Agri-Footprint; a Life Cycle Inventory database covering food and feed production and processing

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ABSTRACT

Agri-footprint is a new life cycle inventory database that focuses on the agriculture and food sector. The goal of this database is to support life cycle assessment practitioners to perform high quality assessments. The database contains a methodologically consistent dataset for a large number of crops, crop products, animal systems and animal products. These inventories can be used as secondary data in LCAs. Non-LCA models were used to calculate a wide array of elementary flows (such as land use change, water use, fertilizer application rates), to support assessment on a multitude of environmental issues. To safeguard relevance and data quality, the database will be updated regularly. As the public interest in food LCAs is expected to increase in the near future, Agri-footprint will be a helpful resource for practitioners in this field.

Keywords: Life cycle inventories, food, agriculture, food processing, crop cultivation

1. Introduction

The goal of the LCI database Agri-footprint is to facilitate life cycle assessments (LCAs) in the domain of food and agriculture by making life cycle inventory (LCI) data available in a single, internally consistent database. LCA studies of food have become more frequent in the last few years, although studies of food and agriculture have been undertaken almost since the emergence of the LCA method. The first agricultural LCAs were performed in the early 1990s. Pioneering food LCA case studies include LCAs about tomatoes, by Gysi and Reist (1990), ice cream, by Bolliger and Zumbrunn (1991) and Margarines, by Unilever (Vis, Krozer, van Duyse, & Koudijs, 1992). The proportion of published agriculture-related LCAs in the international Journal of LCA increased considerably at the end of the 2000s and has remained around 25% since then (Figure 1). Some reasons for this increased share are:

- Public interest in the first edition of the FAO report 'Livestock's Long Shadow' (Steinfeld et al., 2006) which put the environmental impact of agriculture and especially animal production on the agenda.
- Pressure from retailers to provide carbon footprint information on food products since around 2007.
- The introduction of European biofuel legislation in 2009 (European Commission, 2009) and its related policy issues on fuel, feed and food competition.
- Specific agricultural related impact categories and related methodological solutions came up, such as water resource depletion and land use change.

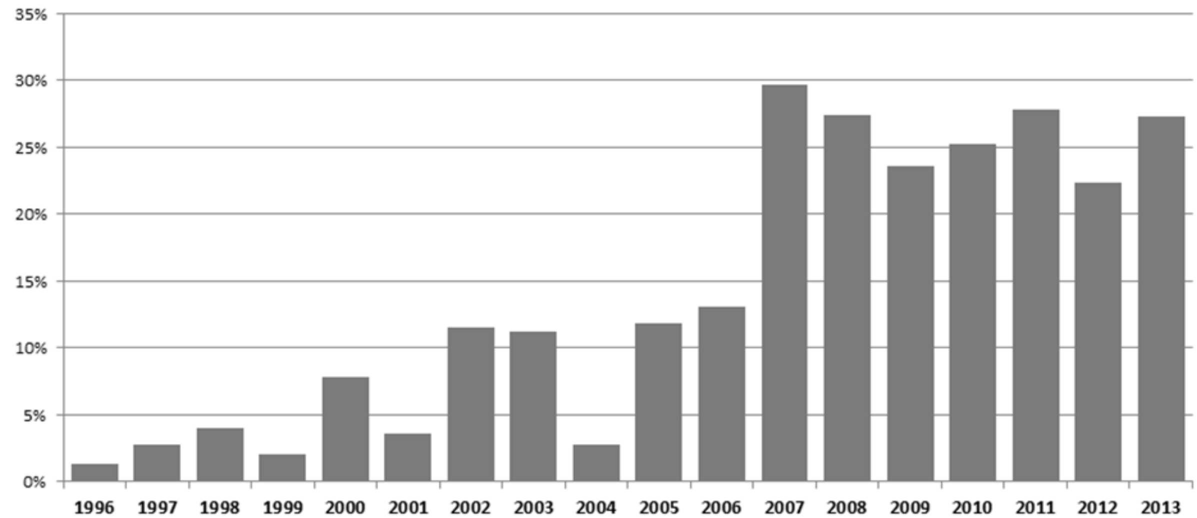

Figure 1. Share of agricultural related LCAs in the International Journal of LCA. Based on our survey of published articles.

In coming years, many food related LCAs will be performed due to the special attention from the European Commission for food, feed and beverages in the Product Environmental Footprint (PEF) program. Also the European research and innovation program Horizon 2020 focuses on more sustainable food production systems which have to include a sustainability assessment in line with the ILCD handbooks.

Therefore there will also be more and more demand for reliable and consistent secondary data in this field. The aim of Agri-footprint is to fulfill this demand by bringing data and methodology together and make it easily available for the LCA community. By having these generic LCIs readily available, future LCAs can be conducted more efficiently and also more reliable.

Although there are already a number of extensive LCA databases available (such as Ecoinvent, (2013) and ELCD (JRC-IES, 2012)), agricultural (processing) and food production LCIs only represent a small fraction of the data covered. Relevant information from a large number of food LCIs and food statistics (e.g. from FAO) are not yet implemented in LCA databases.

In addition, agricultural and food production companies find it often difficult to find a practical way to share their environmental information with the LCA community. Agri-footprint aims to combine information from these disparate sources (scientific literature, statistics and company specific data), into a single internally consistent LCI database. Therefore, Agri-footprint will also serve as a platform for companies to communicate their specific LCI data to a relevant audience. Already, some company specific life cycle inventories are included in Agri-footprint (currently Nutramon fertilizer from OCI and sugar products from Suiker Unie). By making the better performance of specific companies visible, LCA users can more easily identify improvement options in a lifecycle assessment.

The release date of the first version of the database is spring 2014. The database is intended to be used in the public domain and is available to LCA and sustainability experts who have a SimaPro license.

Agri-footprint is intended to be used as a secondary data source or background data for another LCI or LCA (comparative/ non-comparative). More specifically, potential applications of Agri-footprint may be:

- the identification of key environmental performance indicators of a product group
- hotspot analysis of a specific agricultural product.
- benchmarking of specific products against a product group average.
- to provide policy information by basket-of-product type studies or identifying product groups with the largest environmental impact in a certain context.

2. Methods

Agri-footprint includes linked unit process inventories of crop cultivation, crop processing, animal production systems and processing of animal products for multi-impact life cycle assessments. Agri-footprint also contains inventory data on transport, fertilizers production and auxiliary materials. Agri-footprint uses some background data that was sourced from ELCD (JRC-IES, 2012) and USLCI (National Renewable Energy Laboratory, 2012) datasets. Detailed reports are available for the methods and guiding principles (Blonk Agri-footprint BV, 2014a) and the sources and treatment of data (Blonk Agri-footprint BV, 2014b).

2.1. Guiding principles

During the development of Agri-footprint, the first step was to create data that was of consistent quality for all crops and regions covered. For example, all fertilizer application rates, fertilizer types, water use are based on the same methodologies for all crops. To create this consistent baseline dataset, data were derived from documented expert data or data from statistics.

Agri-footprint contains attributional LCIs of crop production, crop processing, animals systems, transport and other background processes (see Figure 2 as an example of types of processes included in database). Generally average mixes are considered that are representative for the specific product and location.

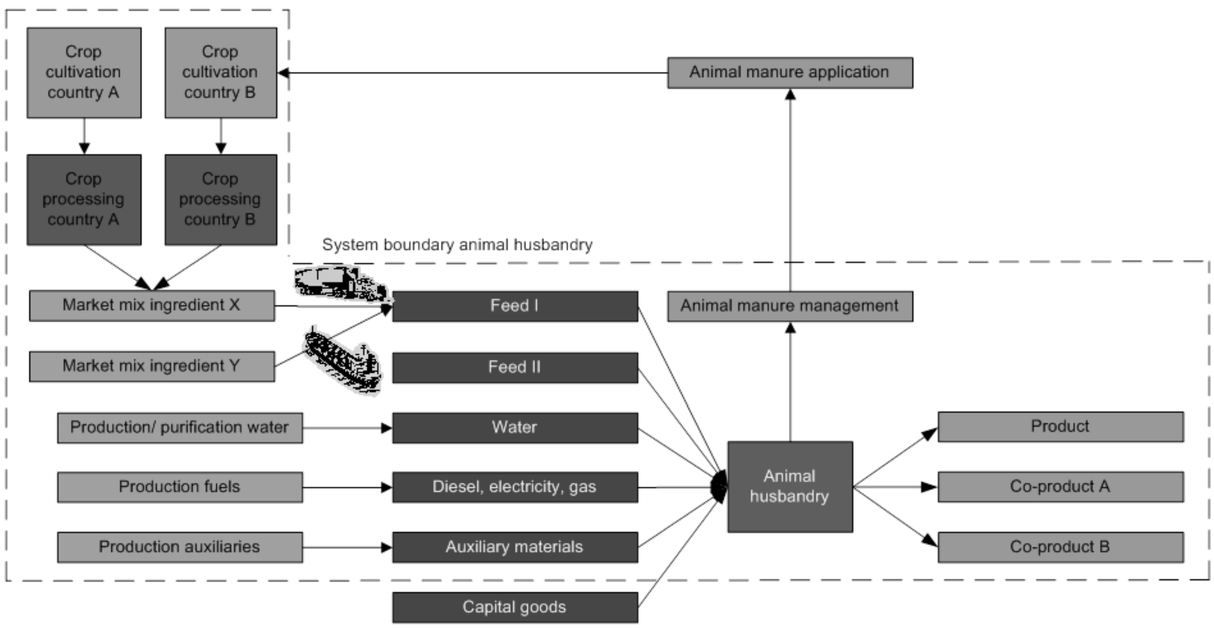

Figure 2. System boundaries of an Animal husbandry LCI in Agri-footprint.

The main baseline data source is the public domain (scientific literature, statistics from (FAOstat, Eurostat, IFA, etc.), using rolling 5 year averages. Data from the public domain are assessed based on representativeness (time-related coverage, technical coverage and geographical coverage), completeness, consistency and reproducibility. When data from public or confidential research by Blonk Consultants are more representative, complete and consistent, these data are used. Where possible, the data have been reviewed by industry experts and, where fit, an uncertainty range and a distribution type has been attributed.

The data in Agri-footprint are derived from different sources. The LCIs for animal husbandry, transport, auxiliary materials, fertilizers etc. have been developed based on previous reports/studies by Blonk Consultants.

Fertilizers production was modeled based on the latest available literature and a specific fertilizer product was based on primary data from a large Dutch fertilizer producer (Calcium Ammonium Nitrate produced by OCI Nitrogen in the Netherlands). Auxiliary materials were based on the ELCD 3 database or literature sources. For some (deep) background processes, estimates had to be made (e.g. the production of asbestos which is used in sodium hydroxide production which is used in vegetable oil refining), and these processes are of lower quality and representativeness.

Processing inventories were drawn from the feedprint study (Vellinga et al., 2013). These inventories are generic for all provided countries and regions. These processes are either largely similar between countries or the data available was not specific enough to create country/ region specific processes. These generic processes are regionalized by adapting the inputs for energy consumption to the country or region where the processing takes place. This means that the processing (in terms of mass balances, and types of inputs) is generally the same for all regions, except the input processes for energy consumption are specific per country. This means that the representativeness may have decreased for these processes. Transport distances and modes from and to the processing plant are also country specific. The geographical representativeness will be improved in future upgrades of Agri-footprint.

The aim is for the LCI data to be as recent as possible, which means that when better quality data or statistics on the processes/ systems are available these are incorporated in Agri-footprint,. To ensure the best time related representativeness, data will be updated regularly.

No specific choice of allocation approach is made, rather multiple options are presented to users. Two physical keys (dry matter and energy) and one economic allocation key are presented in Agri-footprint:

- Physical allocation: mass allocation
  For the crops and the processing of the crops, mass allocation is based on the mass of the dry matter of the products. For the animal products, mass allocation is based on the mass as traded.
- Physical allocation: gross energy allocation
  Water has a gross energy of 0 MJ/kg. The gross energy for protein, fat and carbohydrates are respectively: 23.6, 39.3 and 17.4 MJ/kg which are based on USDA (1973). Nutritional properties for gross energy calculations of products are based on a nutritional feed material list (Centraal veevoederbureau, 2010).
- Economic allocation
  For the crops and the processing of the crops the economic value of the products is based on (Vellinga et al., 2013).This allows users to choose an allocation that is most relevant for the context of their study. To ensure consistency in methodology and LCI modeling approach, Agri-footprint is reviewed by an independent external party.

System expansion is not applied in Agri-footprint because of the practical implications for the structure of the database. System expansion can be applied by the user by modifying processes. The allocation percentages of the unit processes can be set to 100% and 0% and the system can be expanded. In some specific situations avoidance of production is applied when the avoided product can be unambiguously determined such as electricity produced from a CHP delivered to a national grid.

2.2. Practical implementation – collection of data

The starting point of the inventory data development is information gathered in previous studies, particularly information gathered in the Feedprint project (Vellinga et al., 2013). The crop cultivation and processing inventories in that project contained only data to support carbon footprinting calculations. These inventories were further extended to include additional environmental flows to cover more impact categories. The additional flows were determined using a number of non-LCA models and data sources. Other environmental flows were added during the course of the development of Agri-footprint, to support assessment on other environmental impact categories. The LCIs have thus been extended to allow impact assessment on all impact categories of ReCiPe (Goedkoop et al., 2009) and ILCD (JRC-IES, 2011) impact assessment methods. Other impact assessment methods may also be supported, but naming of substances has aligned specifically to these two methods.

2.2.1. Crop cultivation

To expand the data from covering just greenhouse gas (GHG) related emissions, to coverage of a broader environmental scope, a number of models were developed, targeting specific environmental themes, relevant for all crop cultivation systems. These models focused on the themes land use change, fertilizer application, water use and heavy metal emissions. Other environmental themes were investigated using conventional literature or data survey, e.g. pesticide application rates (from a large volume of literature sources). How these models were used to create crop inventories is summarized below.

Fossil CO_2 emissions resulting from direct land use change are estimated using the "Direct Land Use Change Assessment Tool (Version 2014.1 - 21 January 2014)" that was developed alongside the PAS 2050-1 (BSI, 2012) and has been reviewed by the World Resource Institute (WRI) and WBCSD, and has, as a result, earned the 'built on GHG Protocol' mark. This tool provides a predefined way of calculating greenhouse gas (GHG) emissions from land use change based on FAO statistics and IPCC calculation rules, following the PAS 2050-1 methodology. GHG emissions arise when land is transformed from one use to another. This tool can be used to calculate these emissions for a specific country-crop combination and attribute them to the cultivated crops.

The tool provides means of estimating the GHG emissions from land use change based on an average land use change in the specified country. For Agri-footprint, the option "calculation of an estimate of the GHG emissions from land use change for a crop grown in a given country if previous land use is not known" was used. This estimate is based on a number of reference scenarios for previous land use, combined with data from relative crop land expansions based on FAOStat data (FAO, 2012). These FAO statistics then provide an estimate of the share of the current cropland (for a given crop) which is the result of land use change from forest and/or grassland to cropland. This share is calculated based on an amortization period of 20 years, as described in the PAS 2050-1. This results in three scenarios of land transformation (m2/ha*year): forest to cropland, grassland to cropland, and transformation between perennial and annual cropland, depending on the crop under study. The resulting GHG emissions are then the weighted average of the carbon stock changes for each of these scenarios. Further details and documentation can be found in the calculation tool itself (Blonk Consultants, 2014). The calculated CO_2 emissions from land use change (LUC) have been added in the database, the substance flow name is "Carbon dioxide, land transformation". Note that land use change is also reported in m^2. By including the land use change in m^2, the impact categories 'Land use: Soil Organic Matter (SOM)' in the ILCD method and 'natural land transformation' in the ReCiPe method are supported.

Water use is based on spatially explicit water use methodology developed by Mekonnen & Hoekstra (2010). Water is used for irrigation of crops as well as during processing. The amount of (artificial) irrigation water is based on the 'blue water footprint' assessment (Mekonnen & Hoekstra, 2010b). The estimation of irrigation water is based on the CROPWAT approach (Allen, Pereira, Raes, Smith, & Ab, 1998). The blue water footprint refers to the volume of surface and groundwater consumed as a result of the production of a good. The model takes into account grid-based dynamic water balances, daily soil water balances, crop water requirements, actual water use and actual yields. The water footprint of crops have been published per country in m^3/tonne of product (Mekonnen & Hoekstra, 2010b). Combined with FAO yields (2007-2011) the blue water footprint is calculated in m^3/ha.

For the fertilizer application rates (in terms of kg NPK) the values of the Feedprint study are used. The majority of these fertilizer application rates are derived from data supplied by Pallière (2011) for crops in Europe, and data from Fertistat (FAO, 2011) for crops outside of Europe. Data from Pallière was preferred, because it was more recent. To match these total N, P and K application rates, to specific fertilizer types (e.g. Urea, NPK compounds, super triple phosphate etc.), a model was developed using data on country specific fertilizer consumption rates from IFA (IFA, 2012). In the analysis, it is assumed that the relative consumption rates of fertilizers are the same for all crops within a certain country. Some fertilizers supply multiple nutrient types (for example ammonium phosphate application supplies both N and P to agricultural soil). In IFA statistics, the share of ammonium phosphate is given as part of total N and also as part of total P supplied in a region. To avoid double counting, this dual function has to be taken into account.

Therefore the following calculation approach was taken: the fertilizers supplying K were considered in isolation. The relative shares of the K supplying fertilizers was calculated for a crop (e.g. if a crop A in Belgium requires 10 kg K/ha, 35% is supplied from NPK, 52% from Potassium Chloride and 11% from Potassium Sulfate). NPK however, also supplies a certain amount of N and P. The amounts of N and P supplied are subtracted from the total N and P requirements. Next, the share of P supplying fertilizers was calculated (however, the share of NPK in the P mix is not included as it is already accounted for during the calculation of K requirements). As in the P mix there are also fertilizers that contribute to the N supplied, this is also subtracted from the N requirements. For the remaining N required, the purely N supplying fertilizers are used (as NPK and ammonium phosphate are already considered during P and K calculations).

2.2.2. Processing of crops and animal products

Also, the starting point for crop processing was data gathered in the Feedprint project. Here the inventories have been extended to include non-greenhouse gas emissions, to cover more environmental impact categories. For example, additional data was gathered for water use in processing.

Unfortunately, the quality and availability of processing data is far from perfect. In some cases, the data are of quite good quality, meaning that they are representative for the region in scope, recently collected and accurate. In many other cases the data are of lower quality, and improvements are necessary.

Luckily some recent efforts by industry organizations are reducing this data quality issue. For example FEDIOL has recently published data on oil crushing and refining (Schneider & Finkbeiner, 2013). In addition, the Dutch meat processing industry has recently published data that was used to create inventories for slaughterhouse processes (for chicken beef and pigs) (COV & VNV, 2012). Also, some high quality company specific primary data on sugar processing from Suiker Unie has been collected and implemented in the database. As this producer of sugar and sugar products is the only major sugar producer in the Netherlands, the data is representative for Dutch sugar products. All this recent high quality data is included in Agri-footprint. Still collection of high quality processing data is an ongoing effort, and will be a main topic in future updates.

2.3. Data quality and review

Agri-footprint is externally reviewed by the Centre for Design and Society, RMIT University, Melbourne, Australia. This review is not a full ISO 14044 review. Rather, the external reviewers check the consistency and transparency of the methodology applied and completeness and transparency of data documentation.

PRé Consultants, the developers of SimaPro, did a thorough review to check technical database aspects, but also the transparency of the data (for example documentation and annotation of the Agri-footprint data within the software environment, and alignment of naming and structure to other databases already present in SimaPro).

3. Results

The first release of the database covers ~30 crops, ~100 (intermediate) products from processing, ~80 feed compounds, ~35 food products, 4 animal production systems and ~85 background processes (transport, auxiliary inputs for processing, fertilizers), with different versions for a number of countries/regions in the world and three pre-defined allocation systems. The total number of products in the database is ~3500. A full list of processes included in the database can be found on the Agri-footprint website (www.agri-footprint.com).

Also, two company specific LCIs are part of database, one for production of Nutramon (CAN) fertilizer from OCI, and sugar and sugar co-products produced by SuikerUnie.

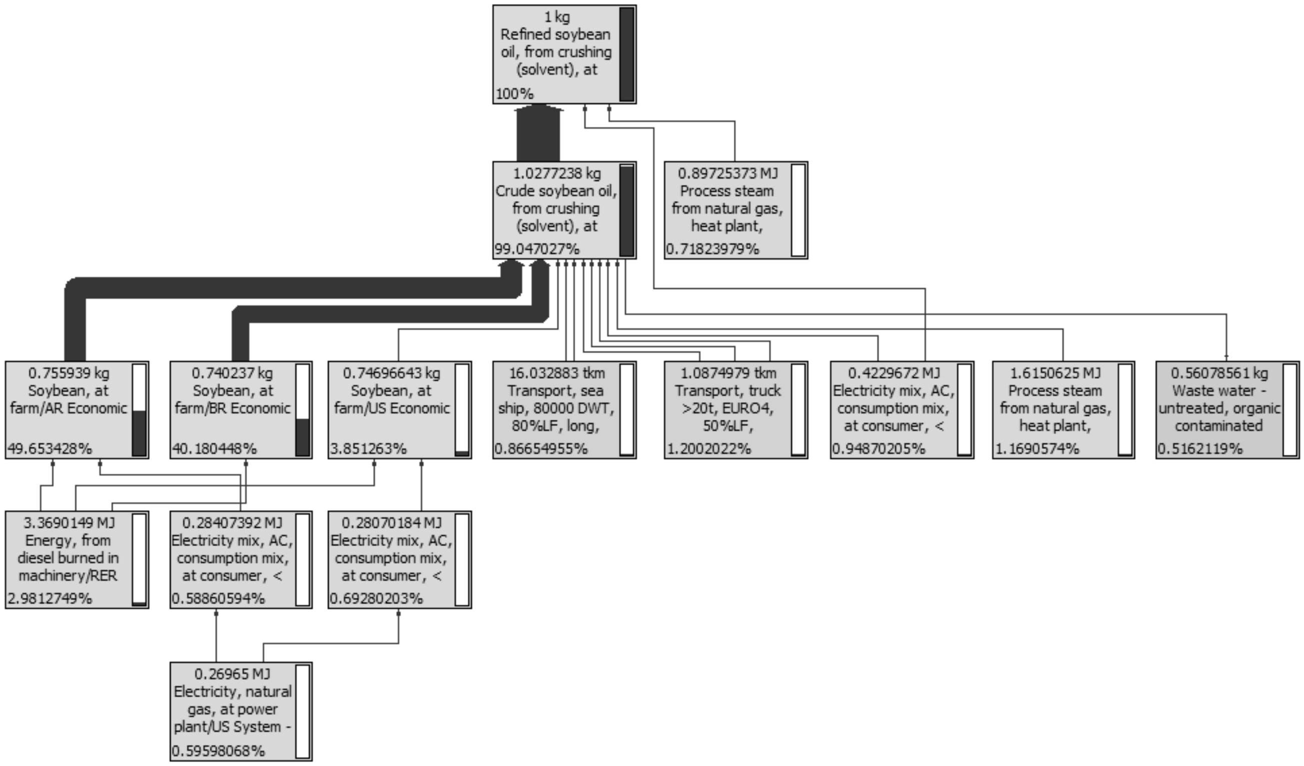

Figure 3. Example of a network diagram (in this case for refined soybean oil in the Netherlands) in Agri-footprint.

4. Discussion and conclusions

There are also a number of limitations that should be taken into account when using Agri-footprint. Internationally accepted LCA methodology for some agriculture specific environmental issues are still under development. For example, the methodology for assessment of loss of biodiversity due to land use or the estimation of direct and indirect land use change will probably evolve further. Due to limited methodology and data availability, elementary flows related to the environmental impact due to soil erosion and soil degradation are not included in Agri-footprint. The reliance on statistical data for crop yields, (artificial and organic) fertilizer application rates may not always appropriately reflect variability within regions and countries. Data availability of crop processing is also an issue that requires attention, as the use of older than desirable data sources and use of data from regions other than the region of interest is currently unavoidable.

To overcome these limitations, the database will be expanded and updated continuously. The aim is to yearly update data on crop yields, fertilizer use etc. Also the expansion to other crops and countries is important so that global production of some commodities can be better represented. Most importantly, the developers will continue to work with industry organizations to gather or gain access to new primary data for processing. Furthermore, additional non-LCA modeling approaches will be used to improve data quality on logistics and pesticide fates.

The database will be useful for LCA practitioners in the field of agricultural LCAs by providing relevant, transparent and consistent background data. As it provides an additional resource for LCA practitioners to use next to other currently available datasets, it will save time and facilitate the development of agriculture related LCAs. Agri-footprint will function as a platform for companies who wish to share their data. To ensure that the database will remain relevant in the future, there will be ongoing efforts to improve, expand and update the data.

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