feedstocks (straw, tree thinnings, poplar-SRC), it was thus impossible to disaggregate at sub-regional level due to a lack of adequate data. The sub-regional agro-ecological zones were obtained by merging several small agricultural areas, administrative units delineated by French authorities as relatively homogeneous zones from the point of view of physical characteristics (climate, pedogenesis and geological substrate), and agricultural production systems. These areas were merged to form wider agro-ecological zones according to their predominant soil type, considered as the major driver of spatial differences (Figure 1).

2.3 Impact assessment

The inventory analysis involves a large variety of compounds (e.g., the greenhouse gases -GHG - CO_2, CH_4, and N_2O), whose emissions are subsequently aggregated into a pre-defined set of impact categories relevant to particular environmental issues. For example, the emissions of GHG may be added by weighing them with their global warming potentials (GWP) relative to CO_2, deduced from the increase in the Earth's surface temperature caused by their accumulation in the atmosphere. Carbon dioxide is the 'reference substance' for the global warming impact category. Other impact categories were considered: primary energy consumption, eutrophication

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[2] Source: M.-L. Savouré (GIE ARVALIS / ONIDOL), document de travail interne ECOBIOM; (4) et A. Bouthier (FCBA) pour peuplier TCR.

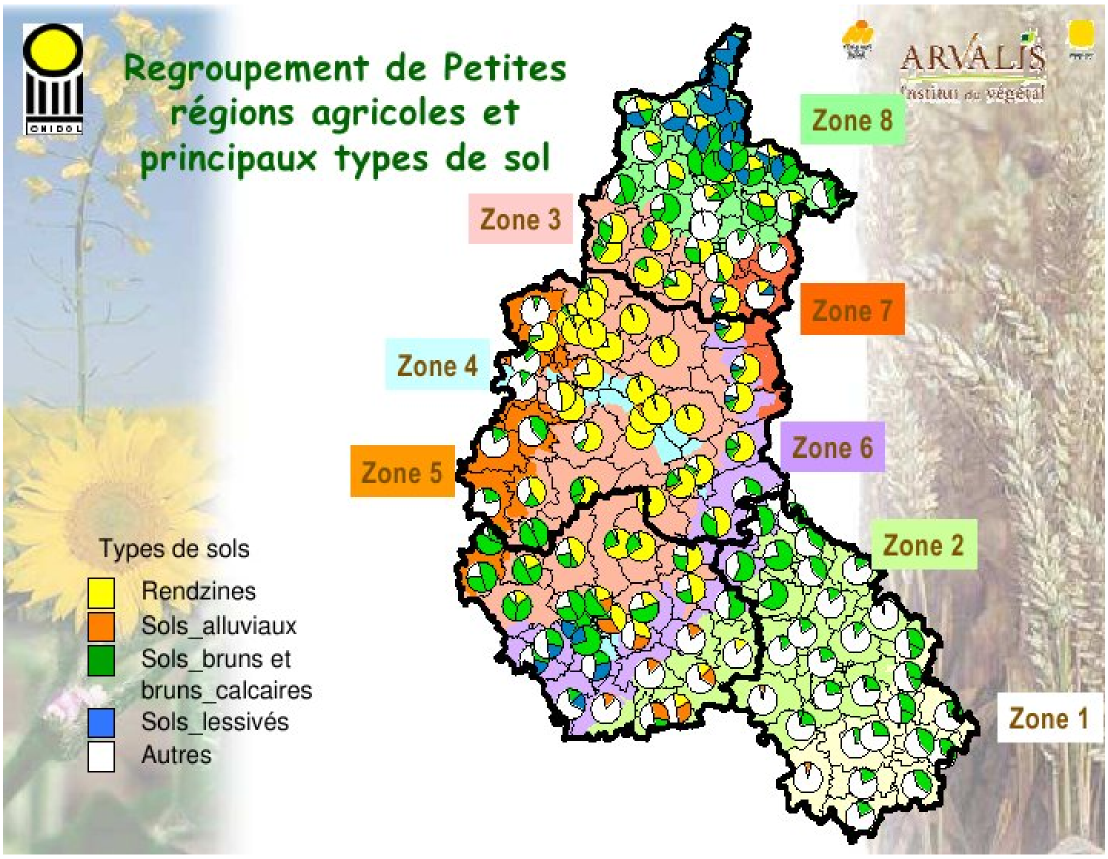
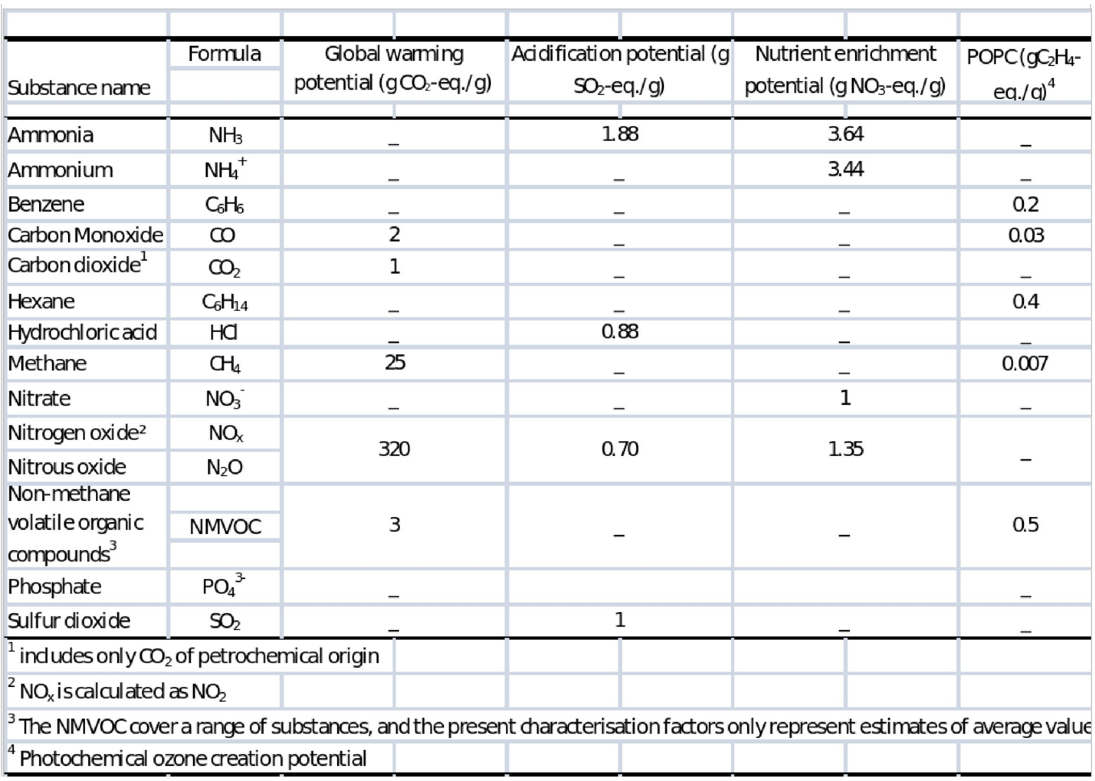


Figure 1: Map of the Champagne-Ardenne region showing the sub-regional agro-ecological zones (SAZ) used in the analysis. The pie charts show the proportion of soil types at county scale (source: GIE ARVALIS / ONIDOL).



Substance name	Formula	Global warming potential (g CO_2-eq./g)	Acidification potential (g SO_2-eq./g)	Nutrient enrichment potential (g NO_3-eq./g)	POPC (gC_2H_4-eq./g)[4]
Ammonia	NH_3	_	1.88	3.64	_
Ammonium	NH_4^+	_	_	3.44	_
Benzene	C_6H_6	_	_	_	0.2
Carbon Monoxide	CO	2	_	_	0.03
Carbon dioxide[1]	CO_2	1	_	_	_
Hexane	C_6H_{14}	_	_	_	0.4
Hydrochloric acid	HCl	_	0.88	_	_
Methane	CH_4	25	_	_	0.007
Nitrate	NO_3^-	_	_	1	_
Nitrogen oxide[2]	NO_x	320	0.70	1.35	_
Nitrous oxide	N_2O				
Non-methane volatile organic compounds[3]	NMVOC	3	_	_	0.5
Phosphate	PO_4^{3-}	_			_
Sulfur dioxide	SO_2	_	1	_	_

[1] includes only CO_2 of petrochemical origin

[2] NO_x is calculated as NO_2

[3] The NMVOC cover a range of substances, and the present characterisation factors only represent estimates of average value

[4] Photochemical ozone creation potential

Table 2: Characterisation factors for impact categories included in the LCA (21).

of ecosystems, acidification, depletion of stratospheric ozone, and photochemical ozone potential. The reference substances, relevant compounds and aggregation factor for those categorie are listed in Table 2. We excluded the impact categories related to human toxicity and ecotoxicity for lack of data on the types of pesticides used (essentially for food crops like wheat and sugar beet) and on their environmental fate in the Champagne-Ardenne region. Also, water use was not included because this resource is not considered scarce in this region. We used the GWPs given by the Intergovernmental Panel on Climate Change (15) to expresses their climate forcing relative to CO_2, and considered the 100 years time horizon. Only fossil sources were considered in the CO_2 emissions, ie CO_2 resulting from biomass burning was discounted. The aggregation coefficients were all taken from (21).

3 Results & discussion

3.1 Feedstock comparison at regional scale

A first series of LCA results was generated using the region-wide management data elaborated for all feedstocks in Champagne-Ardenne. When using one hectare of land as functional unit (Figure 2), the food crops (wheat and sugar-beet) had the highest impacts due to their requirements in agricultural inputs. Next came the annual species (triciale and sorghum), the perennial

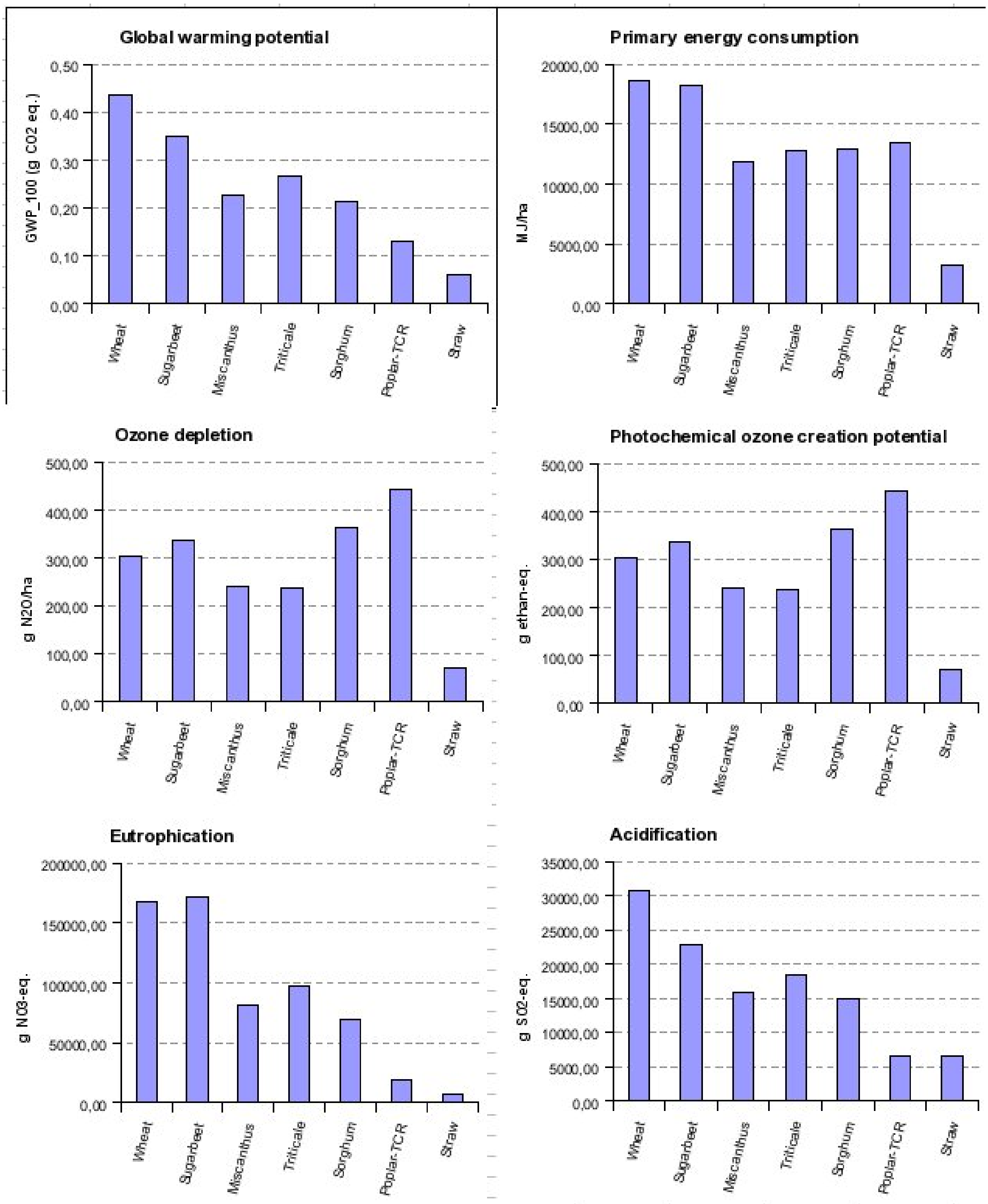


Figure 2: Environmental impacts of the various energy crops in Champagne-Ardenne, using regional-scale data, per ha of land. The following impact categories are depicted: primary energy consumption, global warming, acidification, eutrophication, photo-chemical ozone pollution, and stratospheric ozone deletion.

ones (miscanthus, poplar-SRC) and the co-products (straw and thinnings). Overall, the LCA indicators spanned an order of magnitude between the higest- and lowest-emitting feedstocks, which is rather large.

Among the various cultivation steps, fertilization (especially in N form) contributed most of the overall emissions of the various feedstocks, as exemplified for miscantus on Figure 3. The relative share of fertilizers was higher for the crops with high input rates, such as wheat and sugar-beet and to some extent sorghum and triticale. Conversely, co-products carried only little of that load, conversely, even though the nutrient they exported had to be compensated for by synthetic fertilizer inputs.

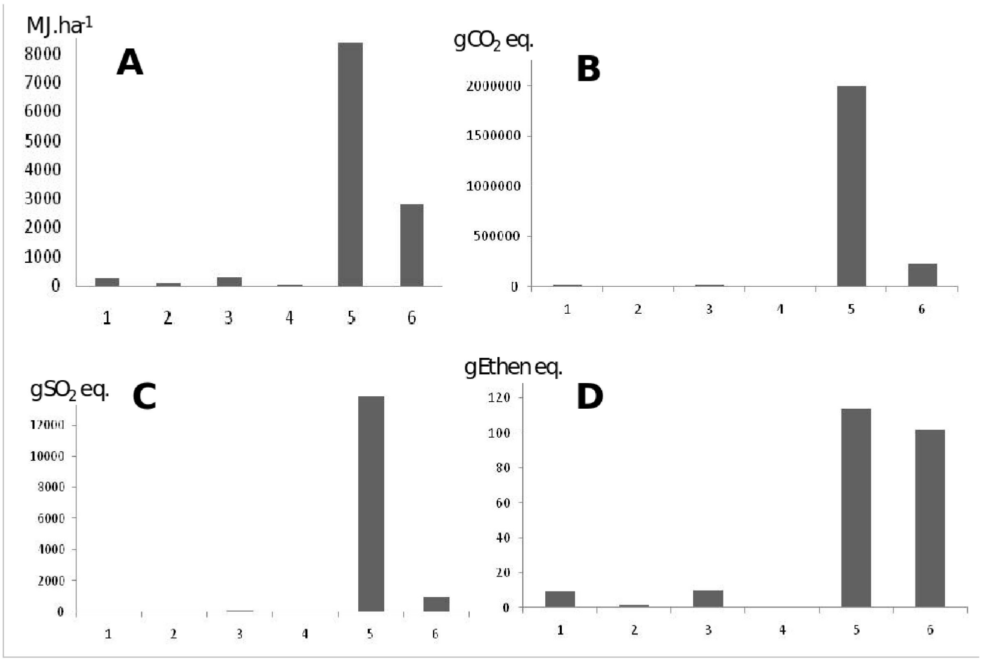


Figure 3: Breakdown of the various impacts of the agricultural process of miscanthus production across the various steps of the agricultural process (averaged over the 16 years of the growing cycle): primary energy consumption (A - in MJ ha^{-1}); GHG emissions (B - in g CO_2eq $^{-1}$); acidification (C - g SO_2 eq $^{-1}$); Photochemical ozone creation potential (D, g Ethen-eq $^{-1}$). 1: Rhizome production; 2: field preparation; 3: planting; 4: pest management; 5: fertilizer; 6: harvest.

When using one MJ of biomass energy content, the general patterns across species were relatively similar to those obtained with the area basis (Figure 4), except for the straw co-product, which ranked only average at best among all the species. This was due to the relatively low biomass yield per ha (3.5 t DM/ha) compared to the other feedstocks (in the 10-20 t DM/ha range). The hypothesis that all the N contained in the straw should have been compensated for by addition of mineral fertilizer N probably artificially increased the load on the straw. This assumption is consistent with previous LCA studies on straw, but there is agronomic evidence that only a fraction of the straw N is available for plant uptake, even in the long-run (10). The other co-product (wood chips from tree thinnings) performed better than straw for 3 of the 4 indicators available for comparison, being unaffected by its nutrient content (which is much lower anyhow). Overall, the spread of the LCA indicators was narrower across feedstock types, and their grouping/ranking varied across indicators. Excluding co-products, poplar SRC performed consistently better than the others, except for primary energy consumption and photochemical ozone formation due to more intensive harvesting operations. Miscanthus followed a similar pattern, albeit to a lesser extent, which confirms the benefits associated with perennial species. Among the annual crops, wheat stood out, as could be expected from the indicators per ha. Sugar beet performed comparatively fairly well, thanks to its higher energy value for ethanol production, but it may be considered somewhat artificial[3]. Lastly, triticale scored less favourably than sorghum, due to the lower input requirements of the latter.

3.2 Sub-regional variations

The disaggregation from regional to SAZ-scale was done by differentiating crop yields and fertilizer N rate, the other management operations being unchanged. This was justified by the predominant weight of N rates on the overall emissions, as underlined in the previous paragraph (and Figure 3). The data at SAZ-level are presented on Table 3.

We selected 3 SAZ (number 3 to 5) with contrasted values for the yields of miscanthus and sorghum, which varied by a factor of 2 across the 3 zones, while the yields of the reference arable crops (wheat and sugar beet) were fairly stable. As noted earlier, some of the feedstocks were not included in this analysis for lack of sub-regional data (poplar-SRC) or sources of variation (for the co-products). When expressed relative to one MJ of biomass energy content, the performance of the various feedstocks was stable for some species (sugar beet, wheat), and significantly variable for others (miscanthus, sorghum) across the 3 zones (Figure 5). This pattern mostly mirrors the above-mentioned patterns in yield variability, implying that biomass productivity has a predominant influence over fertilizer rates. As a result, the ranking of the crops varied markedly across SAZs, and did not always match the regional baseline. The gap between whole-plant wheat and the lignocellulosic crops was much narrower in the three SAZs compared to this baseline. This was particular true for sorghum, whose impacts were only 10 to 20% lower than wheat, compared to a 80% for the GHG emissions at regional level. Sorghum yields were indeed rather low (in the 6-14 t DM ha^{-1} range) compared to other studies under similar climatic conditions (2) from which were the regional baseline was derived. Since the SAZ data were based on local trials, they may be considered more realistic as the regional values. Overall, the analysis at SAZ level emphasizes that biomass supply chains and areas should accomodate the differences in potentials across agro-ecological zones and make the best of their potentials to produce biomass feedstocks at minimal environmental costs.

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[3] The LHV value for sugar-beet was obtained by assigning the energy value of ethanol to the sugar fraction, and a generic LHV value for plant lignocellulosic material to the pulp.

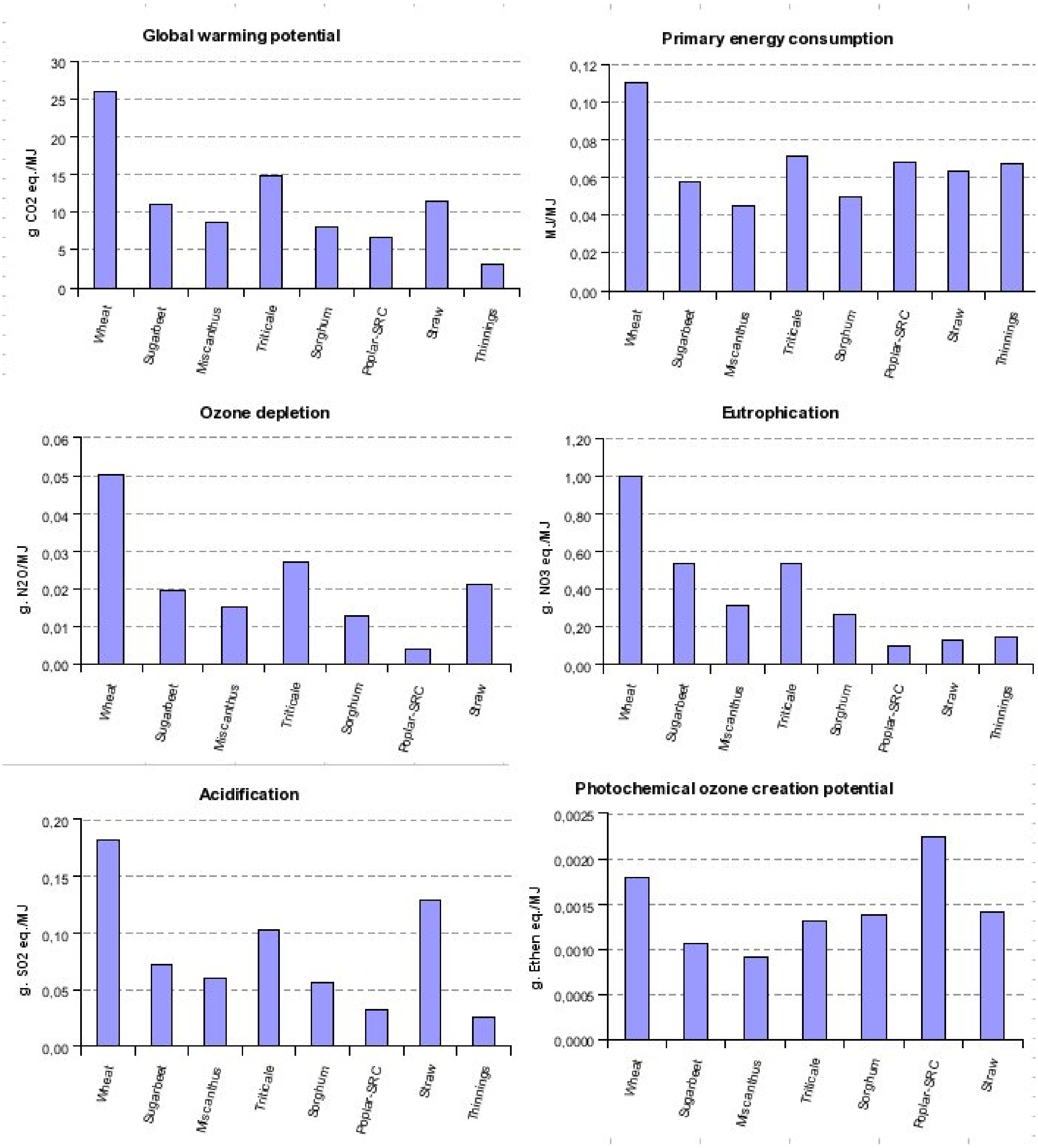

Figure 4: Environmental impacts of the various energy crops in Champagne-Ardenne, using regional averages, per MJ of biomass heating value. The following impact categories are depicted: primary energy consumption, global warming, acidification, eutrophication, photochemical ozone pollution, and stratospheric ozone deletion. Whean available, LCA indicators for wood chips from tree thinnings from another study (1) were also included.

Table 3: Crop yield and management data at the SAZ level (source: GIE ARVALIS / ONIDOL).

Zone number	1	2	3	4	5	6	7
Wheat							
- yield (t grains/ha)	6.5	7.0	8.5	9.0	8.0	7.4	7.2
- N rate (kg N/ha)	160	180	220	180	200	200	180
- P/K rates (kg/ha)	75 / 42	78 / 61	86 / 83	86 / 83	78 / 86	79 / 57	85 / 47
Sugar beet							
- yield (t fresh tubers/ha)			90	90	80		
- N rate (kg N/ha)			130	130	100		
- P/K rates (kg/ha)			117 / 293	117 / 293	104 / 260		
Triticale							
- yield (t DM/ha)	10.0	12.5	15.0	16.0	15.0	14.0	14.0
- N rate (kg N/ha)	120	120	150	150	150	140	140
- P/K rates (kg/ha)	72 / 104	90 / 131	108 / 156	114 / 166	108 / 156	100 / 146	100 / 146
Miscanthus (winter harvest)							
- yield^a (t DM/ha)	8.1	8.1	8.1	16.3	14.6	12.2	9.8
- N rate^a (kg N/ha)	60	60	60	80	80	80	80
- P/K rates^a (kg/ha)	10 / 30	10 / 30	10 / 30	15 / 60	15 / 55	10 / 45	10 / 35
Sorghum							
- yield (t DM/ha)		8.0	6.0	14.0	12.0	8,0	8.0
- N rate (kg N/ha)		80	60	140	120	80	80
- P/K rates (kg/ha)		60 / 60	60 / 60	60 / 60	60 / 60	60 / 60	60 / 60

a: the yields are averaged over the 16-yr growing cycle, while fertilizers are applied annually after the first year.

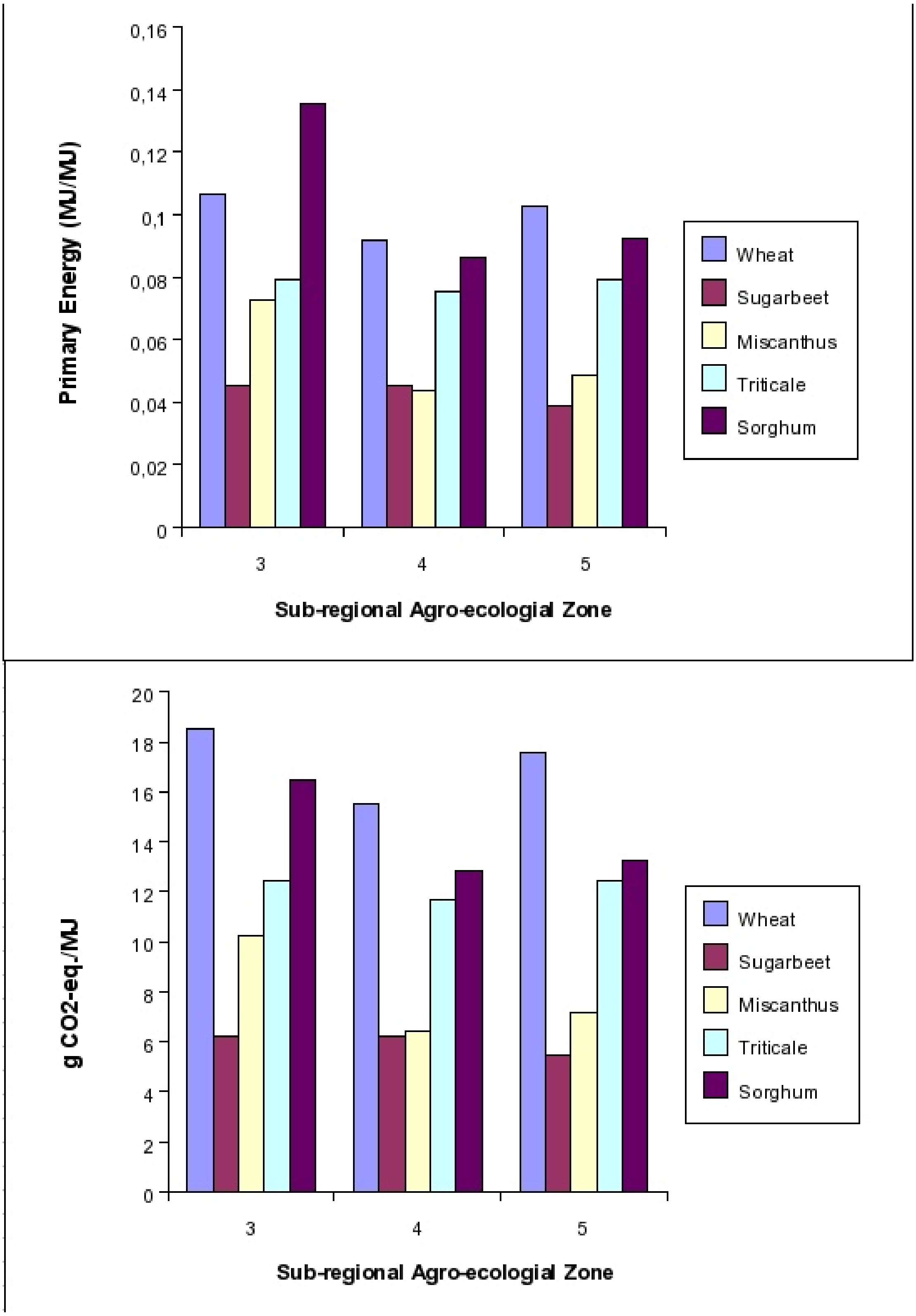

Figure 5: Compared life-cycle primary energy consumption and GHG emissions for the various energy crops in three sub-regional agro-ecological zones (SAZ) of Champagne-Ardenne (see Table 3 for a summary of SAZ's characteristics). The functional unit is the energy content of the biomass (1 MJ).

4 Conclusion

Our study intended to provide decision maker with assessment tools utilizable at a local (or subregional) scale, i.e. a much finer resolution than currently-available analyses whose scale extends from region to continent (8; 21; 14). A major advantage of our approach is that it makes it possible to relate crop production potentials (depending on pedoclimatic conditions prevailing in the SAZs) to management data, therefore implying a high consistency between agricultural inputs and biomass yields. This is paramount to achieving a realistic assessment of the performance of the feedstock production phase (20).
However, the major driver between yield variations is soil type, which we had originally purposed to use as the main variable on the basis of which management and environmental emissions should be spatially differentiated. SARs were actually made up of a mixture of soil types. In that respect, it could have been possible to overlay the SAZs and the Champagne Ardenne soil map to obtain elementary polygons with homogeneous yield potentials and better reflect the subregional variability in soil-related potentials. Factors other than soil type should also have been considered: for instance, water-table depth is a critical for poplars. The slope and distance to the road network is also of prime importance for the harvest operations of tree thinnings. Moreover, the study could be improved by a better modeling of nitrate and phosphorus losses. Indeed we used average coefficient independent of the soil and climate, and which were meant to represent the exchanges of nitrate on the whole field. As this criterion has a relatively important influence on the impact assessment, we could take it into account more precisely. a biophysical ecosystem model such as CERES-EGC could be used to provides a finer estimation of these fluxes (11). Another point is that for dedicated lignocellulosic crops such as miscanthus, it is still not clear what the optimal N fertilizer practices would be, even for wintertime harvest. There might be scope for reducing fertilizer N rates, and the associated impacts.

Although LCA aims at an accurate and comprehensive assessment, it does not routinely account for more qualitative impacts such as biodiversity and landscape. It is generally accepted that perennial species rank higher than annuals in terms of biodiversity (24), while the trend is reversed for landscape impacts because of stands' height and density. In a near future, the LCA data may be input to an integrated economic and environmental biomass supply model under development to explore bioenergy options in Champagne-Ardenne. The final goal is to determine an optimal localization of a bioenergy conversion unit considering both socio-economic and environmental criteria.

References

[1] ADEME and BioIS. Bilan environnemental du chauffage collectif (avec reseau de chaleur) et industriel au bois. Technical report, ADEME, Angers, 2005.

[2] ADEME and Arvalis-Institut du végétal. Etude agrice sur les cultures énergétiques. Fiches techniques, ADEME, Paris, 1998.

[3] CITEPA. Inventaire des emissions de polluants atmosphériques en france. Séries sectorielles et analyses etendues, Centre Interprofessionnel Technique dÉtudes de la Pollution Atmospherique, Paris, 2008.

[4] B. Deschamps. Analyse de cycle de vie des taillis à courte rotation. Rapport de stage - génie des procédés, Université Technologique de Compiègne, 2008.

[5] Simon D. Donner and Christopher J. Kucharik. Corn-based ethanol production compromises goal of reducing nitrogen export by the mississippi river. *Proceedings of the National Academy of Sciences*, pages 0708300105+, March 2008.

[6] ECETOC. Ammonia emissions to air in Western Europe. *Tech. Report no. 62, Brussels.*, 1994.

[7] Ecobilan. Bilans énergétiques et gaz à effet de serre des filières de production de biocarburants. Rapport pour le compte de l'ADEME et de la DIREM, ADEME, Paris, 2002.

[8] R. Edwards, J.-F. Larivé, V. Mahieu, and P. Rouveirolles. Well-to-wheel analysis of future automotive fuels and powertrains in the European context ispra, 2006. Well to wheels report, EUCAR, CONCAWE, JRC, Ispra, March 2007.

[9] A. E. Farrell, R. J. Plevin, B. T. Turner, A. D. Jones, M. O'Hare, and D. M. Kammen. Ethanol can contributo to energy and environmental goals. *Science*, 311:506–508, 2006.

[10] B. Gabrielle and N. Gagnaire. Life-cycle assessment of straw use in bio-ethanol production: a case-study based on deterministic modelling. *Biomass and Bioenergy*, 32:431–441, 2008.

[11] B. Gabrielle and L. Kengni. Analysis and field-evaluation of the CERES models' soil components: Nitrogen transfer and transformation. *Soil Sci. Soc. Am. J. 60:142-149*, 1996.

[12] M. Gorrée, R. Heijungs, G. Huppes, R. Kleijn, A. de Koning, L. van Oers, A. W. Sleeswijk, S. Suh, H. A. Udo de Haes, H. de Bruijn, R. van Duin, and M. A. J. Huijbregts. *Handbook of life-cycle assessment. Operational guide to ISO standards*. Kluwer Academic Publisher, 2002.

[13] J. Hill. Environmental costs and benefits of transportation biofuel production from food- and lignocellulose-based energy crops. A review. *Agron. Sustain. Dev.*, 27:1–12, 2007.

[14] J. Hill, E. Nelson, D. Tilman, S. Polasky, and D. Tiffany. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. *PNAS*, 103:11206–11210, 2006.

[15] IPCC. *Revised IPCC [Intergovernmental Panel on Climate Change] Guidelines for National Greenhouse Gas Inventories*. Bracknell, UK, 1996.

[16] IPCC. *Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme*. Eggleston, 2006.

[17] M. Z. Jacobson. Effects of ethanol (E85) versus gasoline vehicles on cancer and mortality in the United States. *Environ. Sci. Technol.*, 3, 2007.

[18] T. Kägi and T. Nemecek. Life cycle inventories of agricultural production systems. ecoinvent Report 15, Agroscope Reckenholz - Tänikon Research Station ART, Switzerland, 2007.

[19] P. Laville, C. Hénault, **B. Gabrielle**, and D. Serça. Measurement and modelling of no fluxes on maize and wheat crops during their growing seasons: effect of crop management. 72:159 – 171, 2005.

[20] T. Nemecek, J.-S. von Richthofen, G. Dubois, P. Casta, R. Charles, and H. Pahl. Environmental impacts of introducing grain legumes into European crop rotations. *Europ. J. Agronomy*, 28:380–393, 2008.

[21] G. Reinhardt. Bio-energy for Europe. Which ones fit best? Final report EC contract CT98-3832, IFEU, Heidelberg, Germany, 2000.

[22] E. Stehfest and L. Bouwman. N2o and no emission from agricultural vegetation: summarizing available of global annual emissions. *Nutrient Cycling in Agroecosystems*, 74:207–228, 2006.

[23] H. van der Werf and M. Petit. Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. *Agriculture, Ecosystems and Environment*, 93:131–145, 2002.

[24] T. Wiesenthal, A. Mourelatou, J.-E. Petersen, and P. Taylor. How much bioenergy can europe produce without harming the environment? EEA Report 7, European Environment Agency, 2006.

[25] X. Zheng, S. Han, Y. Huang, Y. Wang, and M. Wang. Re-quantifying the emission factors based on field measurements and estimating the direct N_2O emission from Chinese croplands. 18(GB2018), 2004.