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Environmental impact assessment of electricity production by photovoltaic system using GEOSS recommendations on interoperability

Lionel Ménard[1], Benoît Gschwind[1], Isabelle Blanc[1], Didier Beloin-Saint-Pierre[1], Lucien Wald[1], Philippe Blanc[1], Thierry Ranchin[1], Roland Hischier[2], Simone Gianfranceschi[3], Steven Smolders[4], Marc Gilles[5], Cyril Grassin [6]

Abstract

Within the Architecture Implementation Pilot (AIP-3) of GEOSS, we have developed a scenario called "environmental impact assessment of the production, transportation and use of energy for the photovoltaic (PV) sector through Life Cycle Assessment (LCA)". It aims at providing decision-makers and policy-planners with reliable and geo-localized knowledge of several impacts induced by various technologies of the PV sector. The scenario is implemented in the GEOSS Common Infrastructure (GCI) and benefits from the GEOSS interoperability arrangements. The FP7-co-funded EnerGEO project provides a GEOSS compliant Catalogue Service for the Web (CSW) that permits to discover the Web Processing Service (WPS) allowing computation of the environmental impact. A WebGIS client provided by the FP7-co-funded GENESIS platform allows users to interact with geospatial data and computation processes. This scenario has proven to be an efficient tool to disseminate knowledge on environmental impacts related to PV because of the GEOSS capabilities in interoperability.

1. Introduction

Worldwide energy use is growing and should increase by more than 40% from 2007 to 2030 (IEA, 2010), therefore implying considerable pressures on the environment through energy production, its transportation and use. There is a crucial need today for reliable and precise information in order to help stakeholders in assessing current and future impacts on environment and human health at global and local scales.

Renewable energies are considered as part of the solution when aiming at reducing the environmental impacts of energy use. Recent reports on renewable energies promote their green aspect compared with fossil based sources (EWEA, 2009; Greenpeace and European Renewable Energy Council, 2008). For example, electricity generated from renewable energies is considered as CO_2 free over its use phase (Global Wind Energy Council 2010).

[1] Center for Energy and Processes, MINES ParisTech, BP 207, 06904 Sophia Antipolis cedex, France
[2] Empa, ecoinvent Centre, Lerchenfeldstrasse 5 9014 St-Gallen Switzerland
[3] INTECS S.p.A. Via Egidio Giannessi, I-56121 Pisa, Italy
[4] GIM nv - Interleuvenlaan 5, 3001 Heverlee, Belgium
[5] Spacebel – I.Vandammestraat 5-7, 1560 Hoeilaart, Belgium
[6] Thales Alenia Space, 100 Boulevard Midi 06150 Cannes, France

However, if examined beyond direct emissions and from a life cycle perspective, renewable energies do have environmental impacts (such as “indirect CO_2 emissions”), for example during the manufacturing or fabrication phase of an installation. It is therefore necessary to consider impacts over the full life cycle of renewable energies, especially when aiming at comparing different energy pathways.

Life Cycle Assessment (LCA) is a useful tool dedicated to evaluate the environmental and human health impacts over all the life stages of a product by providing a “cradle-to-grave” environmental profile. It takes into account the extraction and processing of raw materials, the manufacturing processes, the transportation, the distribution, the use phase, the possible reuse of the finished product and the end-of-life recycling and waste management. LCAs have been introduced in the 1970s and are used more widely since the methodology was standardized in the ISO 14’040 series (ISO, 2006a, 2006b). Methodological improvements on LCA are continuously developed showing the high interest for this approach (Fava, 2002; Finnveden et al., 2009; Klöppfer, 2006; Rosenbaum et al., 2008).

Using LCA, the environmental performance of renewable systems is highly variable. For instance, Lenzen and Munksgaard (2002) show, in a LCA literature survey, that CO_2 eq. emissions per kWh for wind turbines could range from 7.9 g/kWh to 123.7 g/kWh. Environmental performances of photovoltaic (PV) systems also show significant environmental performance variability. For example, the evaluated level of CO_2 eq. emissions is ranging from 5.4 to 201.3 g CO_2/kWh over a significant sample of publications (Pacca et al., 2007). There are many reasons, which explain this high level of variability, such as the broad technological possibilities that stems from the international development of industry (Beloin-Saint-Pierre et al., 2009). Environmental performances of renewable energy systems are also highly geo-dependent (Blanc et al., 2008; Jungbluth et al., 2008), and driven by external factors influencing electricity production over the PV installations life time.

This wide variability in environmental performances can lead policy makers to consider LCA as an inconclusive method (Reap et al., 2008). To improve confidence in LCA results, it is thus necessary to make these wide-ranging results comprehensive and explain the variability sources through meta-analysis by identifying the main parameters influencing the environmental performance of the system.

Another important step to expand the use of LCAs in industry and to support decision–making is to provide access to a simple tool which present comprehensive evaluation of renewable energies environmental impacts. Simple and easy access to robust environmental performances evaluation would be useful, for example, to identify the most suitable locations for renewable energy systems.

Our efforts are currently orientated to contribute to and to develop this type of tool with the support of GEO (Group on Earth Observation) / GEOSS (Global Earth Observation System of Systems) interoperability arrangements (Singh Kalsa et al., 2009). GEO is an intergovernmental organization at the ministerial level. The GEO vision is to realize a future wherein decisions and actions for the benefit of humankind are informed via coordinated, comprehensive and sustained Earth observations and information. The GEO is coordinating efforts in order to build a Global Earth Observation System of Systems or GEOSS. GEOSS is composed of contributed Earth observation systems, ranging from primary data collection systems to systems concerned with the creation and distribution of information products. GEOSS aspires to encompass all areas of the world, and to include all manner of observations, whether space-based, airborne, or in situ. Technical requirements on contributed systems from a system architecture and data management perspective are known as “interoperability arrangements”. Interoperability arrangements define interactions between components provided by GEO members and participating organizations. Contributed components interact between each other by exchanging structured messages over network communication services. The GEOSS architecture principles define how contributed components fit together in order to produce an overall system capable of providing information and data of added values compared to individual components operating in isolation and meeting societal needs. GEOSS interoperability arrangements favour non-proprietary open and recognized standards with preference given to formal international standards such as ISO.

We took the opportunity to develop a tool for PV systems during Phase 3 of the Architecture Implementation Pilot (AIP-3) (GEOSS, 2011) organized by GEOSS through a scenario called "environmental impact assessment of the production, transportation and use of energy for the photovoltaic (PV) sector through Life Cycle Assessment (LCA)" (Menard, 2011). This scenario aims at providing decision-makers and policy-planners with reliable and precise knowledge of several impacts induced by the various technologies used in the PV sector, and consequently at helping them in selecting the most appropriate technologies or identifying the most relevant locations for PV installations. Potential actors that would fully benefit from this AIP-3 energy scenario range from high-level end-users like policy planners, who need synthetic assessment and reporting, or energy operators, who conduct top-level studies, down to installers of renewable energy systems.

This paper is reporting in detail the methodology to provide environmental impacts assessment of PV systems through LCA and how this specific energy scenario has been designed through technological choices and interactions between the AIP-3 project partners. Finally, outcomes are provided through a set of parameters and maps of geo-localized PV systems environmental performances, which are available on a geographic WebGIS client.

2. Assessing environmental impacts of electricity production by photovoltaic system through Life Cycle Assessment

Based on the work of Ness and co-workers (Ness et al., 2007), indicating that LCA is the most established and well-developed product-related sustainability assessment tool, we choose to assess herewith the electricity production by photovoltaic system. LCA is a tool that covers all life stages of a system. We distinguish four phases in a LCA study according to the ISO 14040 series: the goal and scope definition, the life cycle inventory calculation, the life cycle impact assessment and the interpretation. A life cycle inventory is a compilation of the inputs (resources) and the outputs (emissions) from the product over its life cycle. Impact assessment aims at evaluating the magnitude and significance of the potential impacts (on the environment and on human health) of the studied systems. Inventories are converted into these impacts with specific life cycle impact assessment methods covering different categories of environmental damages such as the consumption of non-renewable resources, the contribution to the greenhouse effect, or the modifications created in the ecosystems, as well as the impacts on human health.

This GEOSS AIP-3 energy scenario works by the linkage of several inputs coming from databases, from impact models as well as from user inputs parameters. Key databases for environmental impacts assessment of photovoltaic systems have been provided by MINES ParisTech and the ecoinvent Centre.

The HelioClim3 database built by MINES ParisTech (Blanc et al., 2011) provides a Web based on-line access to surface solar irradiance (SSI) values for any site and any instant within a large geographical area and a large period of time. The spatial coverage includes Europe, Africa, and the Atlantic Ocean and exploits the enhanced capabilities of the Meteosat Second Generation series of satellites to deliver values of SSI every 15 min, with a nadir spatial resolution of 3 km, in near real-time. In the GEOSS AIP-3 energy scenario the HelioClim3 dataset is limited to monthly means of the year 2005.

The ecoinvent Centre provides life cycle inventory (LCI) data of recognized quality with the database ecoinvent data v2.2 (ecoinvent Centre, 2010). The database contains international industrial life cycle inventory data on energy supply, resource extraction, material supply (chemicals, metals, plastics, paper/board, glass, construction materials, and electronics), agriculture, waste management services, and transport services. In the GEOSS AIP-3 energy scenario only the subset of ecoinvent data v2.2 related to photovoltaic systems has been used.

Several recent and recognized environmental impacts methods have been integrated in the AIP-3 Web service: IMPACT 2002+, IPCC 2007, Cumulative Energy Demand (CED), and Eco-Indicator 99. This selection offers the user methods ranging from detailed environmental impact indicators to aggregated single indicator:

- The IPCC 2007 method reports the global warming potential (GWP) of greenhouses gases (GHG) following the method developed by the International Panel on Climate Change (IPCC) (Forster et al., 2007). The climate effects of a greenhouse gas depends on its ability to absorb heat radiation, on how long the gas remains in the atmosphere and on the amount of gas emitted in the atmosphere. Since the greenhouse gases exhibit different dwell times in the atmosphere one can calculate the GWP for different time intervals. It is common to use a time perspective of a hundred years. Three time ranges are proposed in the Web service: 20, 100 and 500 years. The greenhouse gases are normalized using carbon dioxide as the reference gas.
- The Cumulative Energy Demand method (CED) (Hischier et al., 2010) aggregates the energy resources with relevant characterization factors divided in 5 impact categories: (1) Non renewable, fossil (2) Non renewable, nuclear (3) Renewable, biomass (4) Renewable, wind, solar, geothermal (5) Renewable, water. The inclusion of CED is useful since non-renewable cumulative energy demand explains a significant proportion of the environmental impacts variation between products (Huijbregts et al., 2006).
- Eco-indicator 99 proposes a single aggregated indicator (Dreyer et al., 2003; Goedkoop et al, 2001). Eco-indicator 99 is both a science-based impact assessment method for LCA and a pragmatic eco-design method. It offers a way to measure various environmental impacts, and shows the final result in a single score. Damage models were developed that link inventory results to three damage categories (endpoints in ISO terminology): (1) Damage to human health (2) Damage to ecosystem quality (3) Damage to resources. A weighting scheme has then been applied to these damages based on panellists representing different perspectives: (1) Hierarchist (2) Individualist (3) Egalitarian. Such aggregated scores should always be used for internal purposes and are not suitable to use in public comparisons, marketing and eco-labelling, as they lack the necessary transparency.
- The IMPACT 2002+ life cycle impact assessment methodology (Jolliet et al., 2003) proposes a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results (elementary flows and other interventions) via 14 midpoint categories to four damage categories: human health (expressed in DALY = Disability Adjusted Life Years) climate change (expressed in g CO_2 eq), resources (expressed in MJ) and ecosystem quality (expressed in PDF m^2 year = Potentially Disappeared Fraction).

The scope of the PV electricity production alternatives selected for the AIP-3 PV scenario is the following: a grid-connected PV system installation of 3 kW_p on a slanted roof. Several technologies are considered: multi-crystalline, mono-crystalline and thin film technologies. Inverters of 2500 W are used for this installation and each has a lifetime of 10 years. Energy production performances of different PV systems vary depending on its technology. Lifetimes of 20, 25 and 30 years have been considered allowing for the computation of the electricity produced by different PV systems.

Inputs, models and outputs chain, which are necessary to implement the AIP-3 scenario, can be described as follows. Life Cycle Inventories (available thanks to ecoinvent data v2.2) are selected according to the inputs related to the PV system selection (power, technology and energy efficiency). The electricity production is modelled integrating geo-localized data (solar irradiation on a specific site) as well as the orientation and slope of the PV system. As final results, these inventories are converted into impacts (thanks to a selected impact model) relatively to the electricity produced over the lifetime giving electricity environmental impacts (per kWh) as outputs.

3. Implementation of the scenario in the GEOSS Common Infrastructure (GCI)

This scenario relies heavily on data exchange and combination as well as distributed computation over the network in order to obtain value added information. Choosing interoperability arrangements promoted by GEOSS was a guarantee to reach our goals regarding the final implementation of the scenario. GEOSS fosters the demonstration of interoperability mechanisms by issuing Calls For Participation (CFP) for pilot projects. The opportunity to demonstrate such mechanisms and common practices has been realized in the framework of our scenario response to GEOSS AIP-3 CFP. The GEOSS Common Infrastructure (GCI) (Figure 1) (Concept, 2008) includes the core components and functions that link the various resources of GEOSS together.

The GCI includes three major capabilities:

- Registries of GEOSS components, services, standards, requirements, and best practices,
- A common search facility, known as the GEOSS Clearinghouse, that simplifies search across all offered and registered resources, and
- A web portal that provides human users a "one stop" access to all GEOSS resources

The GEOSS AIP-3 energy scenario is aligned with the GEOSS interoperability arrangements requirements and has made an extensive use of components and capabilities of the GCI.

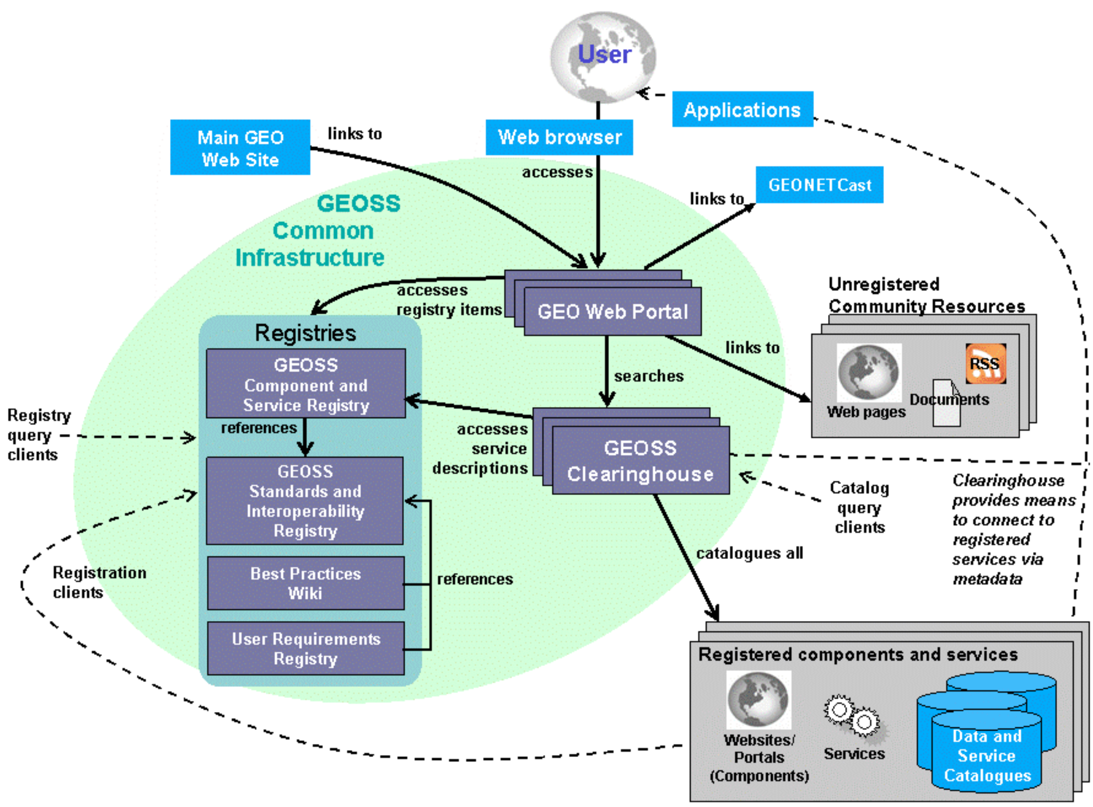

Figure 1: The GCI and the major relationships with external resources

From the GEOSS user perspective, two main requirements should be fulfilled:

1. Allow Search and Discovery of information resources through the GEO Web Portal (http://www.geoportal.org) that provides a single official ‘front door’ for GEOSS users to search, discover and access GEOSS resources.
2. Availability of Client “Helper” Applications providing the user with a way to retrieve and exploit the discovered resources.

In addition to the core components of the GCI, the GEOSS AIP-3 energy scenario relies on components and services that have been provided by two complementary on-going projects co-funded by the European Commission (FP7).

EnerGEO (launched in 2009) is a four years project that aims at developing a strategy for a global assessment of the current and future environment and ecosystem impacts of energy resources exploitation. It also plans to demonstrate this strategy for a variety of energy resources worldwide.

GENESIS (launched in 2008) is a three years project that provides a thematic-independent solution based on a Service Oriented Architecture (SOA). It is made of a generic software package used to facilitate interoperability between information systems providing easy access to databases or services at regional, national and European level.

In order to enable search & discovery of resources as well as making a client application available allowing end-users to exploit the resources, the following components have been contributed.

The GENESIS Legacy Interconnection Toolbox (code.google.com/p/toolboxenvironment) is a software component to easily transform legacy applications into Web services with standard compliant interfaces to facilitate the integration of existing applications into Service Oriented Architectures (SOA). It supports the OGC Web Processing Service (WPS) (Percivall et al., 2011; Schut, 2005) specification to launch processing jobs on remote servers.

The GEOSS energy community portal (www.webservice-energy.org) offers to the GEOSS community a place to access on-line energy and environmental related resources.

The OGC CSW (Catalogue Service for the Web) EnerGEO community catalogue (energeo.researchstudio.at) provides a standard approach using ISO metadata (ISO 19119) to describe resources for dissemination purposes.

The GENESIS Portal is a Portlet (JSR-286) based Portal that allows to easily generate the user interface (client applications) to interact with remote Web Services via standard interoperable interfaces such as OGC Cataloguing and WPS.

The GENESIS Geodata Visualisation Portlet system provides a powerful and flexible WebGIS Client that can be instantiated in various forms and with varying functionality inside any JSR286 compliant portal or used standalone.

4. Description of the components

During the implementation phase of the AIP-3 scenario, several components have been either developed or re-used. This includes a GEOSS community portal, an OGC catalogue, WPS and WMS (Web Map Service) Services, a generic portal and a WebGIS client. This communication focuses on two of them: the WPS and the WebGIS client.

4.1 OGC Web Processing Service (WPS)

Web Processing Services offer a standard and interoperable approach to access, combine and process remote and spread resources to obtain value-added information. Access to environmental impact assessment computation methods has been provided through such a WPS. This WPS implements various

state-of-the-art impact methods for assessing the environmental performance of different PV systems. Those methods make use of two databases: the surface solar irradiance HelioClim3 database and the life cycle inventories of PV systems from the ecoinvent v2.2 database.
To implement and deploy the WPS "impact assessment" we have used the GENESIS Legacy Interconnection Toolbox. This Toolbox is a configurable application released under the GNU GPL license that facilitates the conversion of legacy applications into a WPS. On the front end the Toolbox implements the WPS HTTP and SOAP bindings (both approaches reported in 05-007r7 and 08-091r6 are supported). On the back end it can be connected to GRASS GIS (Geographical Information System) or via shell scripts to any legacy application. The tool automatically downloads any referred remote resource and translates the incoming input parameters into variables to be used in the scripts that implement the service logic. The toolbox also provides a Web-based testing and monitoring tool allowing, for instance, to list all the incoming requests, evaluate their status and inspect the response messages.

In our scenario, we have implemented a single WPS that handles all operations that come from the two WebGIS client applications. The legacy applications that compute environmental performance maps and point datasets are developed in the Python programming language.

4.2 WebGIS Client Application

As mentioned along this text the goal of this scenario is to provide the end-user with an easy to use geographical WebGIS client ("helper application") allowing interaction with geospatial data and computation processes. This has been realised by using the GENESIS Geodata Visualisation Portlet. This Portlet deployed within the GENESIS Portal provides a powerful and flexible WebGIS Client that can be instantiated inside any JSR286 compliant portal or used standalone. The environmental impact assessment WPS clients (maps and points) contain customized geographic Web interface to capture geographic input into services and to display geographically referenced results as maps, tables and charts.

5. Running the environmental impact assessment PV scenario

To start using this WebGIS client, one must access the GENESIS Portal (http://gppf.genesis-fp7.eu/) and log-in using the following credentials: login: demo; password: demo. In the "Environmental Impact Assessment" section, one can access either the map-based option providing environmental performances maps covering Europe or the point-based option providing environmental performances for specific sites selected by the user.

To run the AIP3 Energy point-based option, the followings inputs are to be chosen according to six steps:

1. The user first has to select among several PV modules technologies (monocrystalline, multicrystalline and amorphous silicon as well as thin film technologies: CdTe and CIS)
2. The environmental performances are assessed over the expected PV lifetime to be selected (20, 25 or 30 years).
3. A performance ratio to be confirmed by the user on a scale from 0.5 to 0.9 with a standard value set to 0.8 by default.
4. The orientation of the PV is required ranging from 0° = South to 180 ° = North. A south orientation is advised for better performances.
5. The inclination of the PV is required ranging from 0° to 90°. A 35 ° inclination is set by default.
6. Finally, an environmental impact assessing method has to be selected among the 4 available possibilities. The method choice will provide different types of impacts ranging from detailed environmental impact indicators to aggregated single indicator.

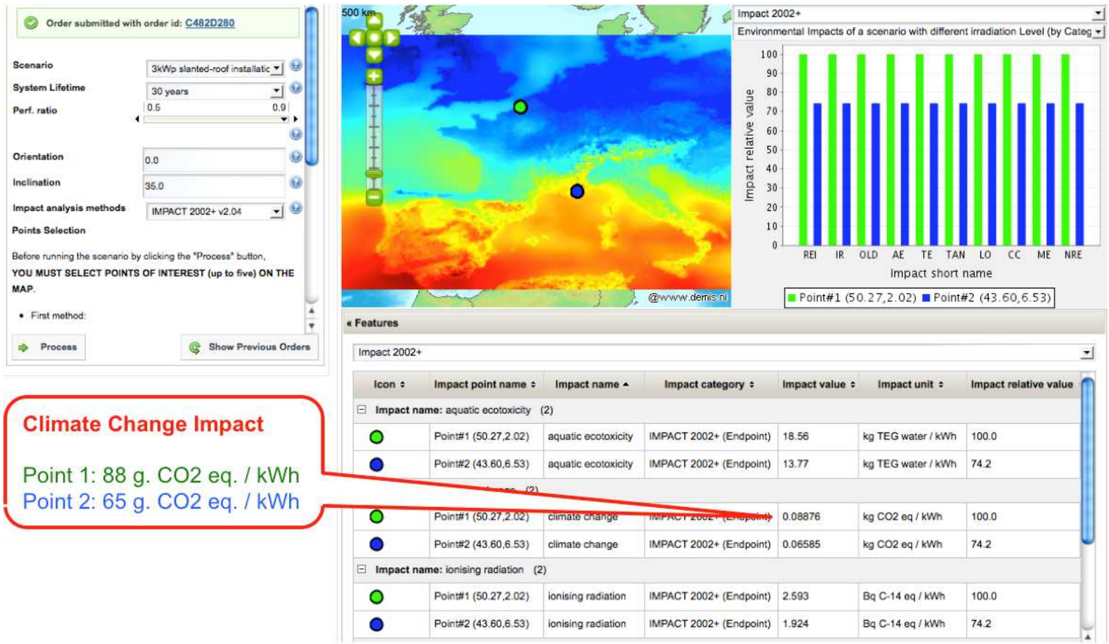

Figure 2: Environmental impact assessment of a PV system results from the WebGIS Client

In Figure 2, two locations have been selected: one in the North of France and one in the South-East of France. For both selections, environmental performances are provided and we have highlighted results for a specific impact issue: climate change. Considering the following characteristics: a South orientation with a 35° inclination for a multi-crystalline technology with a 30 years life time and an installation performance ratio of 0.9, we get a 88 g CO_2 eq/ kWh performance for the North case while the South case has a better performance with 65 g CO_2 eq/ kWh. Access to all other impacts is easily done through the available menus. Such comparison between different locations is very useful for the previously identified users to choose an optimal location in order to minimize environmental impacts.

6. Conclusion

This study has highlighted several key findings. This interoperable energy scenario has first proven to be a formidable tool to disseminate knowledge on environmental impacts related to PV scenarios. Users now have on line access to life cycle environmental performances for a wide variety of PV configurations in terms of technology and implementation, answering to many realistic installation implementations over Europe. Models and data providers (solar irradiation, life cycle inventories and life cycle impact models) also find through the use of web-service technology, a means to simplify and ease dissemination of their models and data. The possibilities to easily share expertise and knowledge for modelers and data providers (GEOSS, 2007) have revealed the high benefit of complying with the GEOSS interoperability recommendations. The GEOSS AIP-3 scenario provided the opportunity to test and further develop a generic geographic Web Processing Service and Client system that can be easily customized for specific processes. The FP7 GENESIS project has contributed to the elaboration of this system and proved its added value by lowering the implementation barrier for the deployment of such systems. Extensions to other renewable energies and technologies are now worth to be undertaken and could be implemented for example in the FP7 EnerGEO project to contribute to an integrated energy platform.

Bibliography

Beloin-Saint-Pierre, D., Blanc, I., Payet, J., Jacquin, P., Adra, N., Mayer, D. (2009): Environmental impact of PV systems: Effects of energy sources used in production of solar panels, In Proceedings of the 24thEuropean Photovoltaïc Solar Energy Conference, 21-25 September 2009, Hamburg, Germany ISBN 3-936338-25-6, pp. 4517-4520. doi: 10.4229/24thEUPVSEC2009-6DV.3.7

Blanc, I, Beloin-Saint-Pierre, D., Payet, J., Jaquin, P., Adra, N., Mayer, D. (2008): Espace-PV: key sensitive parameters for environmental impacts of grid-connected PV systems with LCA: In Proceedings of the 23rd European Photovoltaïc Solar Energy Conference, 1-5 September 2008, Valencia, Spain, ISBN 3-936338-24-8, pp. 3779-3781. doi: 10.4229/23rdEUPVSEC2008-6DV.5.9.

Blanc, Ph., Gschwind, B., Lefèvre, M., Wald, L., (2011): The HelioClim project: Surface solar irradiance data for climate applications. Remote Sensing, 3, pp. 343-361; doi: 10.3390/rs3020343.

Concept of operation of the GEOSS Common Infrastructure, (2008) Available at: http://www.earthobservations.org/documents/excom/ec14/09_Concept%20of%20Operations%20Document%20GEOSS%20Common%20Infrastructure.pdf

Dreyer, LC., Niemann, AL., Hauschild, MZ., (2003): Comparison of three different LCIA methods: EDIP97, CML2001 and Eco-indicator 99 - Does it matter which one you choose? In: The International Journal of Life Cycle Assessment, vol 8, 4, pp. 191-200, doi: 10.1007/BF02978471

ecoinvent Centre (2010), ecoinvent data v2.2. ecoinvent reports No.1-25, Swiss Centre for Life Cycle Inventories, Dübendorf, 2010, retrieved from: www.ecoinvent.org.

EWEA, (2009) Climate change factsheet. European Wind Energy Association.

Fava, J. (2002) **:** Life cycle initiative: a joint UNEP/SETAC partnership to advance the life-cycle economy in : The International Journal of Life Cycle Assessment: vol 7, 4, pp. 196-198, doi: 10.1007/BF02978873

Finnveden, G., Hauschild M., Ekvall, T., Guinée J., Heijungs R., Hellweg, S., Koehler, A., Pennington D., Suh, S. (2009): Recent development in LCA in : Jounal of Environmental Management : vol 91, 1, pp. 1-31.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland (2007): Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. [access on July 20th 2011 : http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf]

GEOSS Strategic Guidance for Current and Potential Contributors, (2007): http://www.earthobservations.org/documents/portal/25_Strategic%20Guidance%20Document.pdf

GEOSS Architecture Implementation Pilots, (2011) http://www.ogcnetwork.net/AIpilot

Goedkoop, M., Spriensma, R., Müller-Wenk, R., Hofstetter, P., Köllner, T., Mettier, T., Braunschweig, A., Frischknecht, R., van de Meent, D., Rikken, M., Breure, T., Heijungs, R., Lindeijer, E., Sas, S.Effting, H.: (2001): The Eco-indicator 99: A Damage Oriented Method for Life Cycle Impact Assessment. Methodology Report: Third Edition, Amersfoort: Pré Consultants. [access on July 21st 2011 : http://www.startipp.gr/methodology%20annex.pdf]

Greenpeace and European Renewable Energy Council (EREC), (2008): Energy [r]evolution a sustainable global energy outlook : Greenpeace International, European Renewable Energy Council (EREC).

Hischier R, Weidema B, Althaus HJ, Bauer C, Doka G, Dones R, Frischknecht R, Hellweg S, Humbert S, Jungbluth N, Köllner T, Loerincik Y, Margni M, Nemecek T, (2010): Implementation of Life Cycle Impact Assessment Methods - Final report Ecoinvent, Ecoinvent.

Huijbregts, MAJ., Rombouts, L., Hellweg, S., Frischknecht, R., Hendriks, A., van de Meent, D., Ragas, A., Reijnders, L., Struijs, J. (2006): Is cumulative Fossil Energy demand a useful indicator for the environmental performance of products? in Environ. Sci. Technol., 40 (3), 641-648. doi: 10.1021/es051689g

IEA, (2010): Key world energy statistics: International Energy Agency [access on Aug 2nd 2011: http://www.iea.org/textbase/nppdf/free/2010/key_stats_2010.pdf]

ISO, (2006a) ISO, ISO 14040 International Standard, *Environmental Management – Life Cycle Assessment – Principles and Framework*, International Organisation for Standardization, Geneva, Switzerland.

ISO, (2006b) ISO, ISO 14044 International Standard, *Environmental Management – Life Cycle Assessment – Requirements and Guidelines*, International Organisation for Standardisation, Geneva, Switzerland.

Jolliet, O., Margni, M., Charles, R., Humbert, S., Payet, J., Rebitzer, G., and Rosenbaum, R., (2003): IMPACT 2002+ : A new life cycle impact assessment methodology," International Journal of Life Cycle Assessment, vol. 8, pp. 324-330.

Jungbluth N., Tuchschmid M. and de Wild-Scholten MJ, (2008): Life Cycle Assessment of Photovoltaics: Update of Ecoinvent data v2.0 [access on July 20th 2011: http://www.esu-services.ch/fileadmin/download/jungbluth-2008-LCA-PV-web.pdf]

Klöppfer, W., (2006): The role of SETAC in the development of LCA in: The International Journal of Life Cycle Assessment : vol 11, Supplement 1, pp. 116-122, DOI: 10.1065/lca2006.04.019

Lenzen, M., Munksgaard, J., (2002): Energy and CO2 life-cycle analyses of wind turbines--review and applications: Renewable Energy, vol. 26 (3), pp. 339-362.

Menard, L., (2011): "Energy Scenario" Engineering Report, GEO Architecture Implementation Pilot, Phase 3: http://www.ogcnetwork.net/pub/ogcnetwork/GEOSS/AIP3/documents/AIP-3-Energy-Scenario-ER-FINAL.pdf

Ness B., Urbel-Piirsalu E., Anderberg S., Olsson L., (2007): Categorising tools for sustainability assessment. Ecological Economics, vol. 60 (3), pp. 498-508.

Pacca S, Sivaraman D, and Keoleian GA, (2007): Parameters affecting the life cycle performance of PV technologies and systems: Energy Policy, vol. 35, pp. 3316-3326.

Percivall G., Menard L., Chung L.K., Nativi S., Pearlman J., (2011): Geo-processing in cyber-infrastructure: Making the Web an easy to use geospatial computational platform: 34th International Symposium for Remote Sensing of the Environment, Sydney, Australia.

Reap, J., F. Roman, Duncan, S., Bras, B., (2008): A survey of unresolved problems in life cycle assessment Part 2: impact assessment and interpretation. International Journal of LCA, 13, pp. 374-388.

Rosenbaum, R., Bachmann, T., Swirsky Gold, L., Huijbregts, M., Jolliet, O., Juraske, R., Koehler, A., Larsen, H., MacLeod M., and Margni, M;, et al., (2008) : USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment in : The International Journal of Life Cycle Assessment: vol 13, 7, pp. 532-546, doi: 10.1007/s11367-008-0038-4

Schut, P., (2007): OpenGIS Web Processing Service specification. OGC document number 05-007r7.

Singh Kalsa S.J., Nativi S., Geller G.N., (2009): The GEOSS Interoperability Process Pilot Project (IP3): IEEE Trans. Geoscience an,d Remote Sensing, vol. 47, n°. 1.