Implementation of a modular web-based multi-method Tool for the Assessment of Biofuel Sustainability Standards

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Abstract

This paper deals with the scope and technical features of a tool that manages the evaluation of the impacts of biofuel production on the environment. It consists out of different modules that calculate a range of different lifecycle-based indicators (for example Greenhouse Gas emissions, hereafter GHG emissions). The data needed for the evaluation process consists of two parts. The first part is provided by the user in a web-based questionnaire. The second part contains LCI material and energy flow data and impact factors from the ecoinvent database and other scientific studies. The LCI data is imported into the database via an XML interface. To ensure easy and worldwide accessibility the tool is implemented as a web-based, database-assisted application. It was developed as combination of multiple modules for the web-content management system Drupal.

The evaluation process covers the whole lifecycle of biofuels including cultivation, processing, blending and transportation cycles. These aspects of the lifecycle can be calculated separately, as they are implemented in different modules. For a combination of the modules and total evaluation the user has to provide information about the crop type / feedstock, the country, the climatic circumstances, the used fertilizers, pesticides, energy and material data for further processing to name but a few. Depending on the users choices the emissions and material flows for the given scenario are calculated for each phase. The results of each phase are cumulated, related to reference data and visualized.

1. Introduction

1.1 Motivation - a Sustainable Development

In the respect of “Sustainable Development” the figures presented by the Intergovernmental Panel on Climate Change in the year 2007 (IPCC 2007) made obvious how pressing a community-wide approach is for sustainable development in environmental protection. Despite phases with little or no economic growth, it is not to be expected that in coming decades the ecosystem will experience periods of natural recovery, quite the opposite in fact. If one considers the current metabolic rates in the world (Organization for Economic Cooperation and Development (OECD) 2008), one finds that they are still rising. The OECD and the World Resource Forum (WRF) estimate that global resource extraction will exceed 80 billion tons in 2020. This means that mankind will have doubled the annual global rate of resource extraction within only 40 years (1980 – 2020) (WRF 2008).

Europe tries to accept the responsibility that comes with this understanding: based on a mutual but differentiated responsibility, the goals formulated for industrialized countries differ between reductions in emissions of 60-80% by 2050 (FRG 2008).

The key factor for this reduction is the energy sector. Understanding this, the European Union is currently on the verge of restructuring its energy production and consummation policy, while science is trying to offer new approaches on a cleaner production, processing and usage of energy. This paper illustrates the technical implementation of an approach to assess the sustainability impact of biofuels.

1.2 The Sustainability of Biofuels

The impetus behind assessing the sustainability of biofuels rather than exploring other new technologies is that the world’s current lifestyle is fuel dependent. Total world consumption of petroleum products in 2009 was 13.3 billion litres per day (Nuffield Council on Bioethics 2011, p.1).

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Even though at this point, biofuel production and consumption make up only a small proportion of world energy use (see Figure 1); the proportion is steadily increasing. Between 2005 and 2007, world biofuel production rose from approximately 2.5 billion litres per day to more than 5.6 billion litres per day (US Energy Information Administration 2009). This amount reflects an increase of more than a 100 per cent in production. A recent study from the Institute for European Environmental Policy estimated that 8.8 per cent of transport fuel in Europe would be biofuels by 2020.

**Figure 1: Biofuel energy share of global final energy consumption, 2008**

This trend has another reason, namely the general world energy consumption, which has been predicted to increase by 49 per cent between 2007 and 2035. This significant increase is mainly attributed to increased demand in developing countries that are not members of the OECD (Hilty and Rudy 2010). In these countries, energy consumption is forecast to increase by 84 per cent, compared with an increase of a comparatively modest 14 per cent in OECD countries. Fuel for transport – cars, aviation and shipping – makes up almost one-third of total world delivered energy consumption, and this demand will rise over the next 25 years (Nuffield Council on Bioethics 2011, p.1).

Considering that the world leaders in biofuel development and use are Brazil, the United States, France, Sweden and Germany (United Nations Department of Public Information 2007) it seems obvious that these countries have different approaches on assessing the environmental, economical and social impacts of their biofuel production and usage. A high risk is therefore the enforcement of developments out of the right reasons, but due to the pressing situation and many different approaches not well thought through or incompatible. For example, only 31 per cent of biofuels used in the UK met an environmental standard in 2009–2010 (Renewable Fuels Agency 2010, p.16). In light of these reasons the European Parliament and the European Council formulated in 2009 the Renewable Energy Directive (RED), which is also basis for one of the methodologies behind the software-tool.

### 1.3 Regulations, the Renewable Energy Directive (RED)

In this directive the European Council “reaffirmed the (...) development of energy from renewable sources” and “endorsed a mandatory target of a 20 per cent share of energy from renewable sources in overall Community energy consumption by 2020 and a mandatory 10 per cent minimum target to be achieved by all Member States for the share of biofuels in transport petrol and diesel consumption by 2020 (...)” (European Parliament / Council 2009).

The Council however added two important lines. The first one states that this “binding character” shall only apply if the production would be “sustainable”, while the second one states that “(...) it is essential to develop and fulfil effective sustainability criteria for biofuels (...)” (European Parliament / Council 2009). In this context, one can question how thought through something can be, when two following sentences basically articulate to apply certain criteria, while some of these criteria are

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somewhat still in development. Without neglecting this inconsistency the imminent situation enforces the further development of criteria and their appliance of sustainability in the context of biofuel production and usage.

The Council furthermore states that future “assessment should be made of the environmental and social consequences of the production and consumption of biofuels” (European Parliament / Council 2009) and therefore acknowledges the so called third pillar of the “house of sustainability” regarding social criteria and reflecting the dilemma of intra- and intergenerational justice. The report from the Nuffield Council on Bioethics, published on 13th of April 2011 comes to the same conclusions.

Anticipating this developed, the implementation of an approach including social criteria began in 2008 and resulted in the development of the Sustainability Quick Check for Biofuels, hereafter SQCB. With this background (the development of a webtool for the assessment of the environmental impact of biofuels, see also Section 2.3), the development of a new tool for the Roundtable on Sustainable Biofuels (RSB) started in 2010 - its main objective: the assessment and qualification of GHG emissions resulting from the cultivation, processing, transport and blending of biofuels.

2. Background of the RSB Tool

2.1 Theoretical Background - Life Cycle Analysis (LCA)

The RSB tool is composed out of different components, called modules, whiles its main module is the GHG module. This GHG module was developed on the basis of the SQCB (Section 2.3) which is a software tool developed between 2008 and 2011 in cooperation between the Swiss Federal Laboratories for Material Sciences and Technology (EMPA) and the HTW Berlin. The SQCB as well as the GHG module of the new RSB Tool are based on the Life Cycle Assessment (LCA) framework. LCA is a technique to assess the environmental impacts of a given product or service over its life cycle, i.e. from cradle-to-grave (Guinée 2001). It comprises the compilation and the evaluation of the inputs, outputs and potential environmental impacts of a products system throughout its life-cycle.

When adapted to practical use, the LCA Framework incorporates four basic steps:

- the goal definition and scoping,
- the Life Cycle Inventory (LCI) Analysis,
- the Life Cycle Impact Assessment (LCIA),
- the interpretation.

The goal definition specifies the direction the LCA will take and defines the subject of the study, while the scoping links the goal of the LCA with the extent/scope of the study, in other words, the definition of what will or will not be included (Schaltegger 1996).

The LCI Analysis aims at identifying and quantifying all inputs and outputs associated with a product system including materials, energy and residuals (Finnveden, Haushild et al. 2009). It quantifies all relevant flows of materials and energy along the value chain. Prior to the assessment of the LCIs all intermediate flows are dissolved to the inputs (resources) and the outputs (emissions) from the product over its life-cycle.

The Life Cycle Impact Assessment (LCIA) is a quantitative and/or qualitative process to classify and characterize the effects of the inputs (resources) and the outputs (emissions) listed in the inventory table (Schaltegger 1996). The LCIA is aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of the studied system (Finnveden, Haushild et al. 2009).

During the interpretation, the results from the previous phases are evaluated and put into relation with the goal and scope, in order to reach conclusions and recommendations (Finnveden, Haushild et al. 2009). Figure 2 (on the next page) shows how this framework was transformed into the workflow of the RSB GHG tool.

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http://www.sqcb.org
As shown in Figure 2, a questionnaire precedes and introduces the goal definition and scoping of the analysis, also it facilitates the data entry, which is then used to generate the LCI. Once the necessary data has been accumulated, different paths for the transformation of the questionnaire data into Life Cycle Inventory (LCI) data are possible.

Some of the data may directly be used as LCI data, for example the amount of mineral fertilizer applied per ha (bubble 1), another part is coming by default from the background data, e.g. the transport of auxiliaries (bubble 2). Depending on the input choices the data is then used in the background models and the LCI supplemented. When all required LCI flows are completed, the LCI is calculated.

2.2 Technical Background - Drupal

The calculation model is developed as a module for the open source web content management system Drupal ⁶. It is written in PHP⁵ and uses MySQL⁶ as database backend. Drupal is an open source software maintained and developed by a community of users and developers. It is distributed under the terms of the GNU General Public License (GPL), which implies a free download, share, and contribution to the project. It is highly modular and provides basic components like user management, a menu system and a template system to handle the outputs. There are also many ready to use add-on modules that are contributed by the active community. Thus standard website features like a feedback system or a newsletter system can simply be added by installing the corresponding module.

Furthermore Drupal provides powerful Application Programming Interfaces (API) that enable the developer to use core functionality like form building and database access and manipulation in a simple and secure way. Drupal features a sophisticated caching mechanism and is therefore used on highly frequented websites because of its scalability.

Out of numerous reasons Drupal was chosen as an appropriate solution to provide static information pages and the calculation procedures. The validation and control of the questionnaire is realized via JavaScript, what was also the case for the predecessor, which will be presented in the following.

2.3 Practical Background - Predecessor SQCB

The Sustainability Quick Check for Biofuels is a software-tool that was developed in cooperation between the EMPA and the HTW Berlin, financed by the Swiss State Secretariat for Economic Affairs (SECO). The main motivation behind its development was to give biofuel related companies, especially small and independent producers, a possibility to assess the sustainability impact of their respective working-processes through an open web-based questionnaire and the calculation

⁴ http://drupal.org/
⁵ http://www.php.net/
⁶ http://mysql.com/
methodology behind it. The tool facilitates the access to the Swiss market, especially for biofuel producers from emerging countries, and therefore contributes to a more sustainable implementation of biofuel production (Faist, Reinhard, and Zah 2008).

Certification schemes at that point always beard the risk that small and independent producers would be locked out and the market for sustainable biofuels dominated by international investors and large-scale plantations, due to complexity and costs. Many environmental impacts of various production chains of biofuels were however known. The SQCB was able to reduce the need for user entries to the most relevant parameters of the biofuel production chain. Based on this user input, a specific inventory was/is automatically modeled and linked to background data. The SQCB then calculates the environmental impact assessment and checks the results against sustainability criteria.

Another goal of the SQCB is/was “to support the market entrance for local biofuel producers, given that strengthening local stakeholders is a key driver for empowering rural communities in development countries” (Zah, Faist, Reinhard, and Birchmeier 2009).

The technical basis for the SQCB and the newly developed RSB tool are the same, regarding the combination of Drupal, PHP and MySQL. The development of the new tool oriented itself a lot on the development of the SQCB, considering the background software architecture, as well as the graphical user interface (GUI). Some of the calculation procedures could be taken over. The main challenge during the development of the SQCB as well as the RSB Tool remained the simplification for the user. The main difference is that the SQCB was only designed to calculate the GHG output, while the RSB tool has additional functions that go beyond that, which will be explained in the coming Section.

3. Scope and Implementation of the RSB Tool

3.1 Introduction

The RSB Tool generally consists out of different custom modules written by developers from the HTW Berlin. The main code is written in PHP and uses Drupal’s APIs in the field of form building, database communication and user management to only name a few.

The database model is very complex, however the majority of the data tables can be categorized under (1) tables necessary to store user information / data input, (2) tables related to ecoinvent LCI data, (3) cross reference tables with calculation parameters based on the methodology from the EMPA.

As mentioned in the introduction some of the conceptual work regarding the sustainability criteria (RED) is still ongoing, which made the implementation of the questionnaire very hard for the developers, as they had to change the design and also the data model during the development process multiple times. It is not unusual that a data model goes through extensive changes during agile implementation processes, but due to the high interdependency, not only in the database, but also in the source code reflecting the interdependent GUI, this process caused a lot of additional work.

Summarizing, the project aimed at developing the RSB Tool in order to enable operators to verify the compliance with all applicable standards of the RSB certification system and with regulatory requirements in the markets that the biofuel is intended for. This includes performing the RSB Principles & Criteria (P&C), a Risk Assessment and a GHG calculation of the production practice.

The intended users, operators, are defined in the standard as “individual, company or other legal entity responsible for the implementation of the RSB certification standards, and applying for participation or participating in the RSB certification system.7 Participating operators are legal entities or natural persons producing, converting, processing, blending, trading, using or otherwise handling biomass and/or biofuels and participating in the RSB certification systems.8

The main functions of the RSB tool can be summarized as: (1) Information, (2) Evaluation, (3) Guidance on applying for RSB Certification, (4) Questionnaires and data evaluation of application data, self-risk-assessment, cross checking against the RSB Principles and Criteria and the GHG impacts of their respective production processes. The GHG emission computation supports different methodologies (RSB, EU RED, swiss regulations, RFS29, LCFS10)

[8] ibidem
[10] Low Carbon Fuel Standard of California announced in Executive Order S-1-07 by Governor Schwarzenegger
3.2 Scope of the RSB Tool

GHG Calculation Module

The main functions of the GHG tool can be summarized as follows: (1) stepwise calculations of GHG intensity of a biofuel, (2) possibility of applying different regulations / schemes, (3) possibility of integrating data of other operators.

The “module” is rather a combination of different modules, depending on the chain step, i.e. there are modules for basic data entry, cultivation, processing, blending and transport, while the processing and blending/transport modules are present numerous times for the different steps between processes.

Furthermore there are two management modules that manage the creation of modules and basic data, also the interaction of the chain data.

The basic data input is always upstream of any data entry; or rather no GHG module can be created without having first created a basic data module. The idea behind it is that all modules need certain raw data and once created, a basic data set can be origin of different other GHG modules. This way the data input for the user is minimized in case he has to fill out different modules or wants to try out different combinations.

Figure 3: Structure of the GHG Modules

The cultivation module asks for all data related to the production of the feedstock, i.e. general context information, land use change, mechanical work, mineral fertilizer, organic fertilizer and pesticides. It is related to the scope of operation of a primary producer.

For the processing of a feedstock the tool contains generic questionnaires for feedstock processing and biofuel production. It asks for all interventions related to the processing of the feedstock/fuel.

The blending modules are related to the scope of operation of an intermediate distributor/blender and the final distributor/blender. The operator is asked to enter data for the blending (which products are mixed) and can add transport interventions. On the basis of these general modules the operator can calculate the GHG intensity of his product. The first tabs of every module offer access to various pages where the user has to input data, which is partly instantly validated, partly validated when switched to the validation, which always precedes the calculation process (Section 3.3 for more details). Once the data input and the validation has been completed the user has the possibility to calculate results. He then gets redirected to a new page, where he can choose different graphical representation of the calculated results. The results always include a comparison against the fossil fuel baseline (see also Figure 4).
RSB Application Module

The RSB Application module is basically a long questionnaire that requires all relevant data to apply for RSB certification. It is based on five tabs, namely Operator Information, Legal Entity Information, Operational Site Information, Facility Information and Internal Processing Step Information. Depending on the users choices and the actual situation the user is enabled to take over already entered information and or just skip parts ahead.

RSB Principles and Criteria Module

The RSB Principles and Criteria Module is a questionnaire reflecting the RSB Principles and Criteria while offering the user the choices to either be in compliance with the requirements of the criteria and its respective indicators, or not. A third option being that the indicator/criteria cannot be evaluated at that time, i.e. there is an N/A choice as additional option. The range of aspects that are reflected by the P&C go from legal questions concerning the land use, to the usage of technology, soil, water and many more.

RSB Risk Assessment Module

The RSB Risk Assessment module is similar to the RSB Principles and Criteria Questionnaire, however its aim is the calculation of a risk class and thus it uses a variety of different main- and sub-indicators to assess different risk-values for different factors. In combination with an elaborate system of quantifiers the input data is accumulated and the risk class is calculated. To give an idea of its complexity, there are currently 38 factors with up to 3 levels of main- and sub-indicators, which then offer in general 6 different choices.

3.3 Implementation and Features

GHG Calculation

In general the GHG calculation is designed to build a life cycle inventory. This means a “list” of material and energy flows (inputs and outputs) of different categories is created during the calculation process. The values representing the individual flows are calculated on the basis of special mathematical models developed by the EMPA. These models are represented in the source code. The parameters needed for the calculation are either taken directly from the user input or from the database depending on the users choices. Resulting flows and individual attributes like origin or category are stored in the database. There are different tables for the intermediate results to increase comprehensibility. The flows are then evaluated with an impact factor that displays the impact (e.g. GHG) according to different methodologies. Finally the detailed results are aggregated to be displayed on the result page.

Land Use Change

The implementation of the Land Use Change (LUC) is by far the most sophisticated part of the tool. To give an idea of the complexity, the LUC requires for its validation and calculation among 60 interconnected data-tables and various user inputs. It is possible and essential to input information considering the land use at reference date as well as the projected land use. The calculation is based around 11 main equations mainly adapted from the IPCC. The final result is the computation of the annual CO$_2$ emissions from LUC in g CO$_2$ per kg crop.

Presentation of Results

For the graphical presentation of results jqPlot$^{11}$ is used. It is a plotting and charting plugin for the jQuery JavaScript framework$^{12}$ that is able to generate line, bar and pie charts. To pass the calculated results from the server-sided, PHP-based calculations to the client-sided JavaScript-based charting library a wrapper function was developed, that can take multiple series of data and other setup

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$^{11}$http://www.jqplot.com/
$^{12}$http://www.jquery.com/
parameters into account. The layout is defined by a custom cascading style sheet. The plot is rendered into classical HTML code and then converted into HTML5 canvas elements. It is multi browser compatible and allows minimal user interaction (mouse-over effects). The results page is subdivided by tabs depending on the chosen methodologies. Each tab shows a stacked bar chart with aggregated results and a detailed table that displays special result categories (see Figure 4).

**Figure 4: Example of the presentation of calculation results**

![Image of calculation results]

<table>
<thead>
<tr>
<th>RSB</th>
<th>RED</th>
<th>CH-Legislation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0808 kgCO₂eq/MJ</td>
<td></td>
</tr>
</tbody>
</table>

### Immediate Saving System

The coding is split up pretty even between the design of the questionnaires, i.e. the graphical user interface (GUI) and the calculation procedures behind it. The implementation of the GUI was substantial, due to the requirement to show the fewest possible number of input fields corresponding to the scope of operation and input choices. This requirement also favored the usage of AJAX elements, in order to have visual indications of changing elements throughout the pages. The GUI uses a lot of AJAX effects to manage the complex dynamic forms, the browser back button problem to prevent possible data loss. To that extend functions were created so that the data is saved on every change.

### Data Validation

The validation of the input data works on different levels. Throughout the tool little helpers were implemented which check the data input values in real time (for example if the user enters data with a comma, while a number is expected it is automatically changed to a dot), also fields that require numeric values do not even save text inputs. These functions use javascript and may mostly not even be noticed by the user, the main validation however is. Before every calculation step the user must first access the validation screen which computes all necessary information considering the desired calculation procedure. Every needed input value is then checked for its plausibility and feedback is given to the user. If a procedure is possible with the input values at hand the user may start the calculation, otherwise he gets error messages that guide him to the fields that need correction.

### Auto Generated Forms

The RSB Risk Assessment is based a very large variety of different factors, main- and sub-indicators and consequently choices for the users to pick. In order not to have to implement tons of different pages and choices and automatic form generation was implemented, which gets the possible indicator levels and choices from the database and then automatically creates the questionnaires for each page/factor. The amount of needed source code was thus reduced.
PHP Excel Export Functionality and Mailing System

Using the PHP Excel Library\textsuperscript{13} interfaces to export data were created. Especially for the RSB Application Form a multi-sheet Excel export was designed, which includes formatting and also has a build-in field validation. In combination with the PHP Mailing functionality a powerful data export was created that is basically able to export and import all the data inputs as Excel and or PDF files (other file types are also possible, though not implemented yet). Also due to the field validation possible work on the processing of Application data can be reduced, as one gets instant feedback, for example if some fields were not filled out. This feature will most likely be extended, to facilitate a quicker way to import the data for everyone who cannot stay online to fill out the long questionnaires.

4. Conclusion / Outlook

4.1 Summary

The main difficulty of developing the RSB tool was the balancing act between wanting a tool that gives the user a “good feeling” through high usability, a variety of smart features, customization and adaptation depending on users choices and on the other hand, the normative goal to have the tool as compatible as possible for different browsers, web-platforms and computers that may also not meet the western standards. The use of the newest technology was therefore sometimes “exchanged” with the use of the most stable versions that possessed a comparable function spectrum. The web approach should make the tool easily accessible and quick to start from everywhere in the world.

The introduction of different methodologies in one tool are likely helping to visualize current differences in assessment and may have the potential to speed up the process of maybe reducing and establishing standards all over the world, which would be the most desired outcome regarding a more transparent and thought through evaluation process.

4.2 Future of the tool

On March 23, 2011 the RSB announced the launch of the tool at the World Biofuels Markets 2011 in Rotterdam, BL. In the following weeks the GHG Calculation procedure was finalized and the tool was opened to anyone who seeks application for certification.

On mid-term the certification platform will be linked with the tool so that the process of assessing all relevant data for the sustainability of biofuel production will be completed.

At the present moment background-work is done considering performance enhancements, module chaining (filling gaps with default data) and enhancements of the presentation components. In the future there may be more In- and Export Formats and Interfaces to other systems and depending on the methodology more pathways and products that can be considered in the calculation.

4.3 Evaluation of the Results

Some of the undesired developments in the last decades are a direct result of missing value-correlations between economical, environmental and social measures. Due to missing models for the environmental and social aspects, even the contribution of a value, indicating a quality of a process, was often just a guess. These days methodology and as result software tools are more and more enabling comparison between the sophistication of measures, production processes and or whole chains/pathways, while not neglecting the different sides of the pillars of sustainability any longer.

There is naturally still a strong variation in the assessment as well as the evaluation, in the RSB tool for example social aspects can only be acknowledged by asking many questions concerning the related fields, and its evaluation is not yet on the same level, compared to the evaluation of environmental or economical data. However it is a start and as such, with growing knowledge about the correlations, methodology is likely to make new leaps ahead, in order to enable new tools and even more precise evaluation of human actions. The RSB tool can be seen as a start in this direction, its evaluation of the environmental consequences of the Life-Cycle of Biofuels is thorough and transparent (all the information concerning the methodology and calculation procedures are open to anyone).

\textsuperscript{13} http://phpexcel.codeplex.com/
In Section 1.2 we stated that the bigger part of the increase in energy demand will be in non-OECD countries, in this respect it is important to enable producers, that may not have the western standards considering technology and regulations, with easy to access and comprehensible systems allowing them to check the environmental impact of their production. The SQCB was already going into this direction while the RSB Tool can been understood as the next step to enforce or at least suggest a cleaner and more transparent process of producing and handling biofuels.

The combination of different methodologies will hopefully lead to a comparison of standards with the long term goal of agreeing to the best possible methods to evaluate the overall quality.

Regarding the variety and the extend of the data one must question the possibility to check the users data input in the real world. That being said, the main intend of the tool itself was the streamlining of the process of data collection, data storage which it provides and due to the extensive validations it may even be able to notice any errors data coherence, i.e. it will reduce the probability that biofuel related companies could “cheat” in compliance to sustainability standards.

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6. Bibliography

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