



Regionalized LCA in practice: the need for a universal shapefile to match LCI and LCIA

Stephan Pfister¹ · Christopher Oberschelp¹ · Thomas Sonderegger¹

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1 The regionalization challenge

Life cycle assessment (LCA) and environmental footprints studies have become prominent tools to assess environmental impacts of products, services, companies, and regions, including the impacts over global supply chains. Many impact categories require regional differentiation for life cycle impact assessment (LCIA), but also require regionally explicit life cycle inventory (LCI) data for emissions, water consumption, and land use. There have been many methodological developments to assess such impacts at a regional scale, such as for water scarcity on a watershed-level or land use impacts on an ecoregion-level (Jolliet et al. 2018). Furthermore, a broad range of regional life cycle inventory (LCI) data has been provided, e.g., for land, water, and air emissions (e.g., Pfister et al. 2011, Núñez and Finkbeiner 2020, Sonderegger et al. 2020a, Scherer and Pfister 2015, Raptis et al. 2016, Oberschelp et al. 2019, Raptis et al. 2020, Quantis 2020).

Recently, a working group of the UNEP-SETAC Life Cycle Initiative published a paper on regionalization, in which several useful recommendations have been made (Mutel et al. 2019). However, the group identified a gap in linking LCI and LCIA data due to the various spatial scales used in practical applications, which currently limits regionalized LCAs largely to research studies. A recent symposium on regionalization further revealed the need for a pragmatic solution to integrate regionalization into LCA (Frischknecht et al. 2019).

One key reason for this gap is the diversity of regional scales (e.g., ecoregions or watersheds) for different life cycle inventories and impact assessment methods. We therefore argue for an agreed upon universal spatial layer that captures the most important features required for impact assessment and environmental footprinting, in addition to political units that are relevant for LCI. This is important for mainstream applications of regionalized methods; many of which have been published in this journal but are currently underutilized due to applicability limitations.

2 A universal shapefile

We suggest using a shapefile that intersects six spatial layers of general relevance for LCA (Fig. 1): (1) political borders, which are primarily important for LCI data and coupling with multi-regional-input-output (MRIO) data for assessing background systems; (2) terrestrial ecoregions, which are the recommended spatial unit for land use assessment (Jolliet et al. 2018) and relevant for other LCIA methods addressing terrestrial ecosystems; (3) watersheds, which are the recommended spatial resolution for assessing water scarcity impacts (Boulay et al. 2015) and important for other impacts on freshwater ecosystems; (4) urban areas, which are essential to assess impacts on human health, as in the case for particulate matter (PM) emissions; (5) coastal marine ecoregions, which are key to address, e.g., marine eutrophication; and (6) fishery zones of oceans, which are, e.g., important for assessing depletion of fish stocks. While other aspects such as climate zones and elevation might be important for specific impact assessment methods, we expect that these 6 layers cover the most important spatial scales of recent LCIA methods and LCI demands. Additionally, the proposed shapefile provides relatively small spatial units, measuring an average area of 16,883 km², with

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✉ Stephan Pfister
pfister@ifu.baug.ethz.ch

¹ Institute of Environmental Engineering, ETH Zurich, 8039 Zurich, Switzerland

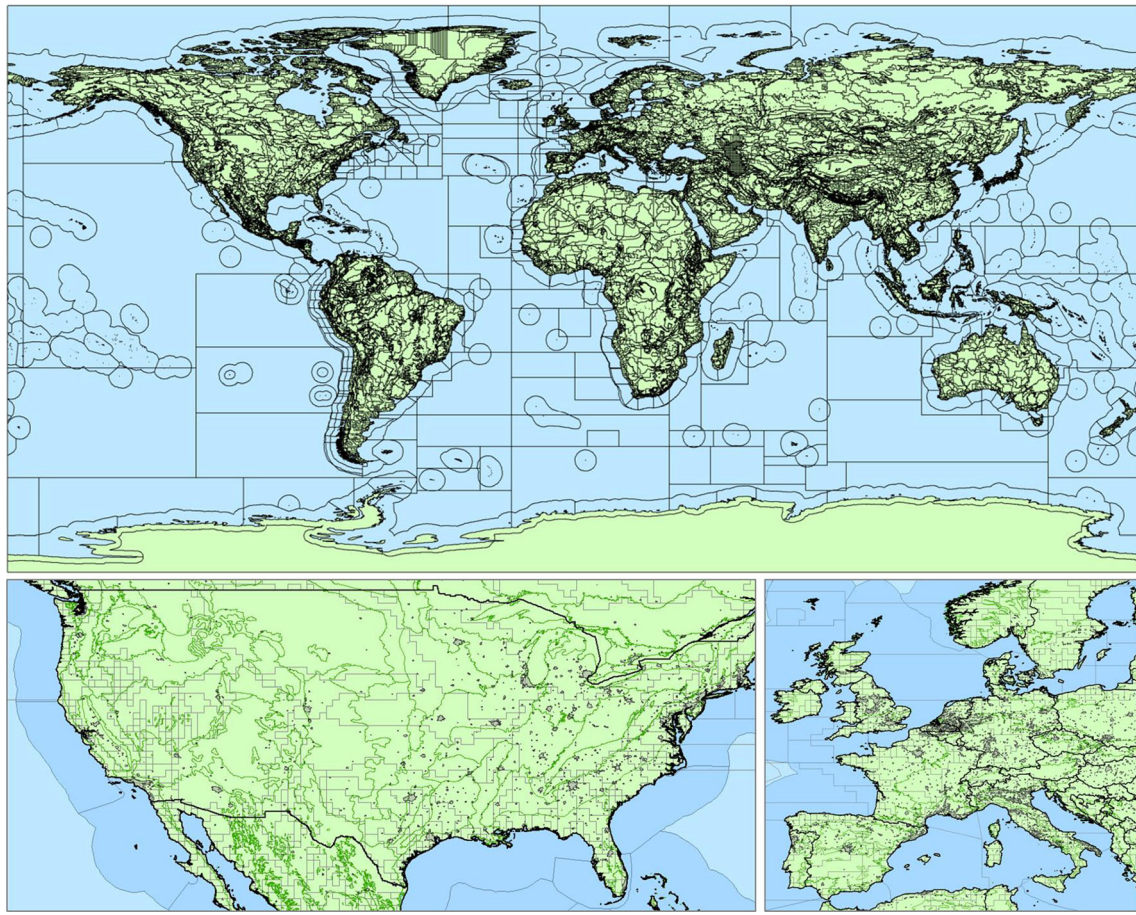


Fig. 1 Spatial layer that covers the most important environmental and socio-economic features in LCA and footprint assessments (top); zoom-in on the USA and Europe (bottom); color code for bottom part: black lines = political borders, green = terrestrial ecoregions, grey lines = watershed

borders, grey areas = urban areas, dark blue = marine ecoregions, light blue = fishery zones (layer available online: <https://data.mendeley.com/datasets/8zxc3kzwj/draft?a=a0083629-72d2-45c4-92e0-06a0b74774db>)

larger areas falling on oceans and smaller areas appearing in populated and geographically diverse regions.

The resulting shapefile and data layer contain 50,626 units (48,612 terrestrial and 2014 marine regions) and thus allow for efficient data management of a multitude and constantly increasing number of regionalized LCIA methods. The suggested shapefile and data are freely available online as a GIS layer and KML file (for google earth), and include a description of the procedure and input data from which was generated (Sonderegger et al. 2020b). The actual data can be stored in a single Excel or text file. However, this is just a prototype for this proposed universal layer. Further refinement and extensions can be applied through a consensus process, such as the GLAM project by the Life Cycle Initiative hosted by the UN Environment. Additionally, the suggested shapefile can also be used to identify the shape IDs of the underlying shapefiles in a specific location in order to directly select available characterization factors (CF), e.g., on watershed or ecoregion level (Jolliet et al. 2018) or identify the location as a property for inventory processes. The provided KML layer allows for a

similar process using the Google Earth application without specific GIS knowledge or software.

3 Practical application

We propose that LCIA method developers use this layer to share their results, and that LCI data providers use the file for identifying the location of their processes. Since the layer contains roughly 50,000 units, it remains feasible to handle with contemporary LCA software and the software developers do not need to create a GIS-based implementation.

Currently, background databases are unable to model the level of detail proposed by the use of this shapefile due to too large matrix sizes and limited computing power, data availability, and quality check restrictions. Using the spatial layer, practitioners can set the proper shapefile ID as a location, and LCA software, through the creation of location-specific new processes, can match the corresponding CFs and calculate the resulting LCIA at a process level. This would limit calculation

efforts and not increase the size of the technosphere matrix except for the typically comparably small foreground system.

Existing LCIA methods on watershed (e.g., for water scarcity (Boulay et al. 2015; Pfister et al. 2009)), ecoregion (e.g., for land use (Chaudhary et al. 2015)) or urban level (e.g., PM emissions (Fantke et al. 2019)) can be directly integrated into the suggested shapefile through the respective watershed, urban areas, and ecoregion IDs, while LCIA methods in raster format can be aggregated to the presented shapefile using the GIS software. We suggest that all method developers provide these aggregated values, as they should be in the best position to use an appropriate weighting layer (this is needed to calculate a representative value in each unit of the shapefile, e.g., weighting grid cell CFs for phosphorus emissions from agriculture with current phosphorus application rates). Nevertheless, it is suggested that LCIA method developers provide the highest level of detail as well, and that they also share their aggregation data and method. Depending on the aggregation mechanism, results for weighting the areas can directly be used for aggregation into larger units like countries or regions, even if it is recommended to start from the grid cell level to aggregate to other units. We therefore also suggest to provide country averages for existing locations in background databases. As an example, the water consumption used as a weighting factor for water scarcity CFs should be added to each spatial unit, since it is used for aggregation to larger units such as countries (Jolliet et al. 2018). The same applies to uncertainty information, which should be representing total uncertainty, including the uncertainty caused by aggregation, such as was done for water scarcity (Jolliet et al. 2018) and soil compaction and water erosion impacts (Sonderregger et al. 2020a).

4 The future is regional

While in science it is acceptable to assume the most detailed data to be sufficient, it is not for dissemination to secondary research and practitioners, which is a key part of LCA and footprint research. Therefore, the presented shapefile is able to be immediately implemented by the LCA software and LCIA methods to avoid delay in the application of regionalization in LCA, despite the fact that further refinement is expected. We therefore suggest to provide all CFs of regionalized impact assessment methods using the suggested layer, or an alternative improved version that might result from a future scientific stakeholder consensus process. Such consensus will take time, and through the process, various questions will need to be addressed, such as the agreed input shapefiles. One prime example is the discussion that will surround the layer representing watersheds. The current iteration utilized a commonly used water consumption LCIA method,

despite its relatively low spatial resolution. Therefore, watershed shapefiles might be replaced in the future by watersheds used in Berger et al. (2018) if more methods use this layer as native resolution. The same applies to the shapefile choices for political boundaries, since country boundaries are inconsistent among various datasets (e.g., UNEP does not consider Taiwan as an independent country but rather as part of China).

Our suggestion for a common layer facilitates a direct match of LCI and LCIA methods at an acceptable level of regionalization for standard assessments, while the native resolution of each impact assessment method (e.g., grid cell level for Scherer und Pfister (2016) and Sonderregger et al. (2020a)) can still be utilized for foreground processes if a very high spatial level of detail is required. Of utmost importance is that regionalization is quickly implemented in the LCA software solutions in ways that can be practically implemented by mainstream practitioners. This will allow for an enhanced understanding of the relevance of regionalization and further discussions of additional challenges in LCI and LCIA in practical applications.

5 Data and methods

The following six shapefiles and datasets have been used as input to create the suggested layer depicted in Fig. 1 and described above:

- Urban areas: Natural Earth, Urban Areas, version 4.0.0, 11877 Urban areas, Source: Schneider et al. (2009)
- Country boundaries (subunits): Natural Earth, Admin 0 – Details, version 4.1.0, 197 countries, Source: Natural Earth (2019)
- Ecoregions: Terrestrial Ecoregions of the World, 867 terrestrial ecoregions, Source: Olson et al. (2001)
- Watersheds: Input data (WaterGAP) for Aware, 11049 watersheds; <http://www.wulca-waterlca.org/aware.html>, Source: (Müller Schmied et al. 2014)
- Marine ecosystems: Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas (2007). Source: Spalding et al. (2007)
- Fishing areas: FAO Statistical Areas for Fishery Purposes-FAO Statistical areas (Marine)-no coastline (for use with custom coastline resolutions)-GIS data (WFS-SHP). Source: FAO (2019).

The six layers described above were combined using ArcMap 10.5 (esri 2017). The code for reproduction is provided in the files “prepare_shapefiles.R” and “create_regionalization_layer.txt” and described in the “README.txt” file available on mendeley data (Sonderregger et al. 2020b).

For terrestrial areas, the country layer and the terrestrial ecosystems layer were merged using the “intersect” method in ArcMAP. This crops the area to the overlapping area of the two layers. As these overlaps are not perfect, some coastlines and 19 minor islands are cropped or eliminated as there are no overlapping areas between the two layers.

Second, the new layer was intersected with the urban areas layer and some of the urban areas are cropped to some extent as well (Fig. 1 available as file here).

Third, the new terrestrial areas and the new urban areas layers were merged using the “identity” method in ArcMAP and the resulting layer was merged with the watersheds layer again using the “identity” method. This crops the watershed layer to the extent of terrestrial areas and further refines the terrestrial area features.

For marine areas, the fishing area layer and the marine ecosystem layer were cropped to non-terrestrial area using the “erase” method and the terrestrial areas layer created before. Then, they were merged using the “identity method.” Finally, the terrestrial and the marine layers were combined using the “union” method.

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