Benefit of GEOSS Interoperability in Assessment of Environmental Impacts Illustrated by the Case of Photovoltaic Systems

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Benefit of GEOSS interoperability in assessment of environmental impacts illustrated by the case of photovoltaic systems

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***Abstract*— Assessment of environmental impacts of a power system exploiting a renewable energy needs a large number of geographically-dependent data and of technological data. These data are located in various sources and available in various formats. To avoid the burden of data collection and reformatting, we exploit the interoperability capabilities set up in GEOSS and combine them with other GEOSS-compliant components proposed by projects funded by the European Commission. This is illustrated by the case of photovoltaic systems. A Web-based tool links the various sources of data and executes several models to offer various impacts factors in different areas: human health, climate change, primary energy, ecosystems.**

***Index Terms*—Environmental impacts, FP7 projects, GEOSS, interoperability, life cycle assessment, photovoltaic systems, standards.**

I. INTRODUCTION

Renewable energies are considered as valuable alternatives to fossil fuels through their contribution to a significant reduction of environmental impacts in a near future [1], [2]. Environmental performances of renewable energies can be assessed thanks to Life Cycle Assessment (LCA), 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. Environmental performances of renewable systems are highly variable: for example CO_2 eq. emissions per kWh for wind turbines could range from 8 g/kWh to 124 g/kWh [3]. Similar variations occur for photovoltaic (PV) systems with levels of CO_2 eq. emissions ranging from 5 g CO_2 eq/kWh to 201 g CO_2 eq/kWh [4]. Environmental performances of renewable energy systems highly depend of their geo-localization [5], [6] and are driven by external factors influencing electricity production over the lifetime of installation. Although wind and solar resources, for example, appear to be abundant, technological, economic and planning issues significantly reduce the theoretical potential of energy production [7]. Numerous geographically-dependent factors and technology data are therefore necessary to assess relevant environmental performances and to support decision makers. GIS solutions are a good means to handle and exploit these multidisciplinary data [8], [9]. In practice, the situation is far from being simple: the data are located in different sources and in various formats.

Consequently, environmental performances of renewable energy systems are difficult to assess. A major step forward will be accomplished in this area if access could be provided to a simple tool that offers a comprehensive evaluation of the environmental impacts in renewable energies. This tool could be Web-based, should be able to link to the various sources of geographically-dependent and technological data needed for the impact assessment, and should be able to execute several models to offer various impacts factors in different areas: human health, climate change, water...

Interoperability has been defined as *the capability of the user interface and administrative software of one instance of a service to interact with other instances of same type of services* [10], [11]. GEOSS (Global Earth Observation System of Systems) addresses interoperability by providing guidance and recommendations on "interoperability arrangements" that promote the convergence of Earth observing systems. The Group on Earth Observation (GEO) is coordinating the development of GEOSS promoting interoperability among members and participating organizations.

The third phase of the Architecture Implementation Pilot (AIP-3) [12] organized by GEOSS has been an opportunity and a framework for the development of a tool targeted towards PV systems practitioners. This tool has been implemented through a scenario called “environmental impact assessment of the production, transportation and use of energy for the photovoltaic sector” [13]. The 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.

Several components, databases, metadata and Web services were needed to fulfill this scenario. It includes: life cycle inventories and surface solar irradiances databases; distributed catalogue enabling service discovery; Web services development and deployment framework;

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community portal and geo-data visualization client. These elements were available among the partners of the group implementing the scenario and were spread over the network. GEOSS has defined interoperability arrangements to promote the use of formal, internationally-recognized, open and non-proprietary standards. Partners have agreed on these arrangements enabling the deployment and the communication workflow among contributed components and consequently permitting the reach of the goals of the scenario.

This article describes briefly the GEOSS infrastructure and GEOSS recommendations on interoperability [14], [15] that support the deployment of the AIP-3 scenario. It explains the data needed to fulfill the scenario, the models for computing environmental impact, and outputs. Finally, it provides a precise description of contributed components leveraging the GEOSS infrastructure.

II. GEOSS INFRASTRUCTURE

Providers of data and/or components wishing to promote resources in GEOSS infrastructure have to cope with a service-oriented architecture (SOA) approach as promoted by GEO in the GEOSS 10-Year Implementation Plan [16].

Nowadays, the maturity of the GEOSS Common Infrastructure (GCI) clearly emphasizes the SOA approach where contributed components interact each other through structured message exchange over the network.

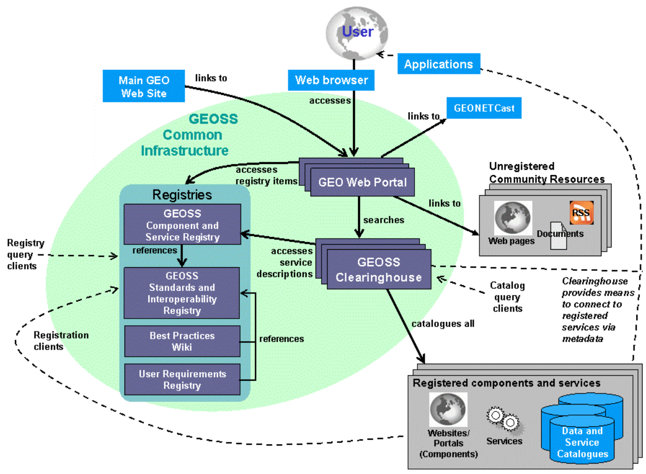

Figure 1: The GEOSS Common Infrastructure (GCI)

The GCI includes core components and functions that link the various GEOSS resources together. As illustrated in Fig. 1, the GCI provides three major capabilities:

- registration of GEOSS components, services, standards, requirements and best practices through several Service Registries;
- a common search facility, known as the GEOSS Clearinghouse, that simplifies search across all offered and registered resources;
- a GEO Web portal that provides human users with a "one stop" access to all GEOSS resources.

User will browse, query and retrieve information available in GEOSS by using the GEO Web Portal. The GEO Web Portal (http://www.geoportal.org) provides the single official 'front door' to access GEOSS resources.

In distributed environment architecture, resources belong to and are hosted by resources providers. Resources providers need to ensure that access to their resources complies with GEOSS recommendation on interoperability. GEOSS provides methodology and consistent support to help potential providers and ensure a smooth interoperable integration of their resources into the GCI. A set of transverse and reusable engineering "Use Cases" has been developed (Fig. 2) that can apply across several thematic areas.

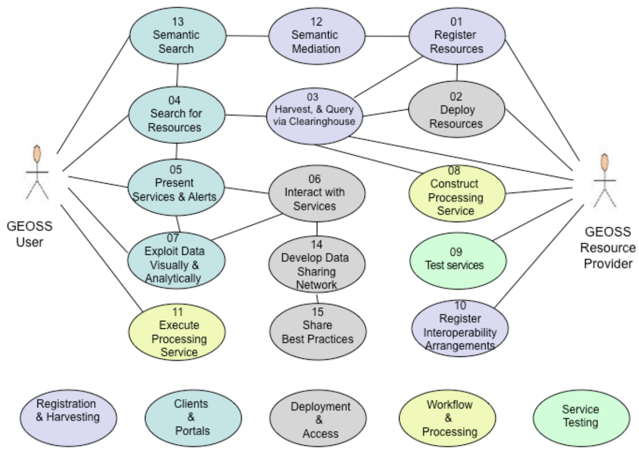

Figure 2: Transverse Engineering Use Cases

The AIP-3 scenario is described in terms of "scenario events", i.e. a detailed list of the steps that will conduct to the creation of resources and products initiated by actors using GEOSS. The steps will be accomplished through the set of existing Use Cases. As a whole, the AIP-3 scenario deals with Use Cases number 1 to 8 and 11. The first 3 scenario events out of 6 are shown in Fig. 3.

III. EVALUATION OF ENVIRONMENTAL IMPACTS

Expanding the use of LCA in the industry to support decision-making implies the development of simple and well-targeted tools. We focus here on providing such a simple tool to support decision-making for the evaluation of environmental impacts of a power system in renewable energies. Evaluating the best localization of a renewable energy system by its environmental performances would be considered as a very useful tool by policy-planners, energy operators, and more generally by decision-makers.

The tool deals with several categories of environmental damages: contribution to the greenhouse effect (so-called climate change), impact on human health, modifications created in the ecosystems, and consumption on non-renewable resources, including primary energy. We illustrate the tool by the case of photovoltaic systems. Such systems produce electricity from solar radiation received on panels.

Steps	Description	Use Case Number (#) and Description
00	A Policy planner, an Energy Operator and /or an Installer of Renewable Energy System is *searching for services* providing value added information of the environmental impacts of the production of PV electricity on a given area. These services are discovered through the *GEOSS Portal*. The *GEOSS Portal* provides minimum information about available services and how to access them.	#4 *Search for resources* in Registry, Clearinghouse, Community Catalogs and Portal.
01	Based on services found at Step 00, the Policy planner accesses a Visualization Portlet integrated within the EC FP7 GENESIS Portal to initiate the environmental impacts assessment. The *Environmental impacts assessment Web Services* available through OGC WMS and WPS compliant interfaces for respectively visualization and value adding processes are also available for either direct machine to machine access or further integration.	#5 User *presentation* of information about available applications and services. #8 *Construct Processing Service* #11 *Execute Processing Service*
02	The client Portlet is triggering various OGC compliant Web Services (*WMS, WFS, WPS*) to perform the Environmental Impacts Assessment Life Cycle Analysis (LCA). The client Portlet as well as *Solar Radiation* and *Environmental Impacts Assessment Web Services* have been previously registered in the GEOSS *Catalog and Service Registry* (CSR) by the Community Resource Providers. In order to allow Search & Discovery mechanism the Community Resource Providers have previously registered the *OGC Web Services* with the *EnerGEO OGC/CSW Energy Catalog Portal*. The Community Catalog Provider has created the appropriate Metadata and ingested this into the Catalog to allow harvesting by the *GEOSS Clearinghouse*.	#1 *Register resources* in the GEOSS CSR. #8 *Construct Processing Service* #11 *Execute Processing Service* #2 #9 *Deploy* and *Test* OGC Web Services. #3 Create GEOSS compliant Metadata and Catalog for GEOSS *Clearinghouse harvesting*.

Figure 3: AIP-3 Scenario events excerpt (*Services in italic* - Products in red - Actors in orange)

IV. MODELS, INPUTS AND OUTPUTS

The workflow and the inputs, models, and outputs, which are necessary to implement the AIP-3 scenario, are illustrated in Fig. 4.

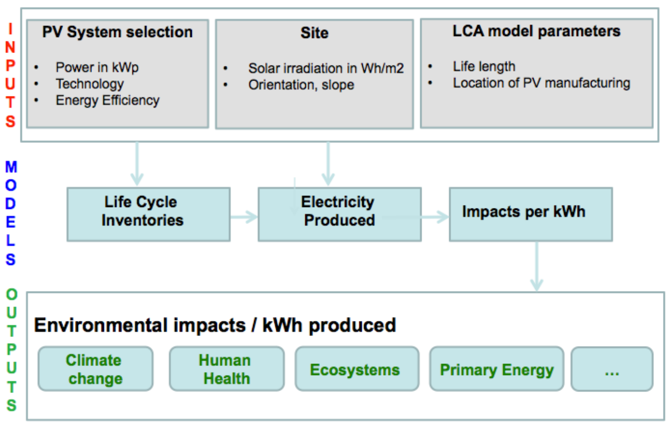

Figure 4: Data inputs, model and outputs results linkage

Decision-makers select the geographical location of interest, and the PV system (power, technology and energy efficiency, slope, orientation). The amount of electricity produced by this system during its lifetime is modeled using as inputs solar irradiation data for this site as well as the orientation and slope of the PV system.

The requested irradiation data originates from the HelioClim-3 database built by MINES ParisTech [17]. This database provides access to surface solar irradiation values for any site and any instant within a large geographical area (Europe, Africa, and the Atlantic Ocean) and a large period of time (2004 to present). The AIP-3 scenario uses monthly means of the year 2005.

The life cycle inventories of the PV system originate from the ecoinvent Centre. This Centre provides inventories of recognized quality with the database ecoinvent data v2.2 [18]. The database contains international industrial life cycle inventory data on energy supply, resource extraction, material supply, agriculture, waste management services, and transport services.

Recent and recognized methods for computing environmental impacts have been integrated in the AIP-3 Web service: IMPACT 2002+, IPCC 2007, Cumulative Energy Demand (CED), and Eco-Indicator 99 [19]. This large panel of methods provides the user with resulting quantities ranging from specific indicators to aggregated single indicator.

Finally, these inventories are converted into impacts relatively to the electricity produced over the lifetime of the system.

V. CONTRIBUTED COMPONENTS

Fig. 5 illustrates contributions of the partners. On the left side of the green dashed line are the legacy databases: HelioClim-3 and ecoinvent V2. The partners have contributed several components that exploit these databases. These components (red boxes) interact between themselves (green arrows) and the GCI. They were either an asset of a partner or contributed in the framework of two projects funded by the FP7 research program of the European Commission: GENESIS [20] and EnerGEO [21]. The components and services include:

- an OGC (Open Geospatial Consortium) CSW (Catalogue Service for the Web) catalogue;
- OGC/WPS (Web Processing Service) and OGC/WMS (Web Map Service) Services [22]-[26] deployed on the GEOSS registered community portal: webservice-energy.org;
- the GENESIS Legacy Toolbox for implementing and

deploying the OGC WPS;

- a generic portal and a WebGIS client or "helper application".

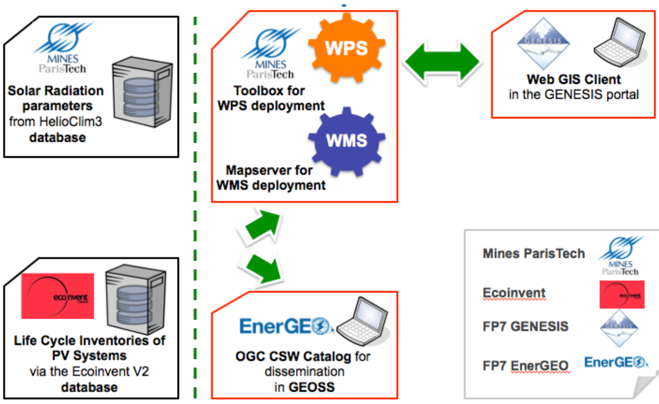

Figure 5: Components: contribution of partners

Figure 6 is a wiring diagram that illustrates how the various components are linked together starting from a user "search and discovery" on the GEO Portal to the use of the WebGIS client (visualization portlet).

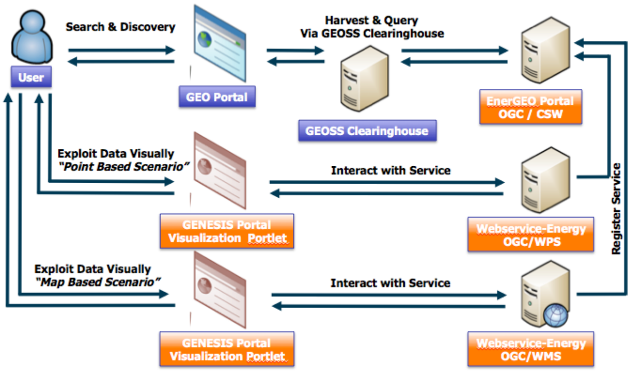

Figure 6: Wiring diagram of the energy scenario

Figs 5 and 6 illustrate the key contributed components: the CSW Catalogue, the GENESIS Legacy Toolbox, and the WebGIS client. These three components ensure the full interoperability of the resources provided by the partners inside the global GEOSS Common Infrastructure. They are detailed hereafter.

A. The OGC/CSW Catalogue

Catalogue is a key element in direct relation with GCI components such as the Clearinghouse and Component and Service Registry. On the one hand catalogue allows the search, discover of and access to available data and services (the search-find-bind paradigm). On the other hand it offers to data providers a perfect framework to describe their resource using standard metadata. Metadata records describing provider's resources are stored in this catalogue. After registration in the Component and Service Registry, the Clearinghouse periodically harvests the catalogue content. Once harvested, content of metadata records are exposed to the search and discovery from the GEO Portal.

The EnerGEO catalogue (http://energeo.researchstudio.at) is a GEOSS-registered catalogue providing links to resources on energy and environment. It is based on OGC CSW 2.0.2 standard and metadata records are implemented using the ISO 19119 metadata standard [27]. This catalogue is used to disseminate the OGC WPS and WMS used in the energy scenario. Figure 7 shows the interface of this Web-based catalogue for editing metadata of the WPS performing the assessment of environmental impacts.

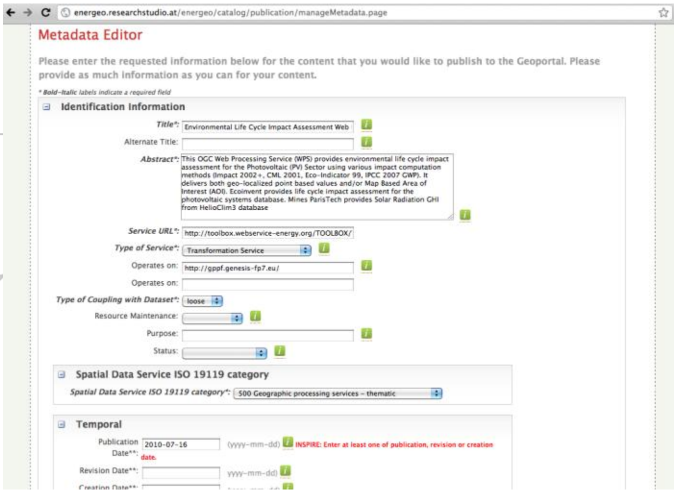

Figure 7: ISO 19119 metadata of the WPS "environmental impact assessment" in the EnerGEO catalogue

B. The GENESIS Legacy Toolbox for deploying OGC/WPS

Web Services offer a standard and interoperable approach to access, combine and process remote and spread resources to obtain value-added information [26]. A WPS performs assessment of environmental impacts. It implements various state-of-the-art methods for impact computation. As written earlier, these methods make use of two databases: the HelioClim-3 database of solar irradiation and the life cycle inventories of PV systems from the ecoinvent v2.02 database. We emphasize that no direct accesses to those databases have been provided as sketched by the vertical dotted line in Fig. 5.

We have used the GENESIS Legacy Toolbox to implement and deploy the WPS. The Toolbox is a configurable application released under General Public License (GPL) that facilitates the conversion of legacy applications into an OGC WPS. On the front end the Toolbox implements the WPS HTTP and SOAP binding; both approaches reported in the OGC documents 05-007r7 and 08-091r6 are supported. On the back end it can be connected via GRASS (http://grass.fbk.eu/) or shell scripts to the legacy application. The tool takes care of automatically downloading any referred remote resource and translates the incoming input parameters into variables to be used in the script that implements 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 with two operations which are in charge of handling the messages that come from the two WebGIS client applications: ExecuteProcess_computeImpactPV and ExecuteProcess_computeImpactPVMap.

The first operation computes the environmental impact of PV system for up to five locations defined by their coordinates and requires the following input parameters:

Name	Type	Abstract
scenario	string	Selection of PV system
method	string	Environmental impact computation method
syslife	integer	Lifetime duration of the PV system
perf_ratio	string	Performance ratio of PV system
lat	string	Latitude of location
lon	string	Longitude of location
azimuth	string	Azimuth of panel
tilt	string	Tilt of panel

The following output element is generated:

Name	Type	Abstract
impact	gml	Impact of PV system

The second operation computes a map of environmental impacts for a given area of interest for a PV system and requires the following input parameters:

Name	Type	Abstract
boundingBox	BoundingBoxData	The bounding box of the area of interest
scenario	string	Selection of PV system
method	string	Environmental impact computation method
syslife	integer	Lifetime duration of PV system
perf_ratio	string	Performance ratio of PV system
azimuth	string	Azimuth of panel
tilt	string	Tilt of panel

The following output elements are generated:

Name	Type	Abstract
OutputContext	URL	The URL to the Web Map Context file containing references to the output Web Map Server layer.

The legacy applications that compute the map service and the point service are written in Python language.

Fig. 8 shows the Web-based runtime environment for the environmental impact assessment WPS on the Toolbox instance deployed on toolbox.webservice-energy.org application server. A screen copy of the WSDL (Web Service Description Language) end-point of the service is overlaid on the figure.

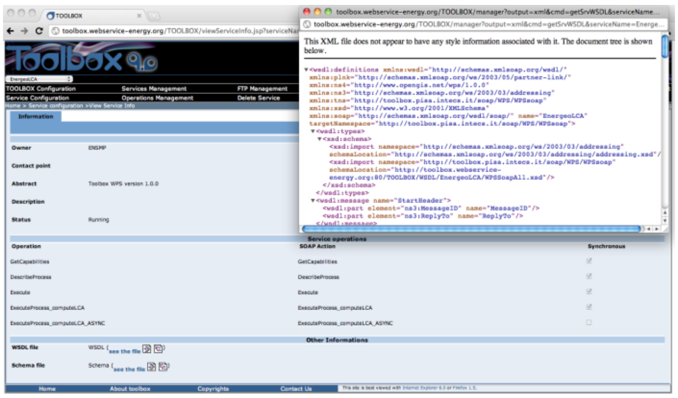

Figure 8: Web-based Toolbox runtime environment for the environmental impact assessment WPS

C. The WebGIS client or "helper application"

Driven by expectations of environmental experts, one of the goals of the AIP-3 scenario was to provide a simple, easy-to-use and accessible geospatial computational service. The WebGIS client or "helper application" has been developed using the GENESIS Geodata Visualization Portlet. This WebGIS client is the means to display on any browser the graphical user interface of the WPS client. This interface includes customized geographic elements for inputs to, and returns from the WPS.

The WebGIS is deployed on the GENESIS Portal solution (http://gppf.genesis-fp7.eu/) and can be accessed over the Internet by any browser. Moreover, the WebGIS client can be either instantiated inside any JSR286-compliant portal or used stand-alone.

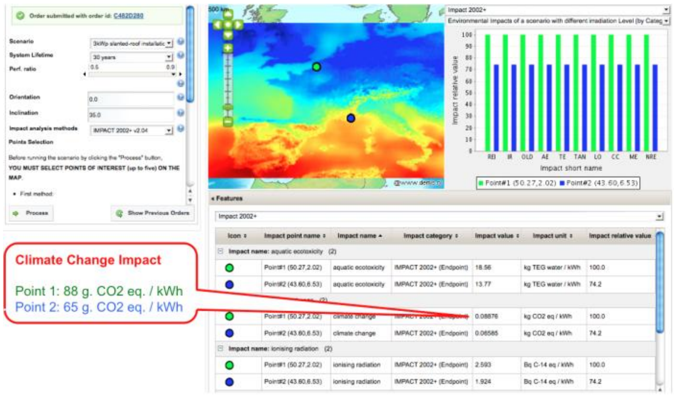

Figure 9: WebGIS client result of environmental impact assessment of a PV system

Fig. 9 illustrates the typical result of the WebGIS for two locations selected by the end-user: one in the North of France and one in the South-East of France. According to input parameters selected by the user, we get a performance of 88 g CO_2 eq/kWh for the North case while the South case has a better performance of 65 g CO_2 eq/kWh. For both selections environmental performances are provided and we have highlighted results for a specific impact issue: climate change. Such a comparison between different locations is very useful to experts and stakeholders to choose an optimal location in order to minimize environmental impacts.

These results are subject to uncertainty related to uncertainties pertaining to input data, inventories and impact models. These uncertainties have been addressed by several authors [28]-[30]. However there is a lack of knowledge on the reliability of the estimates output considering these uncertainties. The main objective when performing LCAs is to compare technologies or scenarios handling therefore comparable levels of uncertainties. Our results are found to be within the range of values published recently by the Intergovernmental Panel on Climate Change (IPCC) report on Renewable Energy Sources and Climate Change Mitigation [31] where greenhouse gas (GHG) performances published in their literature review range mostly from 30 to 80 g CO_2 eq/kWh.

VI. CONCLUSIONS

The GEOSS AIP-3 scenario has provided the opportunity to implement and deploy a set of interoperable components (OGC/CSW Catalogue, OGC/WPS - OGC/WMS Web

Services and WebGIS client) based on GEOSS recommendations.

The methodology adopted by GEOSS suggests that the potential resource provider should consider Societal Benefit Area (SBA) relevance, use transverse engineering use cases, write scenario events description and identify GEOSS-defined actors. It greatly helps our team to better focus on key points ensuring a smooth and straightforward development of GEOSS compatible and interoperable components.

The components developed in the AIP-3 scenario framework have proven to fully interact with the GEOSS Common Infrastructure (GCI) core components (Component and Service Registry, Clearinghouse and GEO Portal) illustrating interoperability concept through real user-driven approach.

For nearly a year now, the AIP-3 scenario has proven to be a great dissemination vector regarding assessment of environmental impacts relating to scenarios of deployment of PV power systems.

Finally it strengthens concepts and developments efforts towards standard and interoperable components carried out into the EnerGEO and GENESIS projects funded by the European Commission FP7 that have teamed for this GEOSS-supported action.

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