SCORE LCA

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INTEREST AND IMPLEMENTATION OF A COUPLING GIS AND LCA

Scientific Summary

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SCORE**LCA** is an association that has been created to financially support collaborative research on LCA and related topics. It aims to promote and organize cooperation between companies, institutional and scientists in order to support the evolution of LCA methods and its practical implementation at European and international level.

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Introduction

The experts in Life Cycle Assessment (LCA) have turned towards a regionalisation of impacts in the years 2000 that was intensified in the last years thanks to the use of Geographical Information Systems (GIS). However, the studies coupling GIS and LCA are still in the research field. The goal of this study is to establish the state of the art, define the feasibility and propose recommendations for implementation of a coupling between LCA and GIS. The conclusions related to the interest of this coupling depending on the context of the study and its implementation are summarised and discussed hereafter.

Interest and application context of GIS for LCA

➢ *State of the art*

In literature, GIS have been used to refine both the geographical representativeness of the life cycle inventory and the impact assessment methods. The studies taking into account GIS data for the life cycle inventory date from the year 2010. One of the major observed applications of GIS is supporting a territorial strategy. In this case, the functional unit considers the activities of a city (e.g. the city of Sheffield in Azapagic et al, 2013), of a region (e.g. Bassin de Thau in Loiseau et al, 2014) or even a country (e.g. USA in Geyer et al, 2013). GIS allows to collect a great amount of data available for the studied territory (via databases or provided by competent authorities) and to visualise results as maps.

In the reviewed study, the main sectors having implemented a coupling LCA-GIS are agriculture, transportations and logistic, infrastructures and energy. These sectors are indeed sensitive to parameters with a significant geographical variability. In agriculture, layers of forest types or crops of a territory, agronomic data (terrain orientation, land use, etc.) or climatologic (e.g. rain, temperatures) can feed the inventory (e.g. Ooba et al, 2015; Gasol et al, 2011). In the transportation sector, the calculation of distances based on GIS layers of transportation networks can facilitate data collection and simulation of logistic scenarios (e.g. Newell et al, 2011; Nahlik et al, 2015). Building or material stock maps can be used to generate impact results in the sector of infrastructures Nichols & Kockelman, 2014 ; Eufrasio Espinosa & Stevenson, 2013). Finally, regarding energy, GIS has been used for the production of energy from biomass (agriculture sector related data), for network modelling (distance calculation) or to solve spatial optimization problems of energy supply (Delivand et al, 2015; Saner et al, 2014).

The spatialization of impact characterization can be important for categories sensitive to spatial variability. In particular, GIS allowed for modelling the acidification potential depending on deposition and soil sensitivity models (Huijbregts et al, 2001; Roy et al, 2014). Eutrophication potential depends on geography-specific parameter such as water courses or sediments cycles (Huijbregts et al, 2001 ; Helmes et al, 2012). In recent times, effort has been put to spatialize toxic impacts (Sala et al, 2011 ; Kounina et al, 2014). In fact, characterization factors depending on the external environment (e.g. precipitation rates, geometry of environmental compartments, population density) influence the behaviour of polluting substances and the exposition to them. GIS applications for the impact assessment of land use are numerous in literature (de Baan et al, 2013 ; Cao et al, 2015 ; Núñez et al, 2013). This is due to the sensitivity of these methods to local specific data, such as soil characteristics (usage type, embodied carbon, etc.). The characterization of water resources extraction is also object of numerous publications (Pfister et al, 2009 ; Boulay et al, 2011 ; Van Zelm et al, 2011) using GIS data such as precipitation rates and hydrologic data. Cucurachi & Heijungs (2014) studied the local aspect of noise-related impacts, very sensitive to geography (e.g. topographic elements, population density). Finally, the method IMPACT World+^{TM}, currently under development, has the goal to regionalize impact characterization related to respiratory effects, human toxicity, acidification, eutrophication, ionizing radiation, water use and land use.

- *Case studies*

The two case studies were selected in relation to the relevance of GIS for the considered sector and impact categories.

The first case study concerns the life cycle of automotive fuel, including the production, transportation, refinement, stocking and combustion. To model the inventory, it is interesting to use GIS to calculate distances between the different life cycle sites, follow the car journey and adapt emission depending on the road type and temperature. Impacts related to the hydric stress and to toxicity are also regionalised.

The objective of the second case study is the evaluation of the environmental impact of residential buildings at scale of the city of Rotterdam (Netherlands) and its reduction potential depending on refurbishment measures. In this case, the relevance of coupling GIS-LCA is great due to the territorial aspect of the study. In addition, city authorities made available numerous data useful for modelling the inventory (e.g. elevation, building footprints, addresses).

- *Recommendations*

The degree of relevance of a LCA-GIS coupling was evaluated according to the objectives and scope of the study, particularly the type of application , the decision context, the target audience, the sector of the studied system, the functional unit, the quality criteria of data and the environmental impacts considered.

Concerning the type of application, the most appropriate use is to support political strategic development (decision context of type B). Indeed, the vast scope and scale of the results requires high quality representation and sometimes geographical resolution of results. In the case of an optimization, the LCA-GIS coupling is essential to make the two tools interact reciprocally. LCA-GIS coupling may also be relevant for decision support, even at a smaller scale, e.g. eco-design, product comparison (decision context of type A). In this case, GIS can avoid biased conclusions due to poor geographical representation (Mutel et al, 2012). The interest of a coupling can also be high to prepare a report of large-scale impacts (balances for a country, a product category, etc.) or for model development (inventory database or calculation of environmental impact). Finally, the interest is lower for LCA applications that are simple from the methodological point of view (p. ex. performance report, environmental declaration).

Regarding the audience, there is no direct link with the use of GIS. However, visualization of results as maps may have greater utility when the target audience is a wide public, not specialized in LCA (more easily understandable and greater impact).

As observed in the state of the art, the use of GIS for inventory data is relevant to the territorial LCA, but also to sectors of high geographic sensitivity, such as agriculture, transport and logistics, infrastructures and energy. Indeed, GIS can facilitate the collection (e.g. map of the buildings of a city, location of production sites, soil types) and allow the calculation of inventory data (e.g. distances, floor surface area, etc.).

The definition of the functional unit (FU) may include geographical features (e.g. energy supply of a municipality, delivery of paper in Los Angeles) that increase the interest of GIS to visualize results for the geographical context of the FU.

After identifying the boundaries of the system and therefore the different flows, the LCA practitioner must specify data quality criteria, sometimes requiring a certain geographical resolution (e.g. by building, by crop field). In this case, a LCA-SIG coupling is required. The relevance of the coupling is high for specific data sensitive to geographic variability (e.g. population density, temperature, distance of transportation).

Finally, regarding the choice of the impacts considered, toxicity (human and ecotoxicity) and the impact of noise are very sensitive to the geographic variability. Other categories also have an accentuated regional aspect: eutrophication, acidification, particle pollution, ionizing radiation, photochemical ozone creation and use of natural resources (land and water). The impacts on climate change, ozone depletion or fossil and mineral resources have a more global scope and do not require a geographic refination. When we aggregate impacts on endpoints, effects on human health and ecosystems depend on regional parameters. The resolution level of characterization factors is still a matter of debate in the LCA community (see paragraph 2.2.4). For now, we recommend the use of GIS only based on the regional nature of the category taken into account.

The degree of relevance of a LCA-GIS coupling according to the objectives and scope of the study is evaluated in Table 1.

Table 1: Interest of LCA-GIS coupling according to the objectives and scope of the study

Interest coupling GIS	**Low**		**High**
Target application	Performance indicator, ecolabel criteria, environmental declaration	Ecodesign, comparison, supply chain greening, policy information, model development	Policy development, optimization
Decision context according to ILCD	C	A	B
Target audience	Others		External, non technical
Target sector	Others	Agriculture, transports, infrastructures, énergie	ACV territoriale
FU definition	Without geographic specification		With geographic specification
Quality data criteria	Others	Specific data, sensitive to geographic variability	Data with spatial resolution
Environmental impact	Climate change, ozone depletion, mineral and fossil resources	Eutrophication, acidification, particulates, ionizing radiation, photoch. ozone, water use, land use	Toxicity, noise

Implementation of LCA-GIS coupling

- *State-of-the-art*

Coupling indicates in computer sciences the interaction level between various software components regarding their information exchange. According to Pressman (1992), seven different levels of coupling exist, from no coupling (no information exchange between software), through weak coupling (limited amount of information exchanged) to strong coupling (interaction between tools with a large amount of exchanged information). In LCA literature, several authors used different degrees of interaction between tools, however, describing rarely the coupling details.

The simplest coupling consists in using spatialized data as inputs, storing them in spatialized database and visualizing data and results via maps (Ooba et al., 2015 ; Geyer et al., 2013). A more advanced level includes the use of GIS to treat automatically spatialized data in order to generate new inventory data (Dresen and Jandewerth, 2012 ; Newell et al., 2011). Some studies apply a weak coupling between software tools. In this case, results from GIS data treatment are used as inputs for inventory without a complete interaction automation. Some authors automatized the GIS data entry in LCA software until a strong coupling where the tools communicate with a feedback. One of the most advanced application for GIS and LCA consists in solving spatial optimization problems (Delivand et al., 2015 ; Saner et al., 2014).

Concerning the generation of spatialized characterization factors (CFs), some works only used some GIS data or models to differentiate the CFs by region or archetype (results in table form). Here, the practitioner can adapt the impact evaluation method in LCA software (modification of CF values) according to the geography context of the studied system for LCA calculation. Other authors followed a more advanced approach by proposing georeferenced CFs (which can be visualized in GIS software). This latter approach allows a better resolution and coupling with georeferenced inventory data (via GIS treatment, as layers superposition).

Finally, studies integrating GIS models both for inventory and impact characterization are rare in LCA literature. Indeed, some studies spatialize inventory data but calculate a global impact which does not need to be spatialized, such as climate change potential. Moreover, the articles developing georeferenced CFs are relatively recent (in general for the last four years). Some publication performed nevertheless this exercise, in particular for the agriculture sector (Pfister et al, 2011 ; Rodriguez et al, 2014).

To end this state-of-the-art, we studied the coupling possibilities given by software and databases. LCA softwares do not provide GIS treatment functions, except OpenLCA and Brightway2. These latter are open-source, the source code can be modified to add for example functionalities linked to LCA spatialization. OpenLCA can add geographic coordinates to a process and visualize region contribution to final score on a map. Brightway2 has a plugin to spatialize inventory and characterization factors, and to export contribution maps. Among LCA databases, only ecoinvent 3, via ecospold 2 format, can store geographic coordinates linked to activities, usable by GIS[1]. Nevertheless, this function is for now rarely used. The formats ecospold1 and ILCD can only store the ISO code of the region or country where the activity takes place (only one region possible). Finally, the files used by GaBi or Simapro do not allow the storage of detailed geographic information.

- *Study cases*

The two realized study cases allow understanding the practical aspects and limitations of weak and strong coupling.

For the first study case, a strong coupling was performed between QGIS and Brightway2 (both using Python scripts and open-source). A QGIS plugin was developed with the following functionalities: automatic GIS data treatment, input data selection, impact evaluation method choice, LCA calculation in Brightway2 and visualize results on maps. For this study case, GIS allowed: increasing data availability thanks to publically available GIS files, generating new inventory data thanks to GIS treatment (layers superposition, distances calculation, spatial differentiation of flows), generating or using regionalized characterization factors, refining LCA calculation for foreground processes (superposition of regionalized inventory data and characterization factors), visualizing results on maps. The identified

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[1] http://geography.ecoinvent.org/

constrains by GIS-LCA coupling are: the difficulty of locating emissions on a journey, background processes characterization, required GIS competences, in particular for treatment operations (e.g. buffer creation, distances calculation, etc.).

A weak coupling has been implemented for the second case study thanks to a connector with open-source software R, linking the open-source software GRASS-GIS and QGIS with SimaPro 7.3.3. R software has been chosen because of its possibility to import, treat and export spatialized data. Foreground inventory is spatialized thanks to automatic GIS treatment, while impacts of reference elements of buildings (including their renovation and end of life) are calculated by dimensional unit (e.g. square meter of envelope area). The coupling allows associating the impacts to GIS data of building and aggregating the results to the city scale. For this study, GIS allowed: testing of different approaches to generate new inventory data from GIS layers, locating impacts sources, visualizing results on maps. The identified constraints by GIS-LCA coupling are: large scale data availability and accuracy, GIS results validation, required GIS competences for management and treatment operation of data and visualization.

- *Recommendations*

The types of possible coupling between LCA and GIS have been screened to detail the techniques, competences, required time and work load for their implementation (Tableau 3). Three type of coupling have been distinguished. No coupling consists in adding manually GIS data in LCA model. This can be practical when GIS and computing competences are low. However, this method can be applied only for a small amount of data and it limits the results replicability. A weak coupling allows automatizing some exchanges between the two tools, in particular via a connector, to treat a larger number of data. Depending on the complexity, the work load and the required competences vary. If the computing competences are advanced, a strong coupling is possible to completely automatize the interaction between GIS and LCA and to control these two tools via the same interface (in LCA software or connector).

Tableau 1 : Competences, work load and GIS data amount depending on the type of GIS-LCA coupling

Type of couplage	Description	Required GIS competences	Required computing competences	Work / time load	GIS data amount
No coupling	No interaction between LCA and GIS tools. Manual addition of GIS data.	Basic (-)	Basic (-)	Small (-)	Small (-)
Weak coupling	Semi-automatic exchanges with pre-treatment in individual software.	Basic to advanced (-/++)	Basic to medium (-/+)	Small to medium (-/+)	Medium (+)
Strong coupling	Complete automation of exchanges with data control in LCA software of connector.		Medium to advanced (+/++)	Medium (+)	Medium to large (+/++)

In order to provide practical recommendations, a decision tree was elaborated (Figure 2). It determines the type of coupling to implement depending on the study objectives and scope, as well as the LCA team competences. First, we test if the LCA is used as decision support, which increase coupling relevance, in particular for a territorial strategy or industrial strategy with geographic resolution of results. A strong coupling is necessary in the frame of spatial optimization. For these types of study, it is mandatory to hold a minimum of GIS competences. The choice between weak or strong coupling is guided by the computing competences of the team. If the study concerns large scale evaluation or decision support for a sector sensitive to geography (transports, energy, agriculture, etc.), spatialized inventory data can be used even if a resolution is not necessary. The recommended coupling depends on data amount to be treated, available time and competences of LCA team. Finally, in the case of low geography sensibility of inventory, coupling has low interest. Only if regionlized impacts are considered, characterization factors can be implemented in LCA software in a table form (no coupling).

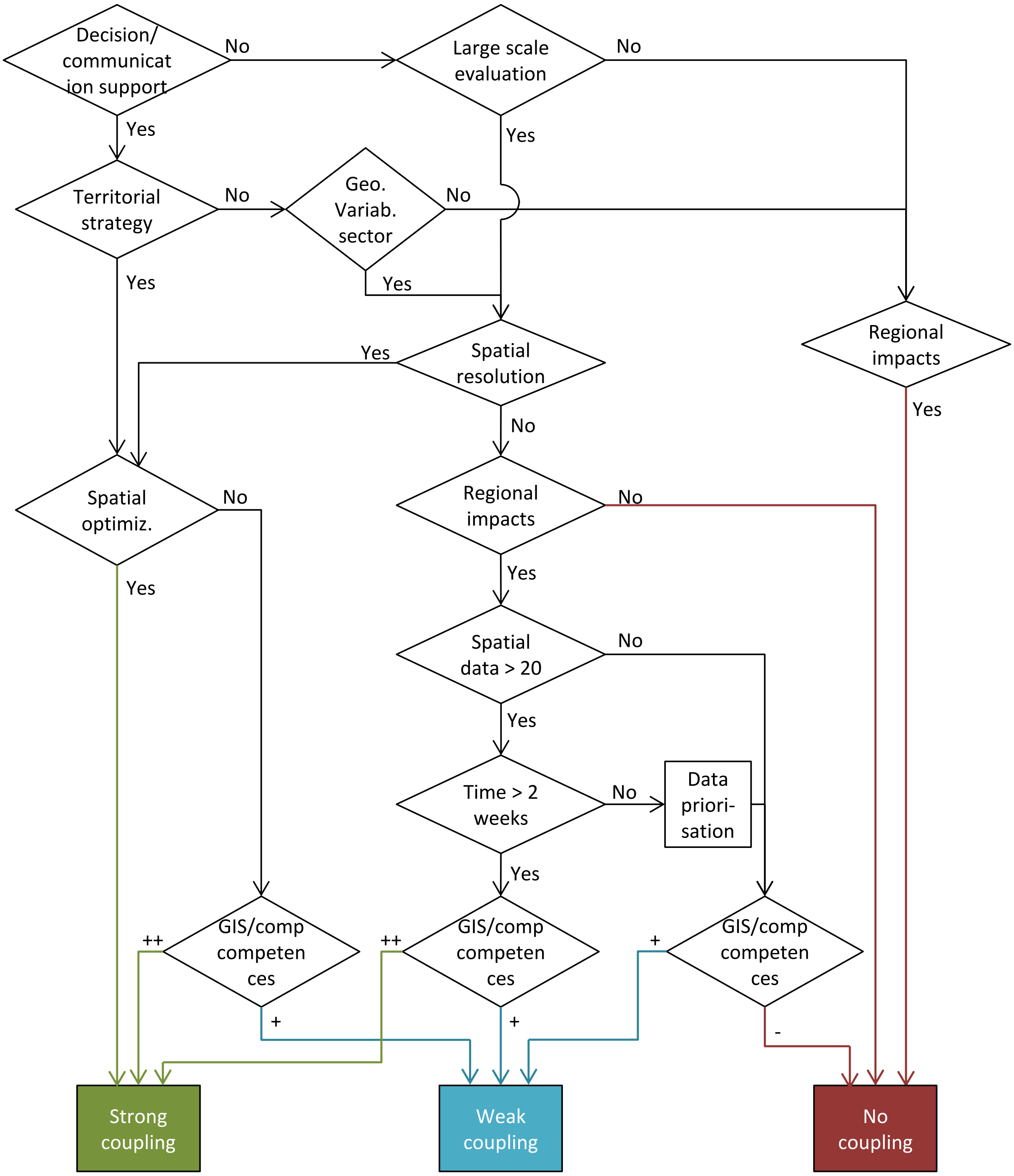

Figure 1: Decision tree for the choice of the LCA-GIS coupling type

Discussion

This section describes the implementation barriers, usage precautions and future developments related to GIS-LCA coupling.

Even if GIS use seems necessary for the LCA study, the practitioner can be confronted to several barriers to implement this coupling. First, inventory or impact evaluation data to spatialize are not always available. Concerning background processes, even if ecoinvent v3 associates GIS identifiers to processes, many of them remains with the code “Rest of the World (RoW)” which differs according to the considered activities. To compensate the lack of data, it is possible to generate new spatialized data from existing data (e.g. height of buildings from footprint and elevation data). A treatment can also be necessary to harmonize the different GIS layers. All these calculation steps require GIS competences which are not common in LCA community. In combination with GIS competences, a coupling needs basic computing competences because common LCA softwares lack of GIS treatment functionalities. Some coupling could be easily implemented (e.g. via Excel table) but the fact to deviate from a conventional LCA software usage can restrain the practitioner to perform this type of operation. Finally, depending on the complexity and amount of data, the additional work load required by a coupling does not facilitate its usage, in particular in private companies. A coupling can also represent an additional budget if the required competences are not present within the team.

Some usage precautions were highlighted by authors. For example, when the practitioner chooses a small resolution (e.g. 10 km x 10 km), the precision increases but the accuracy can decrease. Indeed, as underlined by Mutel et al (2012), the impact evaluation methods include large number of uncertainties related to the cause-effect chain modelling. The multiplication of characterization factors number generates an additional variability which can be unjustified depending on the chosen scale. The practitioner needs to be careful with spatial resolution validity. Regarding interpretation Heijungs (2012) warns also about the fact that a product B can have more emissions than a product A but, because of its geography location (e.g. in ocean), the impacts are lower. This issue can be solved by comparing results with and without regionalization. The author underlines also a possible biased GIS use and an incompatibility of resolution between inventory and impact methods due to lack of precision from LCA database. This confirms the necessity of holding a minimum of GIS competences before performing a spatialization of LCA data and results, in order to make the good choices during the coupling implementation and analyse results with relevance.

To conclude, the use of GIS for LCA is expanded for a few years. We can therefore expect numerous developments in the future to facilitate this coupling. First, several authors (Mutel et al, 2012 ; Koellner et al, 2013 ; Kounina et al, 2014 ; Cucurachi & Heijungs, 2014) highlighted the importance of evaluating the validity of spatialized characterization factors in order to propose to the practitioners a relevant scale for each category and a user guide. The databases will be also refined in the future to insure the cohesion of regionalized results between foreground and background processes (Mutel & Hellweg, 2009). This trend already started with ecoinvent v3 but the coherence and reliability of data still needs to be improved (e.g. need to associate a process for a country with grid cell characterization factors). Finally, the improvement of impact evaluation methods and inventory databases should encourage the implementation of GIS functionalities in LCA software. We already observed the intention of some developers, in particular from GreenDelta GmbH for OpenLCA.

Conclusion

This study allowed identifying the LCA practices related to GIS coupling. Its usage is expanding for the last years, either to spatialize inventory or to develop spatialized characterization factors. However, the studies integrating GIS for these two steps remain rare. The study cases have determined the feasibility and identified the limitations of a coupling (in particular linked to required competences and to lack of functionalities in LCA software and database). Finally, this work allowed us to draw practical recommendations, represented via a decision tree to guide the practitioner depending on study objectives.