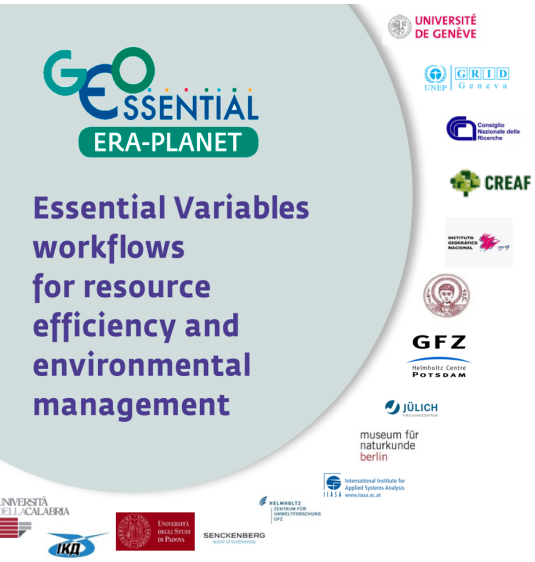


Deliverable 2.3

Report for EVs gap analysis and prioritization

Creator	CREAF, UNIGE
Creation date	February 08. 2019
Due date	
Last revision date	July 28. 2020
Status	Final
Type	Report
Description	This deliverable analyses existing gaps in EVs proposing a possible prioritization.
Right	Public
Language	English
Citation	Serral, I., Masó, J., Lehmann, A. 2019. Report for EVs gap analysis and prioritization. GEOEssential Deliverable 2.3
Grant agreement	ERA-PLANET No 689443

Table of Contents

Introduction

There are over seven hundred multi-lateral environment agreements, and many more addressing social and economic development, all with their corresponding monitoring schemes. One of the principal purposes of the SDGs is to provide a framework within which action towards these various agreements can be coordinated. The SDGs monitoring process should focus on ensuring coordination and fill important gaps among the many areas of activity that have their own individual monitoring indicators. In moving towards a more coordinated logic for SDG monitoring, advances in systems theory offer potential ways to structure such a monitoring system. One approach are the Essential Variables (EVs; Figure 1) which have arisen to prioritise and coordinate the monitoring of climate, biodiversity and oceans, and which is an area of active research and application in other communities. (Reyers, et al. 2017)

List of acronyms describing Essential Variable types including their status of development

Acronym	Description	Status
EV	Essential Variables	
ECV	Essential Climate Variables	Existing
EBV	Essential Biodiversity Variables	Existing
EOV	Essential Ocean Variables	Existing
ESocV	Essential Social Variables	Some existing, but not described as such
ExxV	Essential Variables for missing domains	Proposed for domains not yet thinking in this way that may need collecting under SDGs
ESDGV	Essential Sustainable Development Goal Variables	Proposed entire set of EVs for the SDGs
core ESDGV	Core Essential Sustainable Development Goal Variables	Proposed core set of EVs not collected within sectors, focused on sectoral interactions, transformations and in the social-ecological interface.

Figure 1. EVs status (acronym and description) (Reyers, et al. 2017)

The concept of Essential Variables was first used by the Global Climate Observing System (GCOS) in the 1990s. It defined essential climate variables (ECVs) as “physical, chemical, or biological variables or a group of linked variables that critically contributes to the characterization of Earth’s climate” (GCOS 2010). Ocean scientists adopted a similar approach under the Framework for Ocean Observing, leading in 2010 to community-defined Essential Ocean Variables (EOVs) (Lindstrom, et al. 2012). Similarly, the biodiversity community led by GEOBON started the process of defining the Essential Biodiversity Variables (EBVs) as “essential dimensions of biodiversity change”.

EVs in general could be defined as the minimum set of variables required to characterise change in a system and so could become an important and useful approach to retrieve SDG indicators. In this sense, some studies have been done as the one in (Masó, et al. 2019) where EBVs are analysed in terms of their connections to EO networks and SDG indicators.

Even if the concept of ECV covers areas other than atmosphere and climate, approaches have been followed in various scientific communities working to extent the concept to the Ocean (UNESCO 2012) and Biodiversity (Pereira, et al. 2013) domains. Other communities are currently working on defining a common set of Essential Variables such as the Water (Lawford 2014), Agriculture, Energy and Ecosystems communities (ConnectinGEO 2016b).

Additionally, some authors propose the identification of Essential SDG Variables, considering four new additional criteria for what is “essential”-again through an expert-based approach (Ramirez-Reyes, et al. 2019). (Plag and Jules-Plag 2019), proposes a goal-based approach for linking societal

goals, targets and indicators to Essential Transformation Variables (ETVs), as "a minimal set of variables that are required to develop, validate, and monitor transformation policies and interventions that aim at achieving societally agreed-upon goals".

While the environmental dimension of sustainability is decently characterized by the EV approach, the social and economic dimensions have been addressed in different forums and are not adequately connected to the environmental dimension. This currently makes more difficult the effective tracking of progresses towards sustainable development targets that depend of both dimensions (ConnectinGEO 2016a).

In the overall picture of the EVs, and the DSPIR diagram (Lehmann et al. 2020) (Figure 2), it can be stated that there's less gap in the "State" domain (right side of the diagram). However, within this side, in Geosphere, no specific EVs are being defined right now. Our proposal in the GEO Community activity on EVs will be to set up a joint work with the Land Degradation Neutrality for Soil Group with the objective to start a process in this sphere and try to generate some traction. This could start by identifying existing EVs which might be useful in the topic. On the other hand, there's a big gap on the "Responses" area (left side of the diagram), where socioeconomic is a well-known gap but not the only one. Some attempts are being done in Agriculture domain within GEOGLAM to engage the community in the definition and usage of EAVs. Regarding Urban Development EVs (EUVs), ERA-PLANET SMURBS is tackling to provide some insights in this urban domain as well.

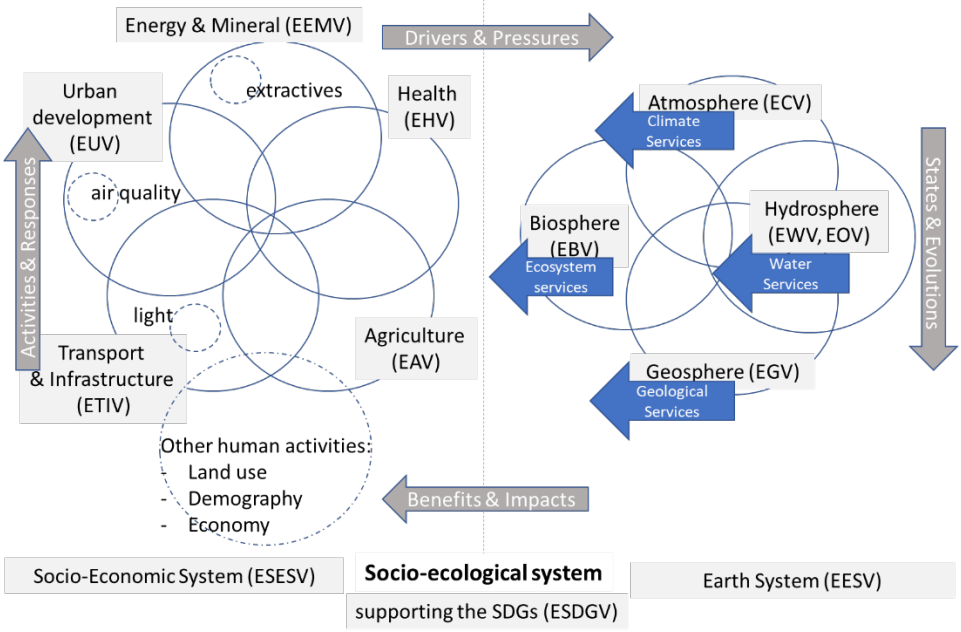


Figure 2. EVs across the Societal Benefit Areas of GEO and across the border between Socio-Economic and Earth systems. Set of proposed EVs groups in grey boxes, Natural resource and corresponding data services generating benefits and impacts the socio-economic system (left-direction arrows), and socio-economic drivers and pressures on Earth system integrity (right-direction arrow). (derived from Lehmann et al. 2020)

Approaches such as the planetary boundaries (Rockstrom et al. 2009; Steffen et al. 2018), ecological footprints (Fang, Heijungs and De Snoo 2015), nexus and socio-ecological system metabolism (Giampietro, Mayumi i Ramos-Martin 2009) are aiming to explicitly link environmental, social and economic dimensions. These approaches have the potential to pave the way to the definition of a set of Essential Socio-Economic System Variables (ESESV).

In this context, the ERA-PLANET GEOEssential[1] project is promoting the use of EVs across GEO Societal Benefit Areas by defining functional workflows to transform available data sources into policy indicators at various scales (Lehmann, Nativi, et al. 2019) (Figure 3).

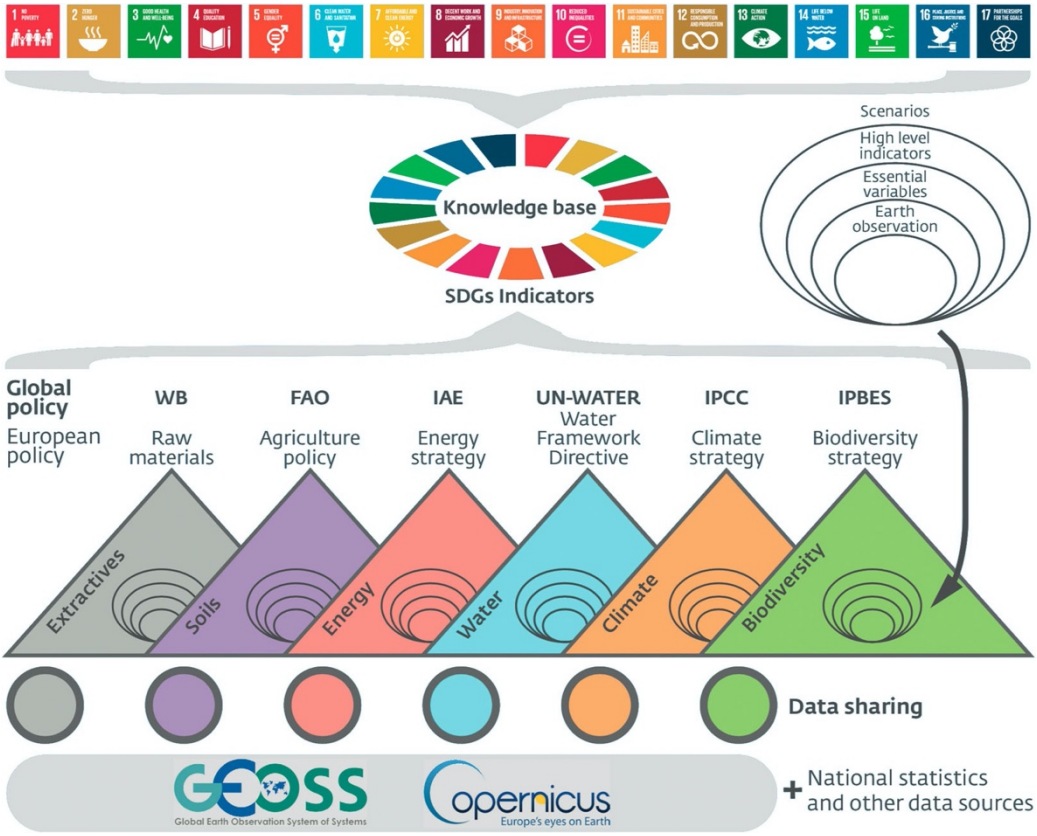


Figure 3. GEOEssential general framework linking data sources to policy indicators through Essential Variables with the help of a knowledge base. (Lehmann et al. 2019)

Gaps existing in EO data can make addressing SBAs and policy frameworks supporting these areas, a difficult task. Consequently, this requires to identify and prioritize gaps as well as demonstrate the applicability of EVs for informing various policy frameworks such as the Sustainable Development Goals (SDGs) (UN 2015).

The purpose of this deliverable is to review the potential for the EV approach to monitoring for the SDGs development by analysing the current status of EVs in terms of gap analysis and propose some prioritization.

Current situation in EVs

[1] http://www.geoessential.eu

Towards integrated Essential Variables for Environmental Sustainability. International Journal of Digital Earth Special Issue

The GEOEssential project recently edited a special issue dedicated to Essential Variables. The editorial paper situates the papers of the special issue within a new comprehensive typology of EV classes describing socio-ecological systems on the basis of GEO Societal Benefit Areas (SBAs) (Figure 2) (Lehmann, Masó, et al. 2020). A set of three papers allows first to set the scene with a broad vision of EVs can be used across domains to inform policy making. (Plag and Jules-Plag 2019) are advocating for a goal-based approach for establishing EVs for the implementation of the SDG agenda (ESDGV). (Nativi, et al. 2019) explore how EVs can be used for knowledge generation. (Masó, et al. 2019) introduce how EVs can link Earth Observations Observatory with policy indicators and monitoring using the Drivers, Pressures, State Impact and Response (DPSIR) framework.

Another set of four papers explore new developments in specific EV domains. (Miranda Espinosa, Giuliani and Ray 2019) review the current status of Essential Climate Variables (ECVs) and their accessibility. (T. Ranchin, et al. 2019) shows how Essential sustainable Energy Variables (EEVs) are currently being developed. EBVs for ecosystem modelling are at the heart of (Dantas de Paula, et al. 2019). The interest of developing air quality EVs in cities is demonstrated in the city of Kiev in Ukraine (EUV) (Kolotii, et al. 2019)

The last papers present integrated approaches. The interest of EVs in transdisciplinary approached such as the food-water-energy nexus is tackled in (McCallum, et al. 2019). A case study for monitoring several SDG indicators from high-resolution land use maps is presented for Ukraine (ESDGV) (Lavreniuk, et al. 2019). The last paper, (Lehmann, Nativi, et al. 2019) discusses how the EV concept can be generalized and how it can be used with different tools provided by the GEOSS Platform to create cross-thematic workflows to evaluate, predict and monitor our progresses towards policy targets such as the Sustainable Development Goals.

Essential Climate Variables

The need for observations is formally addressed through the United Nations Framework Convention on Climate Change (UNFCCC), which has charged the Global Climate Observing System (GCOS) with the responsibility for defining requirements for observations relevant to climate change, both in situ and space-based. GCOS works with partners to establish requirements and to ensure the sustained provision of reliable physical, chemical and biological observations, building on relevant observing systems. GCOS has identified a set of geophysical variables, called Essential Climate Variables (ECVs[2]), which need to be observed to obtain evidence of climate change and to support climate research and emerging climate information services. ECVs are grouped into three categories: atmospheric, terrestrial and oceanic (Figure 4).

[2] https://gcos.wmo.int/en/essential-climate-variables, last visited on March 2020

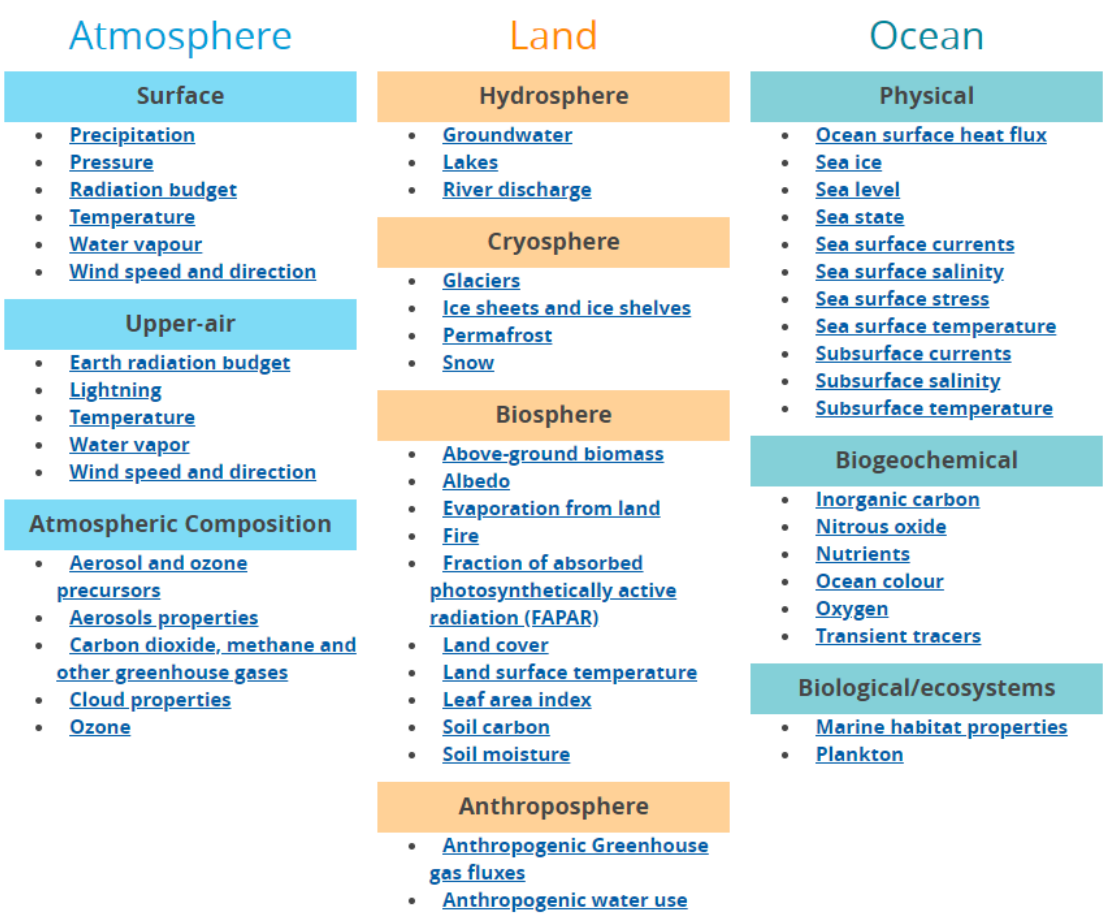


Figure 4. ECVs categories and variables

In view of the relatively slow dynamics of climate change, observations of ECVs have to be accurate, well-calibrated and homogeneous, to generate time-series than span decades; these data records are referred to as Climate Data Records (CDRs). The longest CDRs are used to distinguish climate trends from shorter-term climate variability. CDRs can be used alone to analyse climate variability and change, or can be ingested by numerical Earth system models that are used to reconstruct ("reanalyse") consistent climate records that utilise a broader range of ECVs.

ECVs are identified based on the following criteria:

- Relevance: The variable is critical for characterizing the climate system and its changes.
- Feasibility: Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.
- Cost effectiveness: Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

Essential Ocean Variables

The ocean environment is vast, remote, and harsh, and the cost involved in its observation are high. There is a need to avoid duplication of efforts, across observing platforms and networks, and to adopt common standards for data collection and dissemination to maximize the utility of data. To address these concerns, the Framework is designed to approach ocean observations with a focus on Essential

Ocean Variables, ensuring assessments that cut across platforms and recommend the best, most cost-effective plan to provide an optimal global view for each EOV[3].

Essential Ocean Variables are identified by the GOOS Expert Panels, based on the following criteria (Figure 5):

- Relevance: The variable is effective in addressing the overall GOOS Themes – Climate, Operational Ocean Services, and Ocean Health.
- Feasibility: Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.
- Cost effectiveness: Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

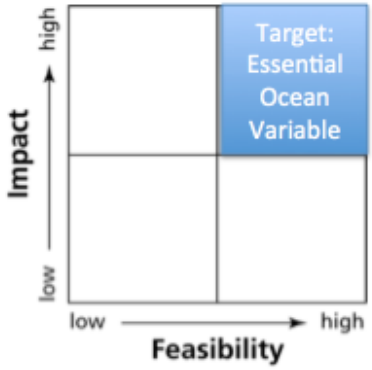


Figure 5. Impact-feasibility relation on the EOVs definition

When EOVs are identified, a series of recommendations are created and disseminated by the Expert Panels (Physics, Biogeochemistry and Biology and Ecosystems; Figure 6), including what measurements are to be made, various observing options, and data management practices.

[3] http://goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114, last visited on July 2019

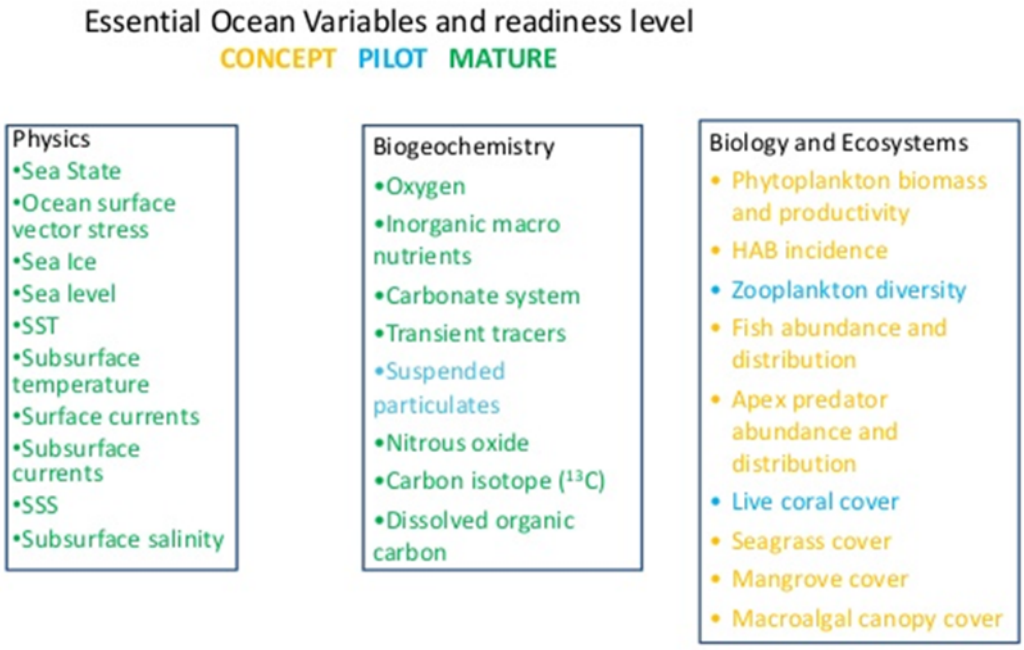


Figure 6. EOVs readiness level by panel

Physics and Climate Panel

The GOOS Physics and Climate panel (The Ocean Observations Physics and Climate panel) is responsible for the Physics EOVs, and is the lead in delivering to the Climate theme for the Oceans domain, in consultation with other GOOS panels. The Panel's mandate is to provide scientific recommendations and to review the implementation of the ocean observations required for climate in support of its 3 sponsors, the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), and the World Climate Research Programme (WCRP).

Biogeochemistry Panel

Scientific and societal requirements for ocean observing have evolved significantly over the past decade from being primarily focused on climate-related issues to include a much wider set of phenomena such as the degradation of coastal habitats, pollution, ocean acidification, over-exploitation of fisheries, biodiversity decline, de-oxygenation and more.

The ocean observing community realized that qualifying and quantifying the simultaneous impacts of multiple stressors on ocean ecosystems cannot be achieved without a truly multidisciplinary (physics, biogeochemistry and biology) approach to observing. This requires re-thinking of many observing strategies and often calls for an approach (within and across-disciplines) based on compromise to building a fit-for-purpose global ocean observing system.

Biology & Ecosystem Panel

The ocean is changing in response to our increasing use. As changes occur, life within the ocean is being affected, with potential consequences for the valuable services it provides from food to the oxygen we breathe. We need continuous, long-term observations to know if, and how, ocean life is responding to human use. These long-term observations will contribute to effectively mitigate or manage adverse changes, help predict potential future changes and plan accordingly. Relevant

changes in marine biodiversity, ecosystem function, and the services they provide can be detected by monitoring some of their essential variables.

The "biological" EOVs are classified into Functional Groups (Microbes diversity and biomass; Phytoplankton biomass and diversity; Zooplankton biomass and diversity; Benthic invertebrates distribution and abundance; Fish distribution and abundance; Marine turtles, birds, mammals abundance and distribution) and Habitat State (Hard Coral cover and composition; Seagrass Cover and composition; Macroalgal canopy cover and composition; Mangrove cover and composition).

Essential Biodiversity Variables

Essential Biodiversity Variables (EBVs[4]), whose development by GEO BON has been endorsed by the United Nations (UN) Convention on Biological Diversity (CBD) are relevant to derivation of biodiversity indicators for the Aichi Targets. Although CBD biodiversity indicators are designed to convey messages to policy-makers from existing biodiversity data, EBVs aim to help observation communities harmonize monitoring, by identifying how variables should be sampled and measured (Figure 7). EBVs help prioritize by defining a minimum set of essential measurements to capture major dimensions of biodiversity change, complementary to one another and to other environmental change observation initiatives. EBVs also facilitate data integration by providing an intermediate abstraction layer between primary observations and indicators. An EBV estimating population abundances for a group of species at a location sits between raw observations (e.g., from different sampling events or methods) and an aggregated population trend indicator that averages multiple species and locations. (Pereira, et al. 2013).

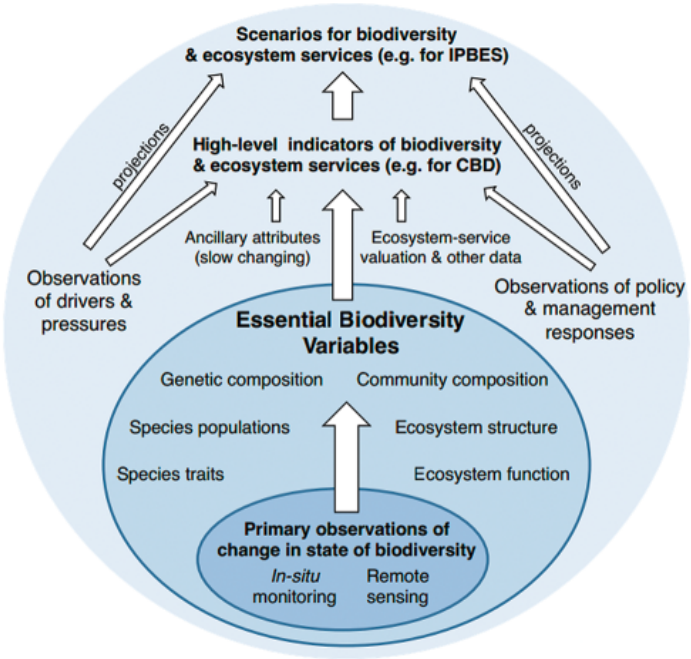


Figure 7. EBVs between low-level primary observations and high-level indicators and policies on biodiversity.

EBVs are a candidate set of 21 variables considered critical to representing different dimensions of biodiversity change and organized in 6 classes: genetic composition, species populations, species traits, community composition, ecosystem function, and ecosystem structure (Table 1). Raw data and

[4] https://geobon.org/ebvs/what-are-ebvs, last visited on March 2020.

biodiversity measurements collected and harmonized over space and time, supplemented with modelled estimates where interpolation/extrapolation is needed, provide the necessary data basis for EBVs, allowing interpretation into high-level indicator information for assessing biodiversity change (Hardisty, et al. 2019).

Table 1. EBVs classes and candidates

EBV class	EBV candidate
Genetic composition	Co-ancestry
	Allelic diversity
	Population genetic differentiation
	Breed and variety diversity
Species populations	Species distribution
	Population abundance
	Population structure by age/size class
Species traits	Phenology
	Morphology
	Reproduction
	Physiology
	Movement
Community composition	Taxonomic diversity
	Species interactions
Ecosystem function	Net primary productivity
	Secondary productivity
	Nutrient retention
	Disturbance regime
Ecosystem structure	Habitat structure
	Ecosystem extent and fragmentation
	Ecosystem composition by functional type

New proposed essential variables

Following the initiative of the climate, ocean and biodiversity communities, others have started the process of thinking and defining the EV concept within their sector. This process was detected and supported by the H2020 ConnectinGEO project which held in 2015 the workshop "Towards a sustainability process for defining GEOSS Essential Variables" in Bari. In that workshop "traditional" EVs were presented, as well as the status and process for defining new EVs in other communities. Those activities in ConnectinGEO led to some reports on the topic: (ConnectinGEO 2015), and (ConnectinGEOa 2016). These new EVs were also reviewed in a dedicated special issue edited by the GEOEssential project (Lehmann, Masó, et al. 2020).

Essential Agricultural Variables

In the context of GEOGLAM, Essential Agricultural Variables (EAV's) are the minimum set of variables that the community requires to understand state and change in agricultural systems to meet their mandate mission, as those variables are already the building blocks of the information they produce. From a practical standpoint they conceive EAVs as a minimum a useful communication device, that

allows them, to reduce complexity when faced with multiple needs, focus our activities, and communicate the outputs in a way that supports coordination with other domains.
From the moment of writing this deliverable, the preliminary EAVs pending further development by GEOGLAM community working group, are (GEOGLAM 2019):

Tier 0. Core Agriculture Indicators for GEOGLAM
Crop type
Crop Condition
Yield Forecast

Tier 1. Supporting Essential Agricultural Variables (GEOGLAM)
Phenology (planting date, current state, harvest date)
Crop Growth Indicators (Biomass, LAI, FAPAR)
Crop Calendars

Tier 2. Supporting Essential Variables (External to GEOGLAM)
Essential Climate variables
Essential Water Variables
Essential Biodiversity Variables

Essential Renewal Energy Variables

No formal attempt by international bodies to define Essential Renewal Energy Variables (EREVs) has been undertaken. Nevertheless, EREVs were first established through the ConnectinGEO H2020 project involving several stakeholders led by MINES ParisTech - École nationale supérieure des mines de Paris. This effort was continued by the Energy Community of Practice (Energy CoP) involved within GEO to develop a set of area-specific EVs linked with the GEO Task US-09-01a. This task is entitled "Identify Critical Earth Observation Priorities for Societal Benefit Areas", and aims at establishing a process for identifying critical Earth observation priorities common to many of the nine GEO societal benefit areas, involving scientific and technical experts, taking account of socio-economic factors, and building on the results of existing systems' requirements development processes.

Other attempts were based on users' needs (industrial users) coming from collaborative projects or users' surveys since 2000. Stakeholders in RE have a pragmatic way to solve their needs of information, data and variables, they did not yet define the term Essential of the EV.

Essential Renewable Energies Variables are defined as a minimal set of variables that determine the state of the energy system, are crucial for predicting its developments, and support metrics that measure its trajectory. The Essential Renewable Energies Variables should be relevant, technically and economically feasible for systematic observation. Relevance: the variable is critical for the objective to achieve, i.e. it should support the goals and targets defined by the community of stakeholders. Feasible: quantifying the variable, either from observations or derived methods, on a global scale is, in principle, technically feasible using proven and scientifically understood methods. Cost effective: generating and archiving data on the variable is affordable with proven technology, taking advantage where possible of historical datasets, observing systems established for other purposes and interoperability technologies. The approach that has been adopted for the

identification of the variables is of a bottom-up and user-driven type with various interactions with various stakeholders, including researchers, academics, enterprises, consultants, other experts, energy agencies at local, national and international levels. The approach has spanned over several years and interactions have been reported in several dispersed documents. This communication documents the approach, synthetises the outcomes and proposes lists of variables in solar, wind and marine energies. (T. Ranchin, et al. 2018)

Socio Economic Essential Variables

There is no serious attempt yet to define a group of Socio Economic Essential Variables that, however, would be crucial for retrieving most of the SDG indicators for monitoring.

Within GEOEssential just a few of them have been defined just because were useful for our analysis in this report. These are: Protected areas, Forest management, Digital Elevation Model (DEM), Crop management and agricultural practices (could be considered EAV), Solar surface irradiance (could be considered EREV), and Sunshine duration (could be considered EREV).

However, socioeconomic EVs should be defined and applied to characterize vulnerability and resilience (e.g., demographics, availability of public services, productive infrastructures, etc.) and to measure the extent of the hazard impacts on human societies leading to disasters. Essential variables have been proposed in the framework of mineral resource extractions (Ambrosone, et al. 2019)

Essential SDG Variables

Some authors propose the creation of the so-called Essential SDG Variables s (ESDGVs), which will highlight interactions and gaps in current monitoring.

The EV processes for climate, oceans and biodiversity reveal a range of criteria for defining what is essential. For the SDG domain these criteria need further development. According to (Reyers, et al. 2017), there are four possible criteria for identifying variables essential to the SDGs:

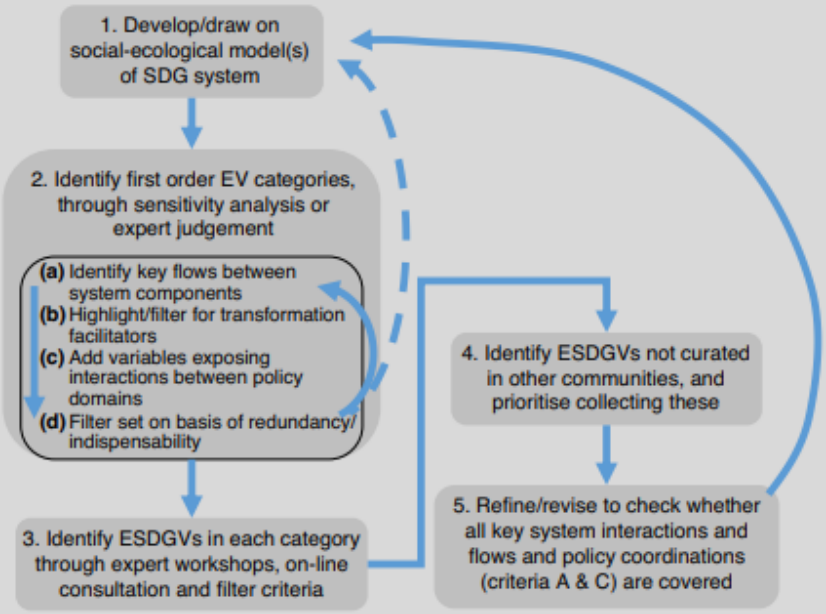
- Capture system essence. Based on knowledge of social–ecological systems, which key features, processes and interactions are critical for describing and projecting their behaviour over time and space.
- Link to system transformations. Whether the variable support the transformative agenda of SDGs, based on our knowledge of system transformations and leverage points.
- Capture key areas where coordination is needed. Whether the variable capture trade-offs or synergies between the SDGs or between policy arenas requiring coordination, especially those where coordination is weak.
- Are indispensable. In terms of whether the variable is foundational and multipurpose for tracking sustainable development or not.

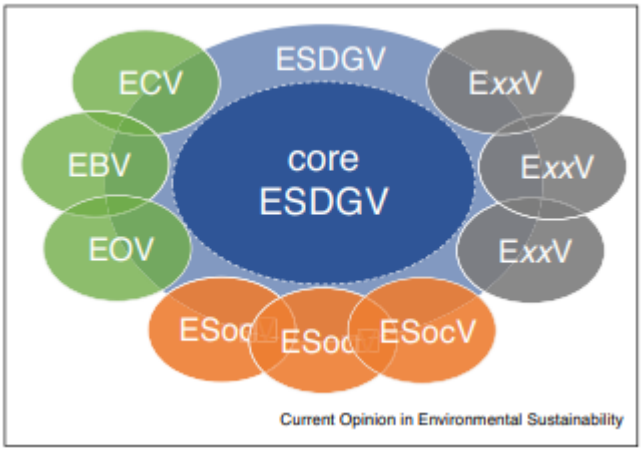
Again, according to (Reyers, et al. 2017), in the process of Essential Sustainable Development Goal Variables (ESDGV), there is still a need for an expert driven, practical approach to draw on existing subsystem models (e.g. biophysical, social, economic) and emerging integrated system models and frameworks to represent the whole linked social–ecological systems of global sustainable development.

Box 1 Proposed steps in a co-design process for ESDGVs

The process to develop ESDGVs must be iterative, evolutionary and transdisciplinary. It must employ multiple approaches and lenses, alternating between systems-oriented steps and domain-specific filtering based on operational criteria. In practice this could be achieved through workshops and syntheses focused in broad areas of the SDGs (*e.g.* around each major transition of [50,51] alternating with higher level consolidations across all the SDGs).

The Figure (below) outlines such a process; the arrows indicate how it is strongly iterative. Step 1 adopts one or more conceptual or quantified social–ecological models of the system encompassed by the SDGs (see main text). Similar to the EBV process [15], Step 2 initially identifies broad categories of ESDGVs, using criteria A-D (see main text), within an inter-disciplinary systems consultation and design phase. This then sets the scene and direction for a broadly engaged, disaggregated input of potential variables (Step 3; also Figure 3). These are subject to further systems sifting, refining, prioritizing and development (Step 4). Finally, a learning loop on the whole process is crucial, given the complexity of the challenge (Step 5). This should be closely aligned with the further development and policy use of the SDGs.





Situation in GEO

The SBAs with a more mature development of EV lists are Climate, Ocean and Biodiversity. The Water SBA is also maturing a set of EVs in GEOSS. There are also SBAs that are working with a common set of variables that can be considered essential for them. In that sense, agricultural monitoring is conducted both by the USA and EU in a similar way; Crop Area, Crop Type, Crop Condition, etc., are obvious candidates for Agriculture EV's. More work is required for an agreement on other EVs for

this SBA. Ecosystems is a cross-domain area that can make use of existing sets of EVs (such as ECVs, EOVs and EBVs) complemented by socioeconomic variables that can help to define ecosystem services to human societies. Renewable energy can also make use of the ECVs but there is a need for additional variables. The Disaster SBA is one of the most heterogeneous areas dealing with disasters caused by a wide range of natural and anthropogenic hazards. Different sets of EVs are required for the different hazards, the vulnerability of exposed assets, and the impacts of the hazards on communities. In particular, socioeconomic EVs are required to characterize vulnerability and resilience (e.g., demographics, availability of public services, productive infrastructures, etc.) and to measure the extent of the hazard impacts on human societies leading to disasters.

GEO Community Activity on EVs

GEOEssential has started a Community Activity in GEO to support Essential Variables across SBAs, and especially in Water, Agriculture, Renewable Energy and Ecosystems. This Community Activity will begin at the GEO virtual symposium in June 2020. The aim of this activity is to be a panel of experts to discuss about the current status of the EVs, exchange knowledge, experiences and methodologies in EVs definition, analyse the usefulness of some of them in creating SDG indicators and the gaps to be solved in communities in the near future. This initiative does not have the intention to interfere in the on-going communities already working on the definition of the EVs, but to become a common point to share expertise and to have a single voice inside GEO regarding EVs (GEO 2019).

Figure 8. GEO Initiatives and Candidate GEO Initiatives from the GEO Work Programme 2020-2022

Making EVs operational requires a globally interoperable, trans-national information systems from local to global extent (Hardisty, et al. 2019). GEOSS could provide this framework where most EVs operate. The challenge is to agree on how to build a dependable and stable body of sufficiently comprehensive data, and how to package and deliver it in a manner that can be most easily used to facilitate assessment and forecasting. Such agreement must be based upon cooperation, practicality and interoperability among those collecting and mobilising data with EV potential, those processing, modelling and organising data, and those publishing and preserving data (Kissling, et al. 2015). This

can be compared with the situation currently prevailing for climate data, where stable, dependable essential climate variable (ECV) data are coming from the Global Observing System for Climate (GCOS). (Hardisty, et al. 2019)

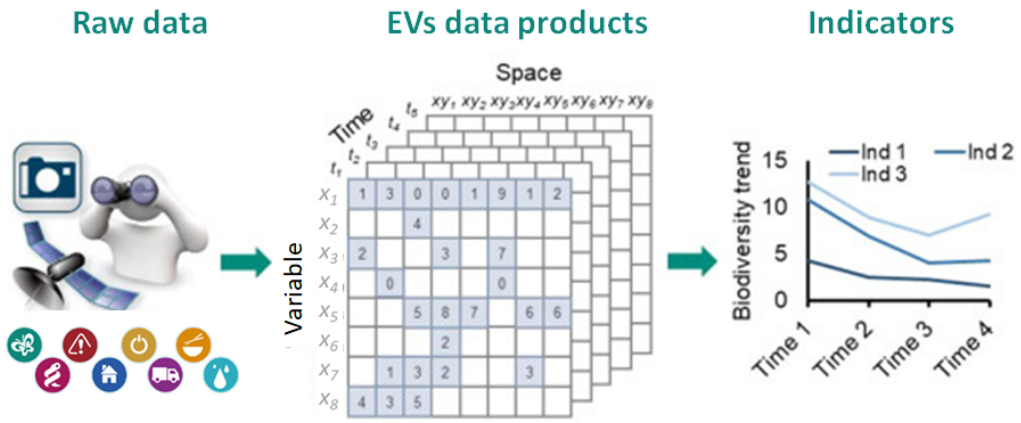


Figure 9. Essential Variables (EVs) are derived from raw data (i.e., primary observations) obtained, for example, from camera traps, field surveys, satellite remote sensing, etc. Harmonized, standardized and organised as packaged EV data products, they provide the building blocks for indicator development. EV data products can be conceptualized as cubes with dimensions of time, space and domain (sea salinity, for example). Modified figure from (Kissling, Ahumada, et al. 2018).

EVs interoperability and workflows

According to (Kissling, Ahumada, et al. 2018) building EBV data products requires taking into account the scales (space, time, taxonomy, etc.), the attributes, and the acceptable uncertainties of raw data that can be usable for EBV purposes to be defined. Measurements must be in the desired format and should be collected and processed following standardized protocols, providing sufficient associated metadata ((Kissling, Ahumada, et al. 2018), (W.D. Kissling 2018)). Data need to be consistently quality assured, using standard tests and associated. EBV data products should also meet minimum requirement standards for structure, packaging and metadata description. For (Hardisty, et al. 2019) such minimum standards have not yet been specified in the EBV context.

Also according to (Hardisty, et al. 2019), workflows for generating EBV data products must cover all aspects of transforming raw data into published data products, including harmonizing and modelling data, as well as publishing and preserving data product ((Kissling, Ahumada, et al. 2018), (W.D. Kissling 2018)). From the view of Research Infrastructures (IRs), or EO networks in this study, workflows should be independent of the underlying computational and data management infrastructure, so they become portable and adoptable. Raw data, the workflows and software should be traceable, allowing provenance to be tracked. EBV data production should be repeatable to allow easy updates as new data is collected. These needs can be met by using non-proprietary workflow formats, based for example, on the Common Workflow Language (CWL), and standard provenance mechanisms (such as the W3C PROV family of specifications). Resulting data products, including any component sub-parts, must be consistently structured (dimensioned, formatted, represented, packaged) and clearly described by metadata. They must be identifiable when published so they are discoverable and citable. Each data product must be preserved for the long-term as part of the dependable and stable body of EBV data. Much work remains to be done to achieve all this, keeping in mind that everything (raw data, data products, workflows, etc.) should be

'Findable, Accessible, Interoperable, Reusable', i.e., complying with the FAIR principles for scientific data management and stewardship (Wilkinson, et al. 2016). This infers that both humans and machines can easily find, understand and exploit the data they need for their work.

All these advices and good practices could also be applied to EVs in general.

Within GEOEssential, some attempts have been made to develop workflows (Figure 10).

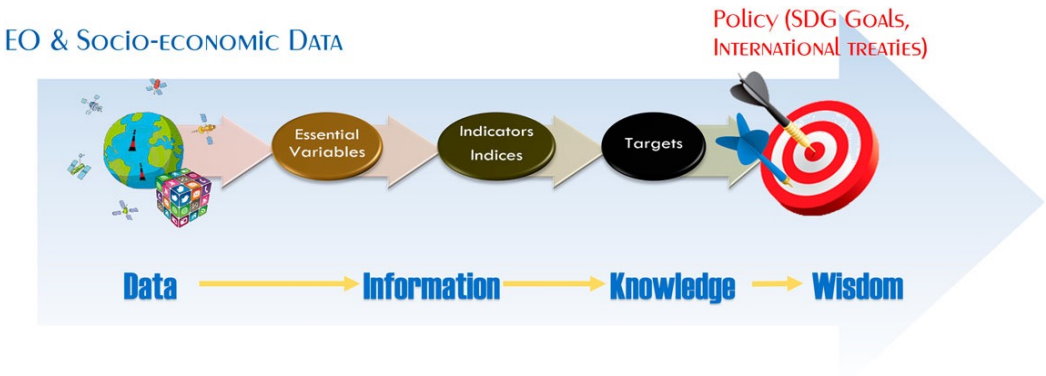
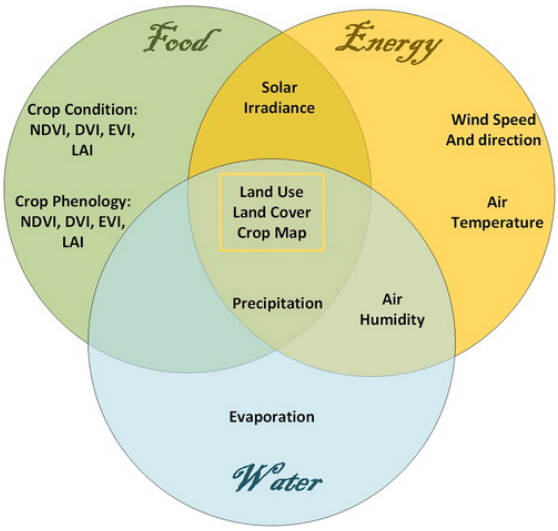


Figure 10 Systematic process to generate Knowledge from Data, for addressing policy goals. (Nativi et al. 2020)

An example is to retrieve the land cover variable (ECV), which can be used as a proxy for 15.1.1 – 'Forest area as proportion of total land area'; 15.3.1 – 'Proportion of land that is degraded over total land area'; and 2.4.1 – 'Proportion of agricultural area under productive and sustainable agriculture'. Workflows for calculating these indicators were implemented in a Virtual Laboratory Platform. We conclude that newly available high-resolution remote sensing products can significantly improve our capacity to assess several SDGs indicators through dedicated workflows (Kussul, et al. 2019).



Using cloud computing resources, with direct access to data of the GEOSS Portal, VLab has the ability to introduce workflows to calculate and monitor essential variables of water, food and energy and, accordingly, to calculate SDGs indicators for different countries around the world. We use the VLab tool to calculate the indicator 2.4.1 and 15.3.1. The benefits of using VLab are an opportunity to implement complex workflows in a cloud platform with an easy access to data from GEOSS and other major data providers and the possibility of knowledge generation for ECOPotential storylines.

Workflows are implemented as python scripts in the docker that can be imported in Vlab platform with further workflow launch. The SGD indicator 2.4.1 calculation workflow is available via GitHub (https://github.com/LeonidShumilo/Vlab_241). To run this workflow (available as a test model at the VLAB site), a VLAB-user should provide an input URL to download Landsat-8 and Sentinel-2 data jointly with classification map for the territory of interest. After data processing, the workflow will produce a text file with the value of SDG indicator 2.4.1 for the territory of interest.

The second workflow is implemented in a similar way and available via a GitHub repository (https://github.com/LeonidShumilo/Vlab1531). In this use case, a VLAB user should provide an input URL to download land cover change map and land productivity map. As an output, the workflow generates a text file with a value of the SDG indicator 15.3.1 for the territory of interest. The similar implementation for the SDG indicator 15.1.1 is available via GitHub repository (https://github.com/LeonidShumilo/Vlab1511).

Gap analysis

In this deliverable we have analysed gaps in terms of EVs existence and availability and their connection to SDGs indicators, instead of gaps in data which were studied within ConnectinGEO H2020 (ConnectinGEOb 2016).

Gap analysis on EVs regarding SDGs

This analysis has been done using the information gathered in an extension of the ENEON graph done within the GEOEssential project: http://www.eneon.org/graph-EV-SDG/index_beta.htm . The information presented in the graph has been compiled using the following sources:

- The description of EVs as they appear in their websites up to April 2019.
- The description of SDGs as they appear in the https://sustainabledevelopment.un.org [April 2019].
- The description of the most relevant EO networks (or Research Infrastructures) in a global level (global, European) as found in their official websites. Data portals (which can collect data from several networks) or the regional/national networks are excluded from this study. Only in some cases, an exception has been done, for the sake of completeness. For instance, regional/national LTER networks have been added to the graph as they directly relate and contribute to European LTER.
- Interrelations between EVs, SDGs and EO networks have been established using the own criteria of the authors as part of the work done in GEOEssential, and based upon existing literature.

In GEOEssential, we have developed another tool to analyze the graph that can be found at http://www.eneon.org/graph-vis/index.htm (see Figure 11). This new graph operates on the same json file that contains all the relations but allowing queries among elements and analysing every relation and direction. Queries are also defined in a json file.

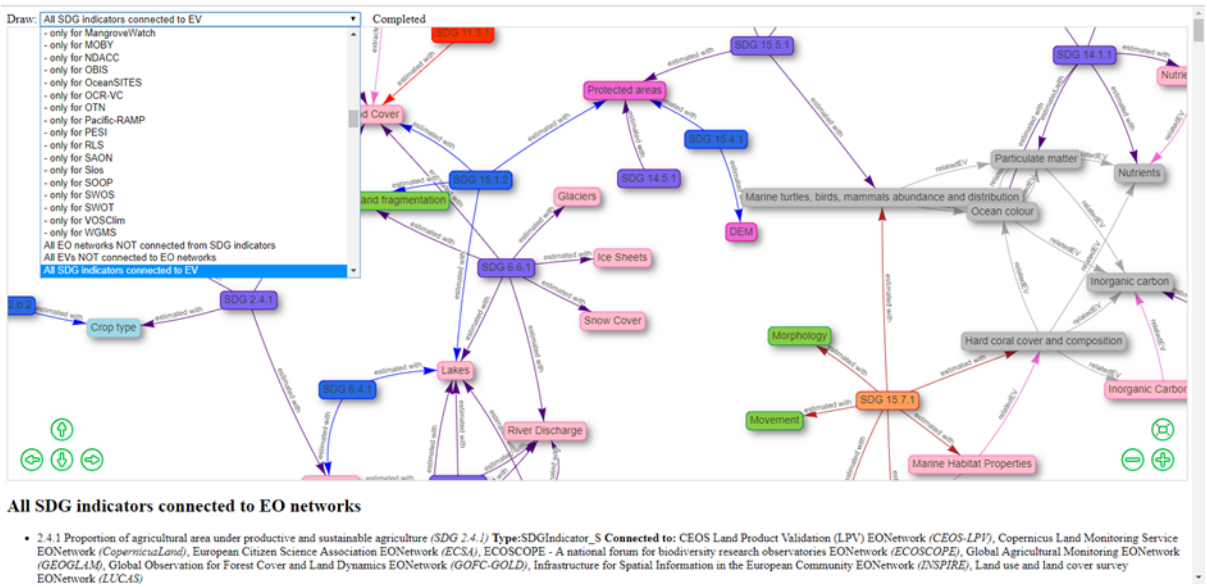


Figure 11. New tool developed within GEOEssential for analysing relations among EVs, SDGs and EO networks

EVs used by some SDG indicator

There are 79 interactions between EVs and SDG indicators. The most "interacted" EVs are the ECVs with the 61% of the interactions, followed by the EBVs and the EOVs (15%) (Figure 13). The SDG indicators have been classified following the characterization of DPSIR framework (Driving Forces-Pressures-State-Impacts-Responses) according to (Masó, y otros 2019). Most of these SDG indicators are from a "state" nature (64%), followed by those of a "response" nature (15%); see Figure 14. This is an expected result as state indicators are the most "feasible" to be monitored and so are the indicators with more possible relations with EVs.

The most connected EV are "Anthropogenic water use" with 7 SDG indicators, "Lakes" with 6 SDG indicators, "Land cover (Lakes)" with 5, and "River Discharge" with 4, all of them ECV. See Figure 12.

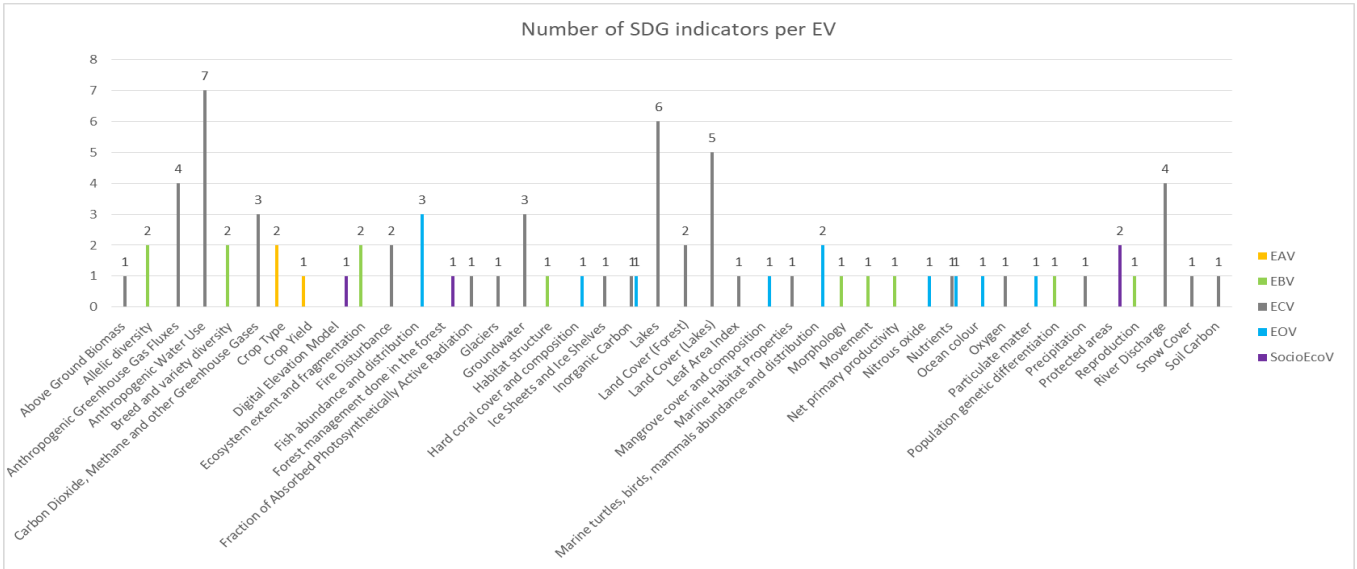


Figure 12. Distribution of the interactions between EVs and SDG indicators. The number indicates the interactions per EV, and the colour shows the type of EV

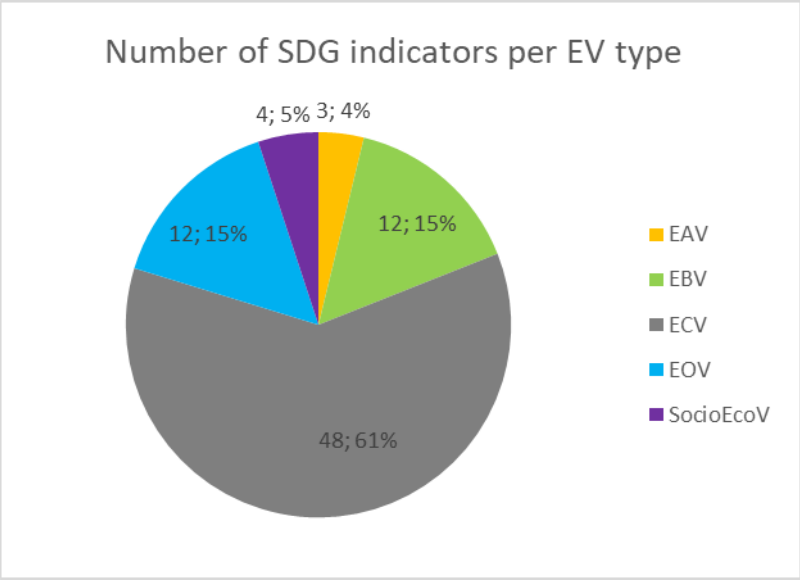


Figure 13. Number of SDGs indicators with interactions with EVs, classified by EV type

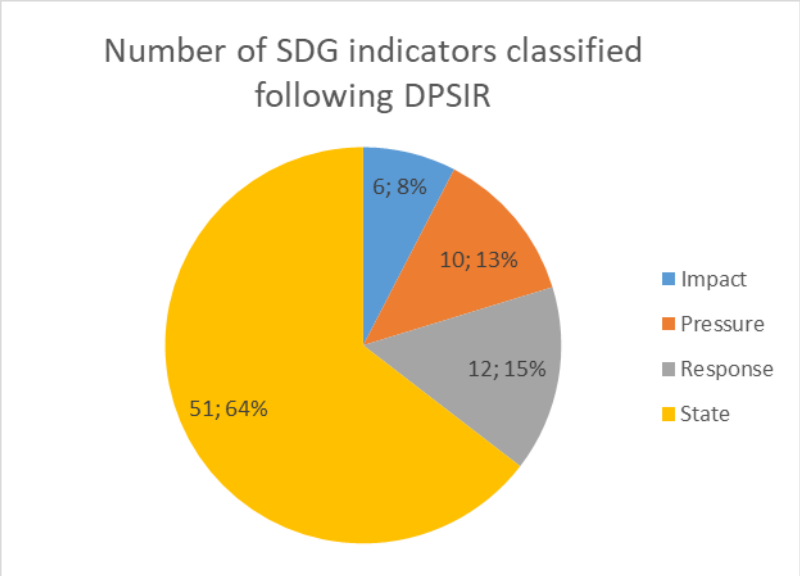


Figure 14. Nature of the SDG indicators that interact with EVs, following the DPSIR framework

Table 2. All SDG indicators related to EVs

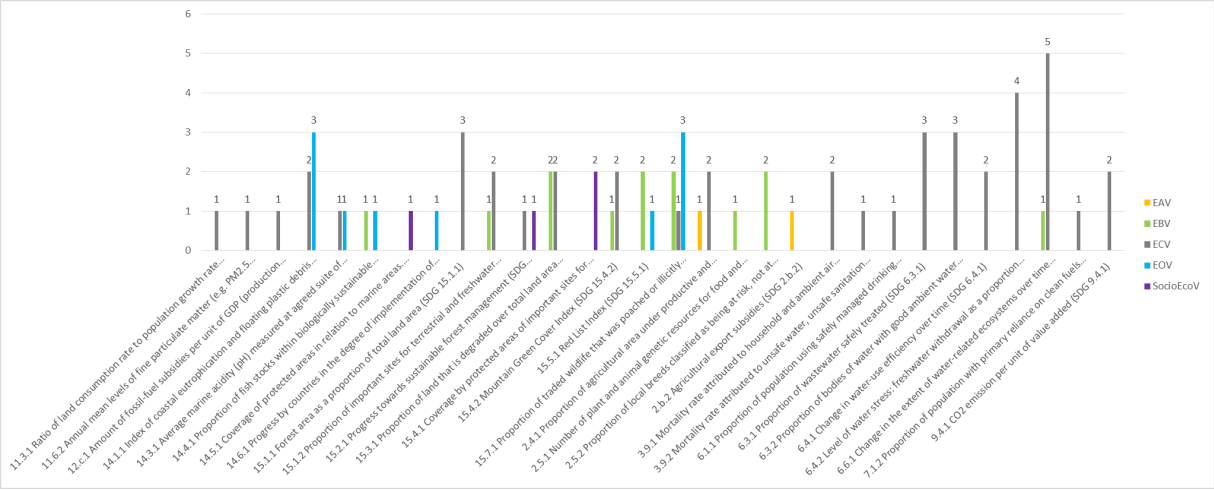
EV	Type of EV	SDG indicator	Type of SDG
Allelic diversity	EBV	2.5.2 Proportion of local breeds classified as being at risk, not at risk or at unknown level of risk of extinction	State
Population genetic differentiation	EBV	15.5.1 Red List Index	State
Species distribution	EBV	15.5.1 Red List Index	State
Population abundance	EBV	15.5.1 Red List Index	State
Breed and variety diversity	EBV	2.5.1 Number of plant and animal genetic resources for food and agriculture secured in either medium- or long-term conservation facilities	Response
		2.5.2 Proportion of local breeds classified as being at risk, not at risk or at unknown level of risk of extinction	State
Morphology	EBV	15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked	Pressure
Reproduction	EBV	14.4.1 Proportion of fish stocks within biologically sustainable levels.	State
Movement	EBV	15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked	Pressure

Net primary productivity	EBV	15.4.2 Mountain Green Cover Index	State
Habitat structure	EBV	15.3.1 Proportion of land that is degraded over total land area	Pressure
Ecosystem extent and fragmentation	EBV	6.6.1 Change in the extent of water-related ecosystems over time	State
		15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type	Response
Precipitation	ECV	6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	State
Carbon Dioxide, Methane and other Greenhouse Gases	ECV	3.9.1 Mortality rate attributed to household and ambient air pollution	Impact
		7.1.2 Proportion of population with primary reliance on clean fuels and technology	State
		9.4.1 CO2 emission per unit of value added	State
Inorganic Carbon	ECV	14.3.1 Average marine acidity (pH) measured at agreed suite of representative sampling stations.	State
Nutrients	ECV	14.1.1 Index of coastal eutrophication and floating plastic debris density.	State
Oxygen	ECV	14.1.1 Index of coastal eutrophication and floating plastic debris density.	State
Marine Habitat Properties	ECV	15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked	Pressure
Above Ground Biomass	ECV	15.4.2 Mountain Green Cover Index	State
Anthropogenic Greenhouse Gas Fluxes	ECV	3.9.1 Mortality rate attributed to household and ambient air pollution	Impact
		9.4.1 CO2 emission per unit of value added	State
		11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)	Impact
		12.c.1 Amount of fossil-fuel subsidies per unit of GDP (production and consumption) and as a proportion of total national expenditure on fossil fuels	Impact
Anthropogenic Water Use	ECV	2.4.1 Proportion of agricultural area under productive and sustainable agriculture	State
		3.9.2 Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services)	Impact
		6.1.1 Proportion of population using safely managed drinking water services	State
		6.3.1 Proportion of wastewater safely treated	State
		6.3.2 Proportion of bodies of water with good ambient water quality	State
		6.4.1 Change in water-use efficiency over time	Response
		6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	State
Fire Disturbance	ECV	15.1.1 Forest area as a proportion of total land area	State
		15.3.1 Proportion of land that is degraded over total land area	Pressure
Fraction of Absorbed Photosynthetically Active Radiation	ECV	15.4.2 Mountain Green Cover Index	State
Glaciers	ECV	6.6.1 Change in the extent of water-related ecosystems over time	State
Groundwater	ECV	6.3.1 Proportion of wastewater safely treated	State
		6.3.2 Proportion of bodies of water with good ambient water quality	State
		6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	State
Ice Sheets and Ice Shelves	ECV	6.6.1 Change in the extent of water-related ecosystems over time	State
Lakes	ECV	6.3.1 Proportion of wastewater safely treated	State
		6.3.2 Proportion of bodies of water with good ambient water quality	State
		6.4.1 Change in water-use efficiency over time	Response
		6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	State
		6.6.1 Change in the extent of water-related ecosystems over time	State
		15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type	Response
Land Cover (Lakes)	ECV	2.4.1 Proportion of agricultural area under productive and sustainable agriculture	State
		6.6.1 Change in the extent of water-related ecosystems over time	State

		11.3.1 Ratio of land consumption rate to population growth rate	Impact
		15.1.1 Forest area as a proportion of total land area	State
		15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type	Response
Land Cover (Forest)	ECV	15.1.1 Forest area as a proportion of total land area	State
		15.2.1 Progress towards sustainable forest management	Response
Leaf Area Index	ECV	15.4.2 Mountain Green Cover Index	State
River Discharge	ECV	6.3.1 Proportion of wastewater safely treated	State
		6.3.2 Proportion of bodies of water with good ambient water quality	State
		6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	State
		6.6.1 Change in the extent of water-related ecosystems over time	State
Snow Cover	ECV	6.6.1 Change in the extent of water-related ecosystems over time	State
Soil Carbon	ECV	15.3.1 Proportion of land that is degraded over total land area	Pressure
Nutrients	EOV	14.1.1 Index of coastal eutrophication and floating plastic debris density.	State
Inorganic carbon	EOV	14.3.1 Average marine acidity (pH) measured at agreed suite of representative sampling stations.	State
Particulate matter	EOV	14.1.1 Index of coastal eutrophication and floating plastic debris density.	State
Nitrous oxide	EOV	14.1.1 Index of coastal eutrophication and floating plastic debris density.	State
Fish abundance and distribution	EOV	14.4.1 Proportion of fish stocks within biologically sustainable levels.	State
		14.6.1 Progress by countries in the degree of implementation of international instruments aiming to combat illegal, unreported and unregulated fishing.	Response
		15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked	Pressure
Marine turtles, birds, mammals abundance and distribution	EOV	15.5.1 Red List Index	State
		15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked	Pressure
Hard coral cover and composition	EOV	15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked	Pressure
Mangrove cover and composition	EOV	15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked	Pressure
Ocean colour	EOV	14.1.1 Index of coastal eutrophication and floating plastic debris density.	State
Protected areas	SocioEcoV	14.5.1 Coverage of protected areas in relation to marine areas.	State
		15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type	Response
Forest management done in the forest	SocioEcoV	15.2.1 Progress towards sustainable forest management	Response
Digital Elevation Model	SocioEcoV	15.4.1 Coverage by protected areas of important sites for mountain biodiversity	Response
Crop Type	EAV	2.4.1 Proportion of agricultural area under productive and sustainable agriculture	State
		2.b.2 Agricultural export subsidies	Response
Crop Yield	EAV	2.4.1 Proportion of agricultural area under productive and sustainable agriculture	State

From the other way around, the SDG indicators with more interactions with EVs are

- "15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked" with 6 interactions with EVs (3 EOV, 2 EBV and 1 ECV),
- "6.6.1 Change in the extent of water-related ecosystems over time" with 6 interactions with EVs (5 ECV and 1 EBV),
- "14.1.1 Index of coastal eutrophication and floating plastic debris density" with 5 interactions with EVs (3 EOV and 2 ECV).



This means that the SDG goal with more interconnections between EVs and SDG indicators is “SDG 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss” with a 36% of the relations, followed by “SDG 6. Ensure availability and sustainable management of water and sanitation for all” with 27% of interconnections, and the “SDG 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development” with a 15%. See Figure 15. This suggests that they are SDG goals more feasible to be monitored than others, at least with the current definition of EVs.

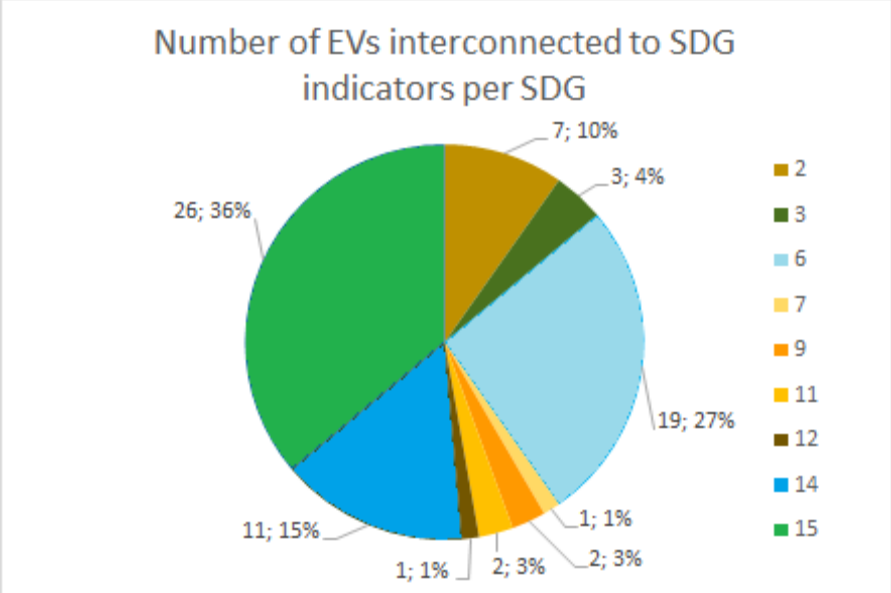


Figure 15. Number of EVs interconnected to SDG indicators per SDG goal

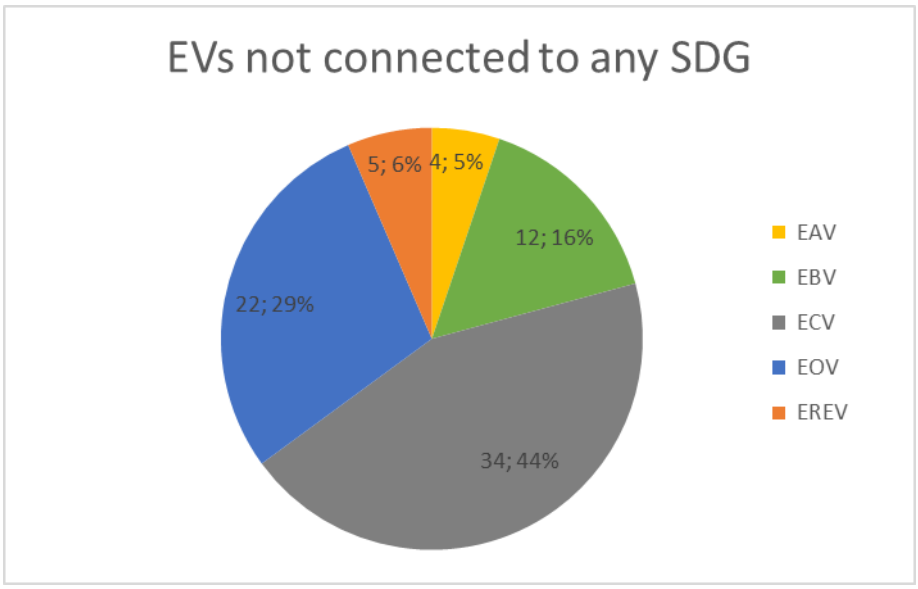
SDG indicator	Type of SDG	EV	Type of EV
2.4.1 Proportion of agricultural area under productive and sustainable agriculture	State	Anthropogenic Water Use	ECV
		Land Cover	ECV
		Crop type	EAV
2.5.1 Number of plant and animal genetic resources for food and agriculture secured in either medium- or long-term conservation facilities	Response	Breed and variety diversity	EBV
	State	Allelic diversity	EBV

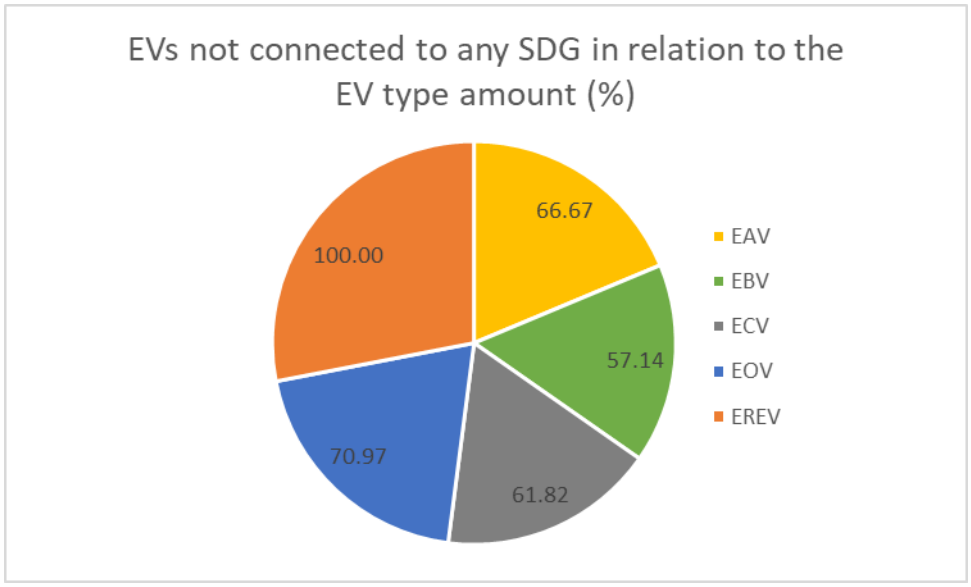
2.5.2 Proportion of local breeds classified as being at risk, not at risk or at unknown level of risk of extinction		Breed and variety diversity	EBV
2.b.2 Agricultural export subsidies	Response	Crop type	EAV
3.9.1 Mortality rate attributed to household and ambient air pollution	Impact	Carbon Dioxide, Methane and other Greenhouse Gases	ECV
		Anthropogenic Greenhouse Gas Fluxes	ECV
3.9.2 Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services)	Impact	Anthropogenic Water Use	ECV
6.1.1 Proportion of population using safely managed drinking water services	State	Anthropogenic Water Use	ECV
6.3.1 Proportion of wastewater safely treated	State	Anthropogenic Water Use	ECV
		Groundwater	ECV
		Lakes	ECV
6.3.2 Proportion of bodies of water with good ambient water quality	State	Anthropogenic Water Use	ECV
		Groundwater	ECV
		Lakes	ECV
6.4.1 Change in water-use efficiency over time	Response	Anthropogenic Water Use	ECV
		Lakes	ECV
6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	State	Precipitation	ECV
		Anthropogenic Water Use	ECV
		Groundwater	ECV
		River Discharge	ECV
6.6.1 Change in the extent of water-related ecosystems over time	State	Ecosystem Extent and fragmentation	EBV
		Glaciers	ECV
		Ice Sheets and Ice Shelves	ECV
		Land Cover	ECV
		River Discharge	ECV
		Snow Cover	ECV
7.1.2 Proportion of population with primary reliance on clean fuels and technology	State	Carbon Dioxide, Methane and other Greenhouse Gases	ECV
9.4.1 CO2 emission per unit of value added	State	Carbon Dioxide, Methane and other Greenhouse Gases	ECV
		Anthropogenic Greenhouse Gas Fluxes	ECV
11.3.1 Ratio of land consumption rate to population growth rate	Impact	Land Cover	ECV
11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)	Impact	Anthropogenic Greenhouse Gas Fluxes	ECV
12.c.1 Amount of fossil-fuel subsidies per unit of GDP (production and consumption) and as a proportion of total national expenditure on fossil fuels	Impact	Anthropogenic Greenhouse Gas Fluxes	ECV
14.1.1 Index of coastal eutrophication and floating plastic debris density	State	Nutrients	ECV
		Oxygen	ECV
		Nutrients	EOV
		Nitrous oxide	EOV
		Ocean colour	EOV
14.3.1 Average marine acidity (pH) measured at agreed suite of representative sampling stations	State	Inorganic Carbon	ECV
		Inorganic carbon	EOV
14.4.1 Proportion of fish stocks within biologically sustainable levels	State	Reproduction	EBV
		Fish abundance and distribution	EOV
14.5.1 Coverage of protected areas in relation to marine areas	State	Protected areas	SocioEcoV

14.6.1 Progress by countries in the degree of implementation of international instruments aiming to combat illegal, unreported and unregulated fishing	Response	Fish abundance and distribution	EOV
15.1.1 Forest area as a proportion of total land area	State	Fire Disturbance	ECV
		Land Cover	ECV
		Land Cover category forest)	ECV
15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type	Response	Ecosystem Extent and fragmentation	EBV
		Lakes	ECV
		Land Cover	ECV
15.2.1 Progress towards sustainable forest management	Response	Land Cover category forest)	ECV
		Forest management done in the forest	SocioEcoV
15.3.1 Proportion of land that is degraded over total land area	Pressure	Habitat structure	EBV
		Ecosystem Extent and fragmentation	EBV
		Fire Disturbance	ECV
		Soil Carbon	ECV
15.4.1 Coverage by protected areas of important sites for mountain biodiversity	Response	Protected areas	SocioEcoV
		Digital Elevation Model	SocioEcoV
15.4.2 Mountain Green Cover Index	State	Net primary productivity	EBV
		Above Ground Biomass	ECV
		Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)	ECV
15.5.1 Red List Index	State	Species abundance	EBV
		Species distribution	EBV
		Marine turtles, birds, mammals abundance and distribution	EOV
15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked	Pressure	Morphology	EBV
		Movement	EBV
		Marine Habitat Properties	ECV
		Marine turtles, birds, mammals abundance and distribution	EOV
		Hard coral cover and composition	EOV
		Mangrove cover and composition	EOV

EVs NOT used by any SDG indicator

There are 77 EVs that could not currently be used as a proxy to derive or monitor any SDG indicator. These could be considered as **gaps in EVs** regarding SDGs as they can't be used to derive them. If EVs have to be useful for SGDs perhaps they should be redefined. From these, the most unlinked EVs are ECV, but just because there are more ECV than any other EV. If we take a look respect to the total of each EV type, we will see that none of the EREV have connections to any SDG, whereas the most connected EVs are EBVs (42.86 %).





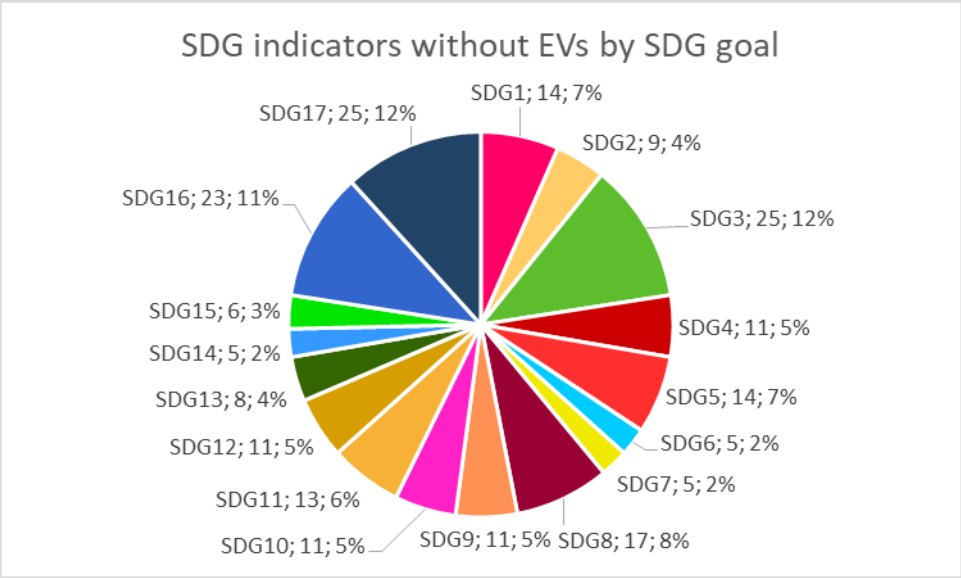
The EVs not connected to any SDG indicators are:

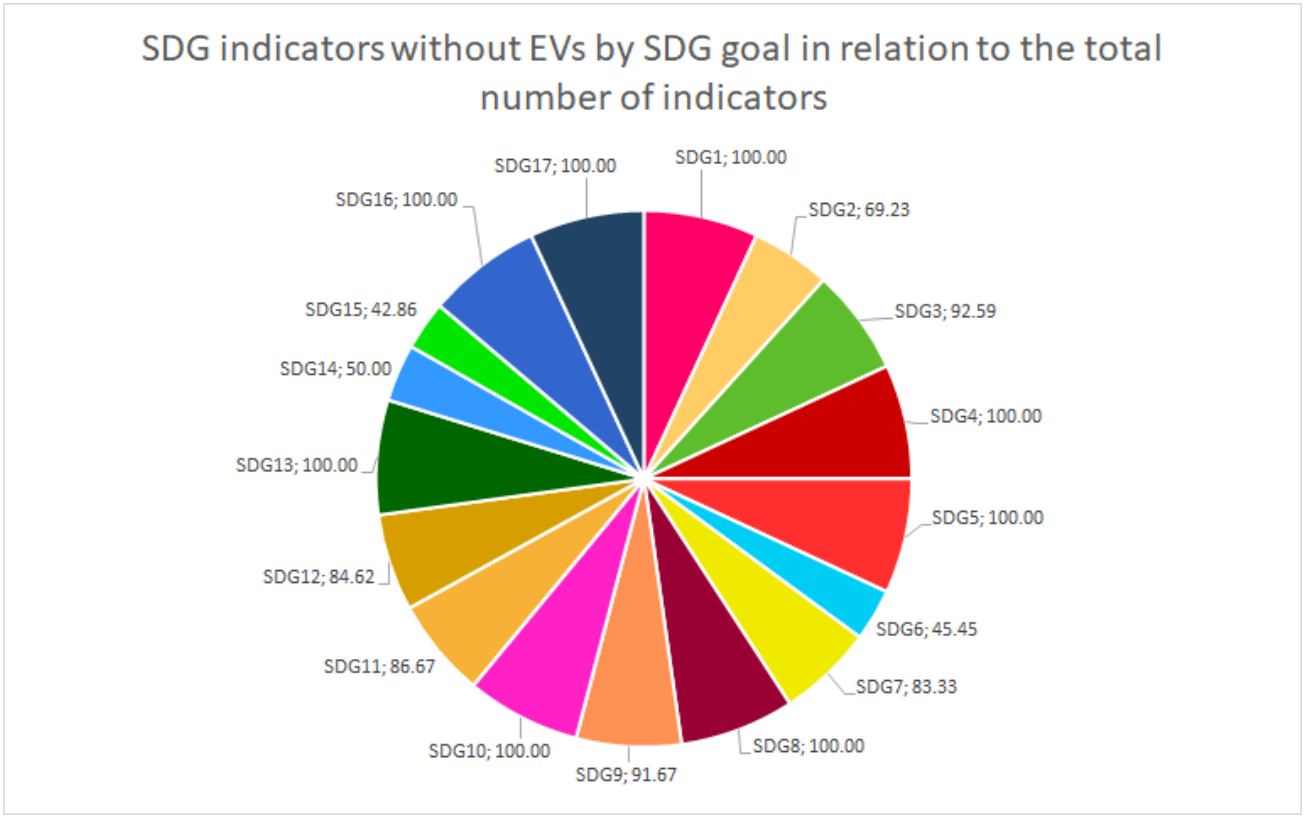
- Co-ancestry, EBV
- Species distribution, EBV
- Population abundance, EBV
- Population structure by age/size class, EBV
- Phenology, EBV
- Physiology, EBV
- Taxonomic diversity, EBV
- Species interactions, EBV
- Secondary productivity, EBV
- Nutrient retention, EBV
- Disturbance regime, EBV
- Ecosystem composition by functional type, EBV

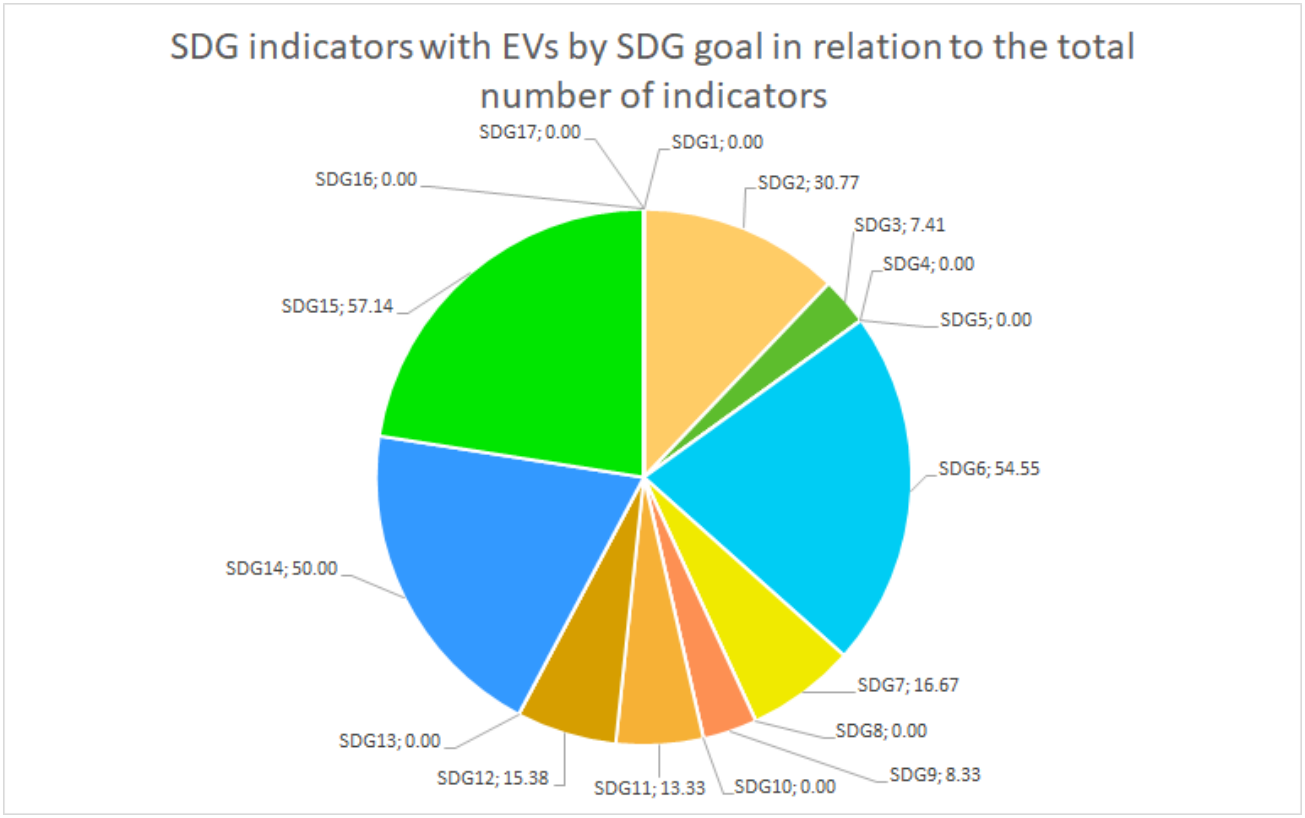
- Pressure, ECV
- Surface Radiation Budget, ECV
- Surface Wind Speed and Direction, ECV
- Temperature, ECV
- Water Vapour, ECV
- Earth Radiation Budget, ECV
- Lightning, ECV
- Temperature Upper, ECV
- Water Vapour Upper, ECV
- Wind Speed and Direction Upper, ECV
- Aerosols Properties, ECV
- Cloud Properties, ECV
- Ozone, ECV
- Precursors (supporting the Aerosol and Ozone ECVs), ECV
- Ocean Surface Heat Flux, ECV
- Sea Ice, ECV
- Sea Level, ECV
- Sea State, ECV
- Sea Surface Salinity, ECV
- Sea Surface Temperature, ECV
- Subsurface Currents, ECV
- Subsurface Salinity, ECV
- Subsurface Temperature, ECV
- Surface Current, ECV
- Ocean Surface Stress, ECV
- Nitrous Oxide, ECV
- Ocean Color, ECV
- Transient Tracers, ECV
- Plankton, ECV
- Albedo, ECV
- Land Surface Temperature, ECV
- Latent and Sensible Heat Fluxes, ECV
- Permafrost, ECV
- Soil Moisture, ECV
- Sea state, EOV
- Ocean surface stress, EOV
- Sea ice, EOV
- Sea surface height, EOV
- Sea surface temperature (SST), EOV
- Subsurface temperature, EOV
- Surface currents, EOV
- Subsurface currents, EOV
- Sea Surface Salinity, EOV
- Subsurface salinity, EOV
- Ocean surface heat flux, EOV

- Oxygen, EOV
- Transient tracers, EOV
- Stable carbon isotopes, EOV
- Dissolved organic carbon, EOV
- Phytoplankton biomass and diversity, EOV
- Zooplankton biomass and diversity, EOV
- Seagrass cover and composition, EOV
- Macroalgal canopy cover and composition, EOV
- Microbe biomass and diversity (emerging), EOV
- Invertebrate abundance and distribution (emerging), EOV
- Ocean sound, EOV
- Crop Area, EAV
- Crop condition, EAV
- Crop management and agricultural practices, EAV
- Crop phenology, EAV
- Solar surface irradiance, EREV
- Sunshine duration (demand in energy), EREV
- Wave characterization, EREV
- Ocean bathymetry, EREV
- Ocean floor type, EREV

From the other way around, the SDG indicators with no links to EVs are 214, most of them from SDGs 3 (12 %), 16 (11 %) and 17 (12 %).







EVs connected to some EO network

There are 112 EVs from a total of 347 EVs connected to EO networks (Figure 16). The EVs with more connections with networks are the ECVs (41%), the EBVs (26%), and the EOVs (24%).

In this study, EREVs do not appear to be related to any EO network even though there is a strong community behind. This is because of the nature of the EREVs that are strongly related to other EVs that already have a network behind. So, in this case, the information needed to derive EREVs could be obtained from these other networks.

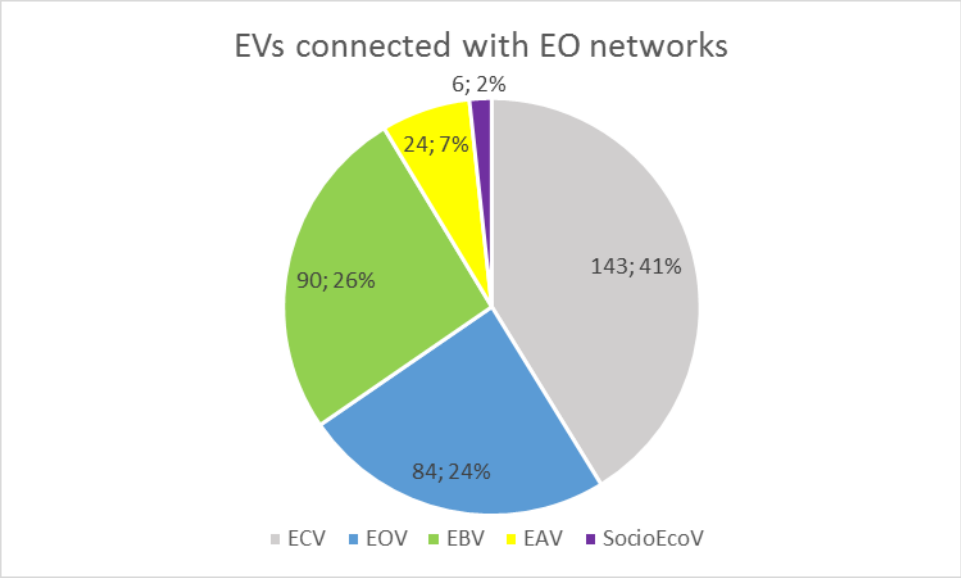


Figure 16. Number of EVs that have relation to some EO network

EVs not connected to any EO network

Most of EVs have some EO network that could provide some kind of data for their monitoring. Only one ECV has no clear network (Lightning), and 3 EOVs, 2 of them due to an emerging state of definition (Microbe biomass and diversity and Invertebrate abundance and distribution). Most of the non-connected EVs (5 from 6 in total) are from the Renewable Energy domain. This is not completely true as already explained in the previous section.

- Lightning (ECV)
- Ocean surface stress (EOV)
- Microbe biomass and diversity (*emerging*) (EOV)
- Invertebrate abundance and distribution (*emerging*) (EOV)
- Solar surface irradiance (EREV)
- Sunshine duration (demand in energy) (EREV)
- Wave characterization (EREV)
- Ocean bathymetry (EREV)
- Ocean floor type (EREV)

EVs related to other EVs

It is known that some EVs are in fact related to other EVs. This is because domains are not strictly closed from one another and, for instance, many variables in the ocean can also be monitored from a biodiversity point of view. Some studies have already been done in this direction as the one presented by (Muller-Karger, et al. 2018) in which we can appreciate the estimated relations between EOV and EBV (Figure 17).

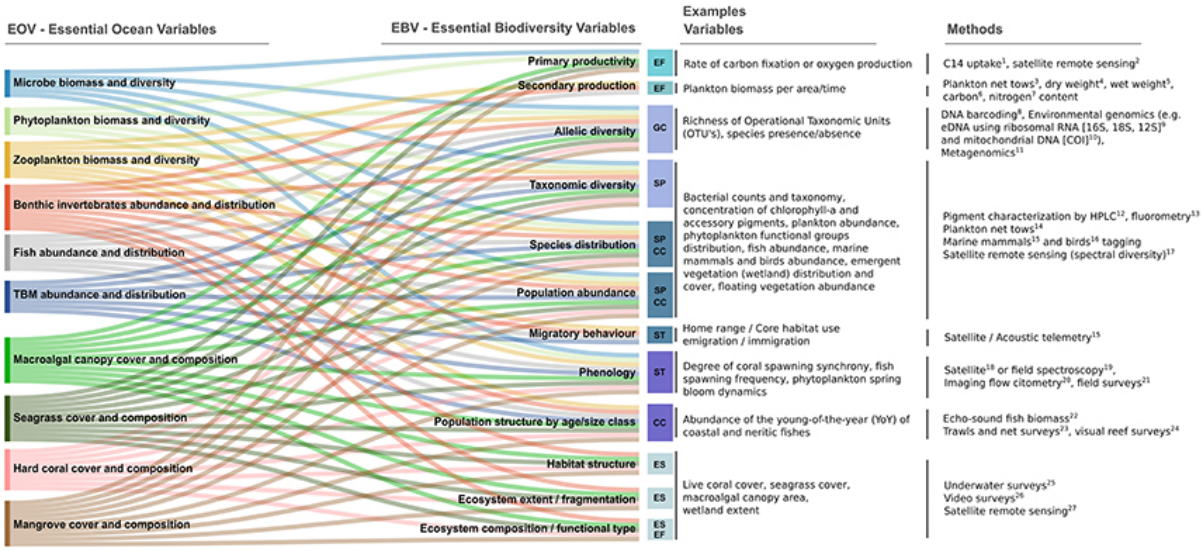


Figure 17. Conceptual relationship between EOVs and EBVs, with simple examples (extracted from (Muller-Karger, et al. 2018)).

In GEOEssential, we have analysed the interactions of each EV with other EVs. Following this analysis, we have observed that the major number of interconnections an EV has is 13, which is the EOV Marine turtles, birds, mammals' abundance and distribution (Figure 18). Following this, the highest number is 10 interactions per EV. These are:

- among EBVs: Allelic diversity, Population abundance, Population structure by age/size class, Taxonomic diversity, Net primary productivity, and Ecosystem composition by functional type
- ECV Plankton,
- and among EOVs: Particulate matter, Dissolved organic carbon, Phytoplankton biomass and diversity, Zooplankton biomass and diversity, and Invertebrate abundance and distribution.

The EVs with a major number of overall interactions are EOVs with the 64% of the total interactions, followed by ECV (22%) and EBV (9%) (Figure 19).

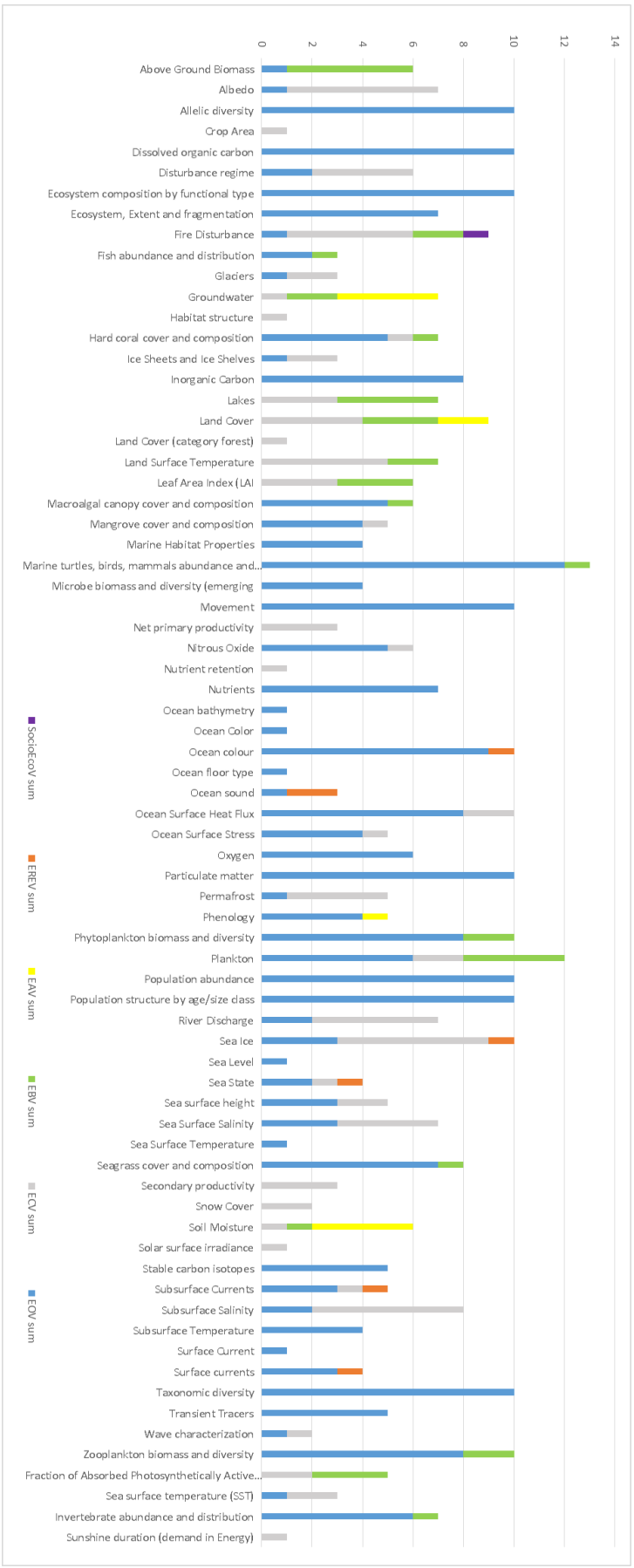


Figure 18. Number of interactions between EVs for every EV.

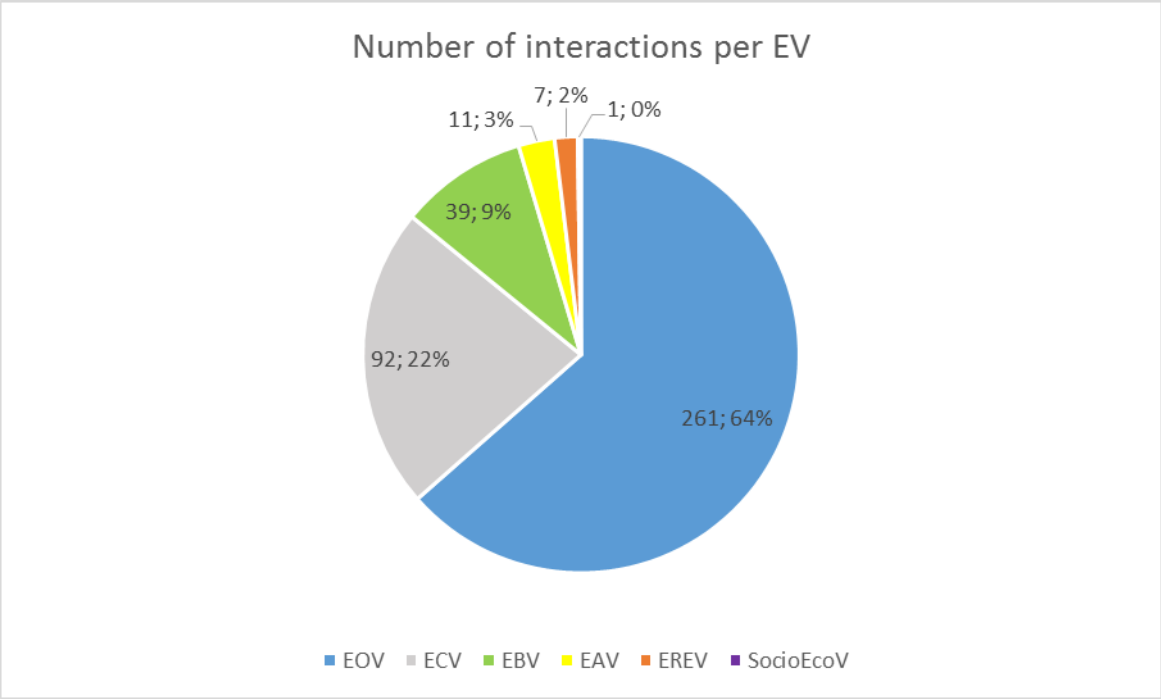


Figure 19. Number of interactions per type of EVs

In Annex 1, are listed the complete interactions for every EV.

EOVs directly connected to other EVs

In the particular case of the EOVs (the EVs which are more connected to other EVs), we can state that the major number of relations is among other EOVs (77%). This is because many EOVs can be derived from other EOVs, for example, Surface currents that is related to Subsurface currents. The second group of frequent interactions is with ECVs (14%), followed by EBVs (5%) and EREVs (4%). See Figure 20. Among the EOVs, the most interconnected one is Marine turtles, birds, mammals' abundance and distribution, with 13 interactions (Figure 21).

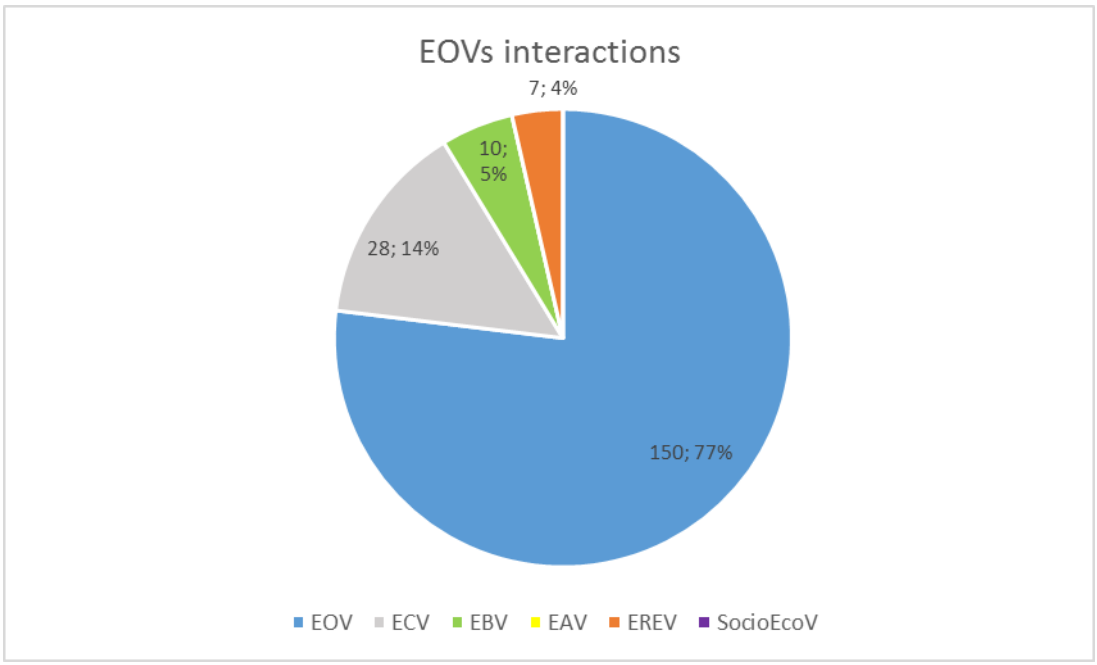


Figure 20. Overall number of connections between EOVs and other EVs

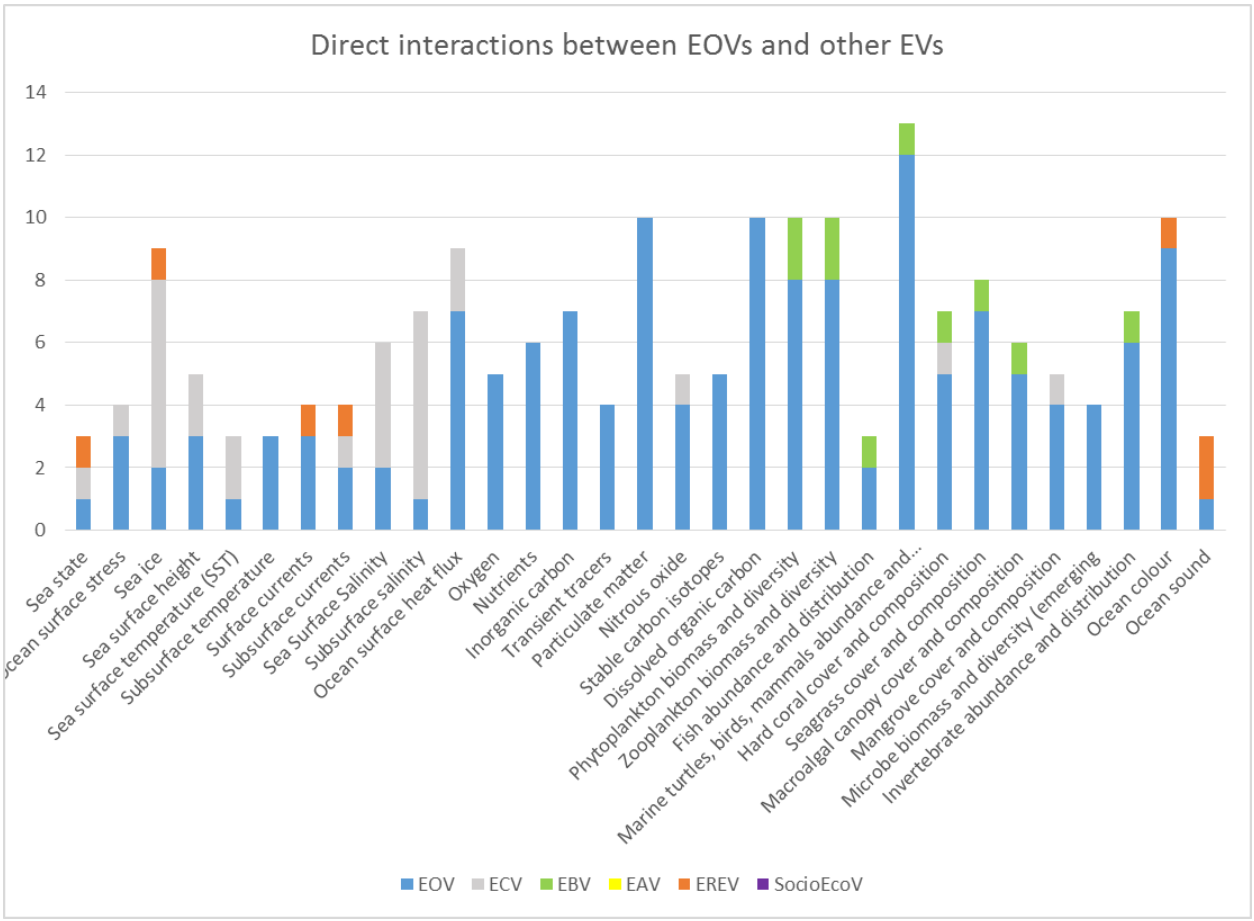


Figure 21. Number of interactions between EOVs and other EVs, per EOV

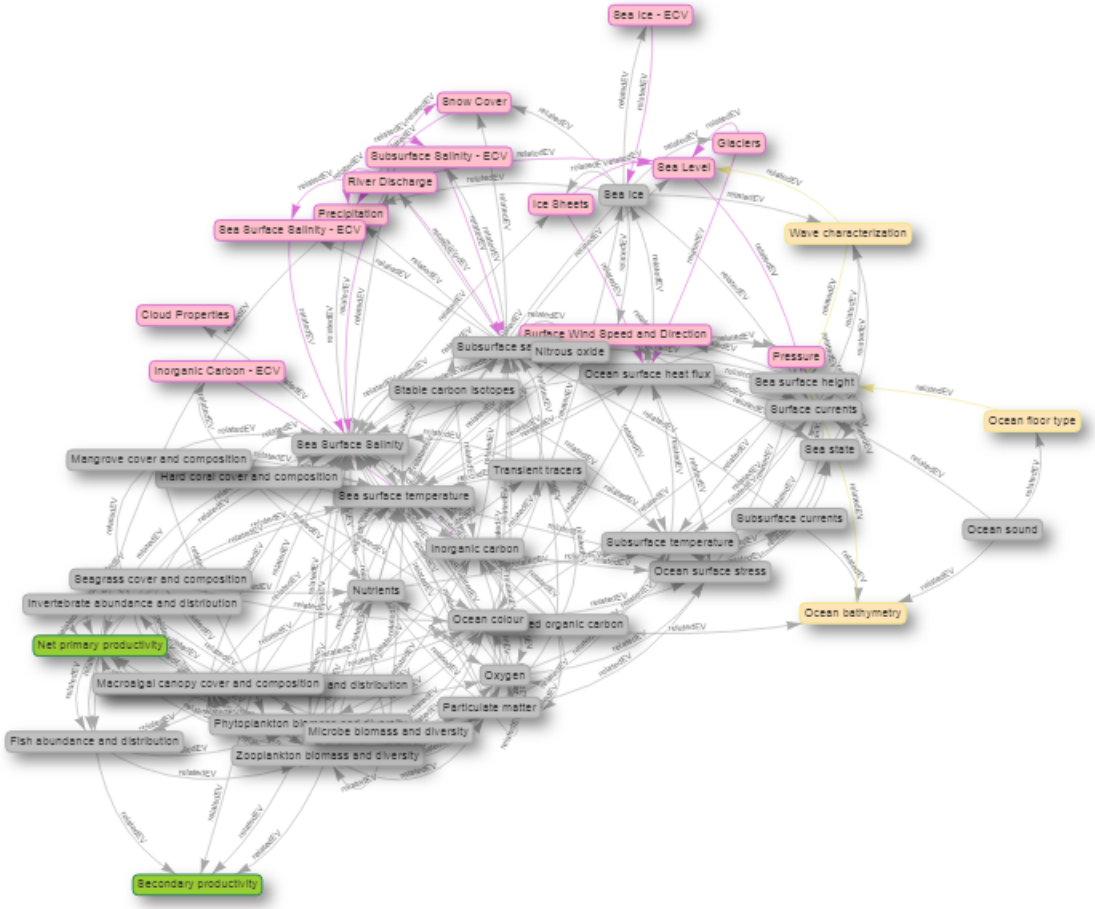


Figure 22. Screenshot from the ENEON graph showing the connections between EOVs and other EVs

In Annex 2, are listed the complete interactions for every EOV.

ECV directly connected to other EVs

In the case of ECV, the major number of interactions are done with themselves (39%), followed by EOVs (28%), EBVs (24%) and EAVs (8%), see Figure 23. ECVs have a quite strong relation with EAVs and this suggests that ECVs could be good variables for agriculture monitoring.

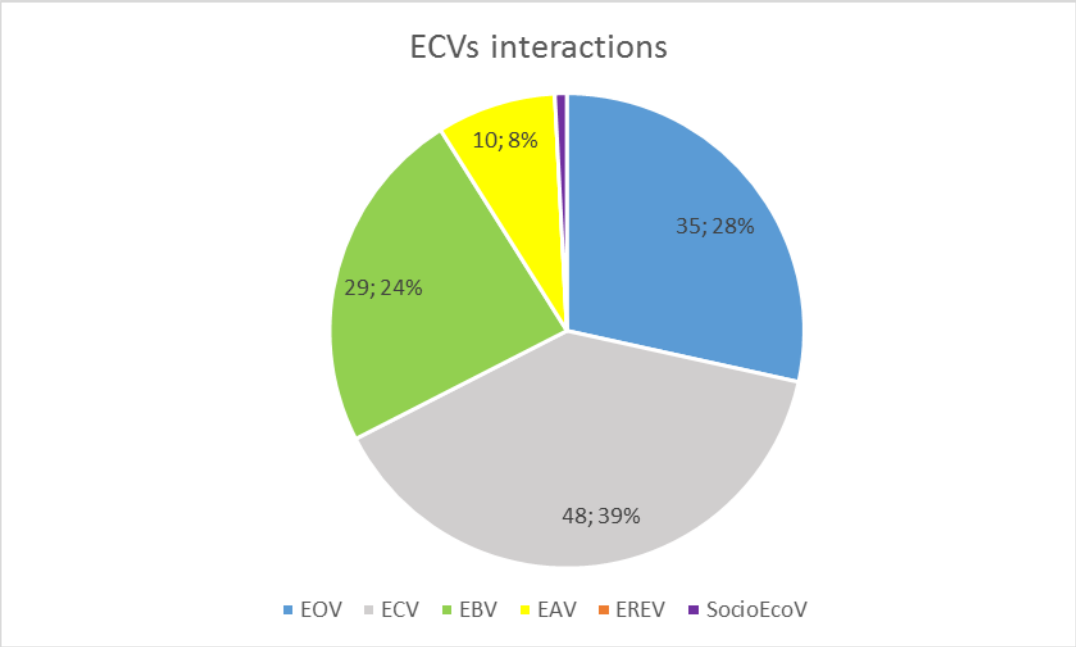


Figure 23. Overall number of connections between ECVs and other EVs

There is a strong relation between some ECVs and EOVs in a one to one relation (Figure 24). This is because there are some ECVs that are almost equal to a correspondent EOV. These are:

- Ocean Surface Heat Flux – ECV *connected to* Ocean surface heat flux - EOV
- Sea Ice – ECV *connected to* Sea ice - EOV
- Sea State – ECV *connected to* Sea state - EOV
- Sea Surface Salinity - ECV *connected to* Sea Surface Salinity - EOV
- Sea surface temperature - ECV *Connected to* Sea surface temperature - EOV
- Subsurface Currents - ECV *connected to* Subsurface currents - EOV
- Subsurface Salinity - ECV *connected to* Subsurface salinity - EOV
- Subsurface Temperature - ECV *connected to* Subsurface temperature - EOV
- Surface Current - ECV *connected to* Surface currents - EOV
- Ocean Surface Stress - ECV *connected to* Ocean surface stress - EOV
- Inorganic Carbon - ECV *connected to* Inorganic carbon - EOV
- Nitrous Oxide - ECV *connected to* Nitrous oxide - EOV
- Nutrients - ECV *connected to* Nutrients - EOV
- Ocean Color - ECV *connected to* Ocean colour - EOV
- Oxygen - ECV *connected to* Oxygen - EOV
- Transient Tracers - ECV *connected to* Transient tracers - EOV

This suggest that these EVs could be reviewed in terms of redundancy and maybe they could be merged into a single one.

Apart from these, the ECVs with more interconnections is Plankton with 12 other EVs associated.

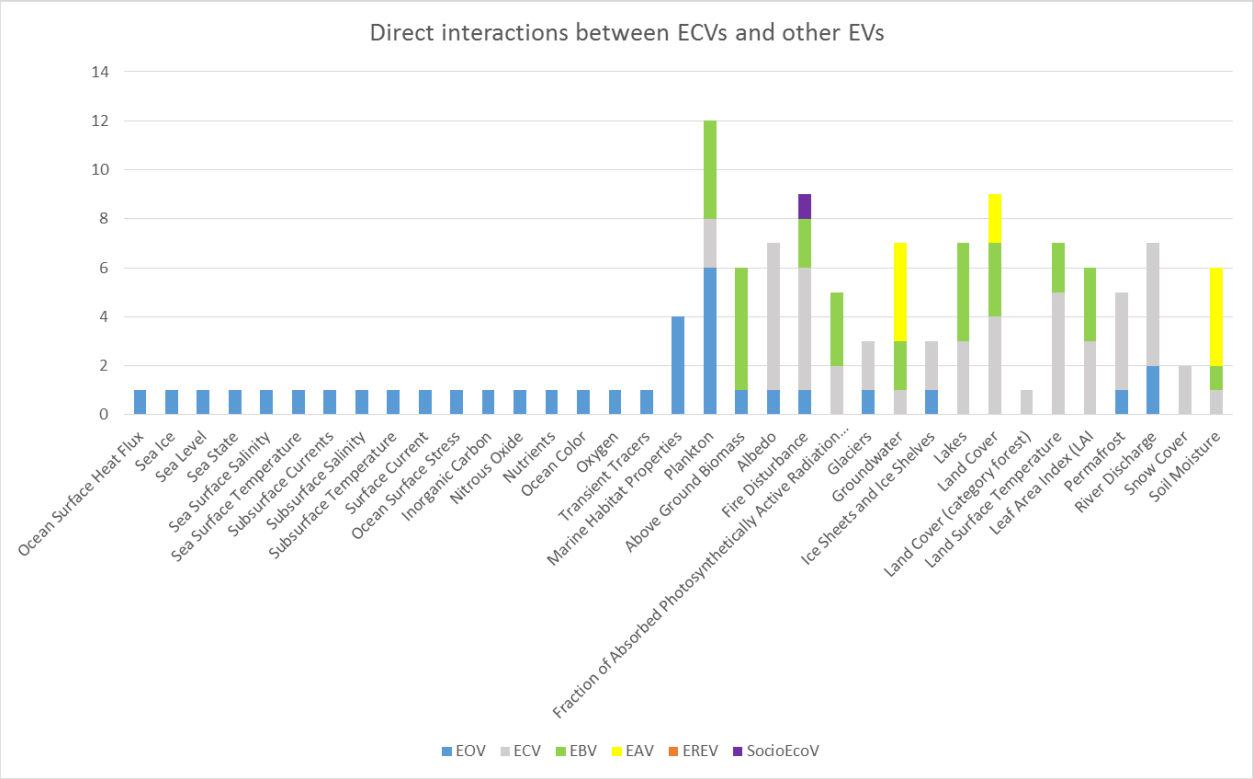


Figure 24. Number of interactions between ECVs and other EVs, per ECV

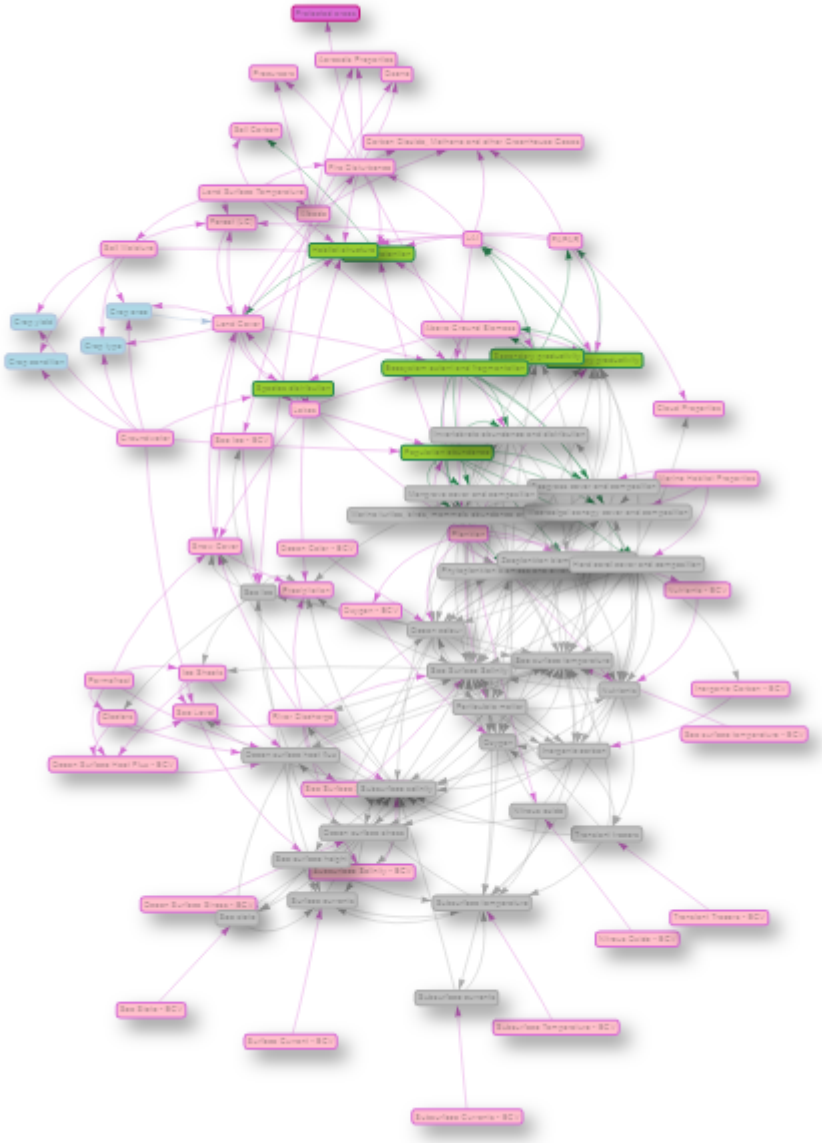


Figure 25. Screenshot from the ENEON graph showing the connections between ECVs and other EVs

In Annex 3, are listed the complete interactions for every ECV.

EBVs directly connected to other EVs

As deeply discussed in (GEOEssential 2019), EBVs have some interactions with other EVs. The major number of interactions is between EOVs (85%) followed by ECVs (14%). One interaction is being done with EAVs (Phenology → Crop phenology). See Figure 26.

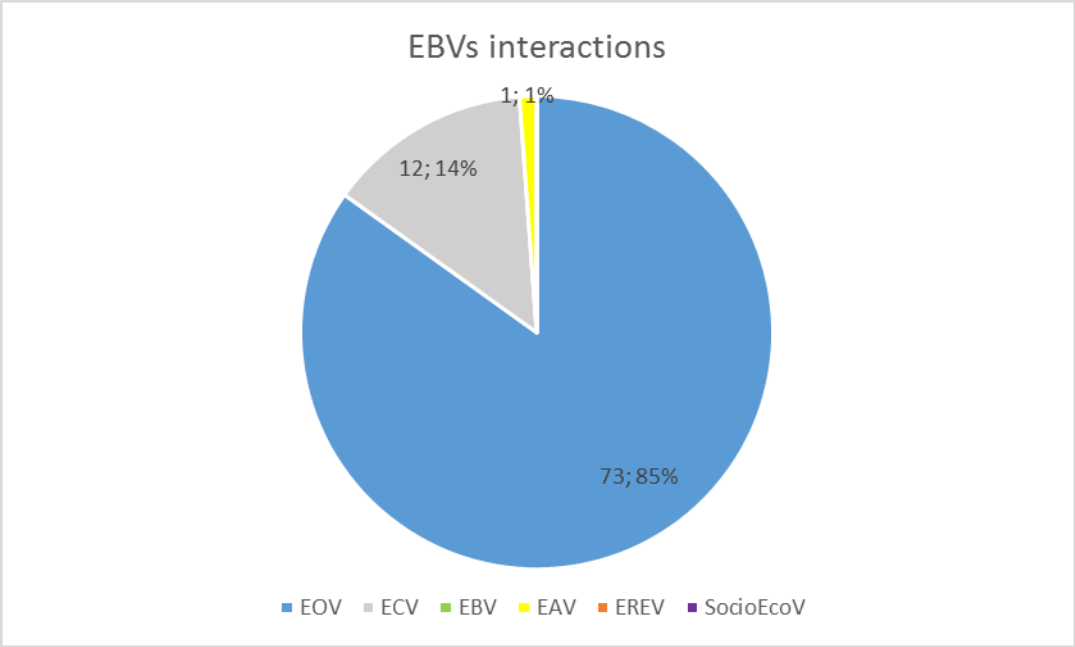


Figure 26. Overall number of connections between EBVs and other EVs

Most of the EBVs have up to 10 interactions with other EVs, mostly EOVs (Figure 27). This is because some EOVs have a strong biosphere component. In general, physical and biogeochemical ocean variables, already included in EOVs, provide the environmental context for biological EOVs and for EBVs. Yet, to facilitate integration into observing systems and enable broader interpretation, the EBVs need to be co-developed and mapped alongside the biological and ecological EOVs (bio-eco EOVs). (Muller-Karger Frank E. 2018)

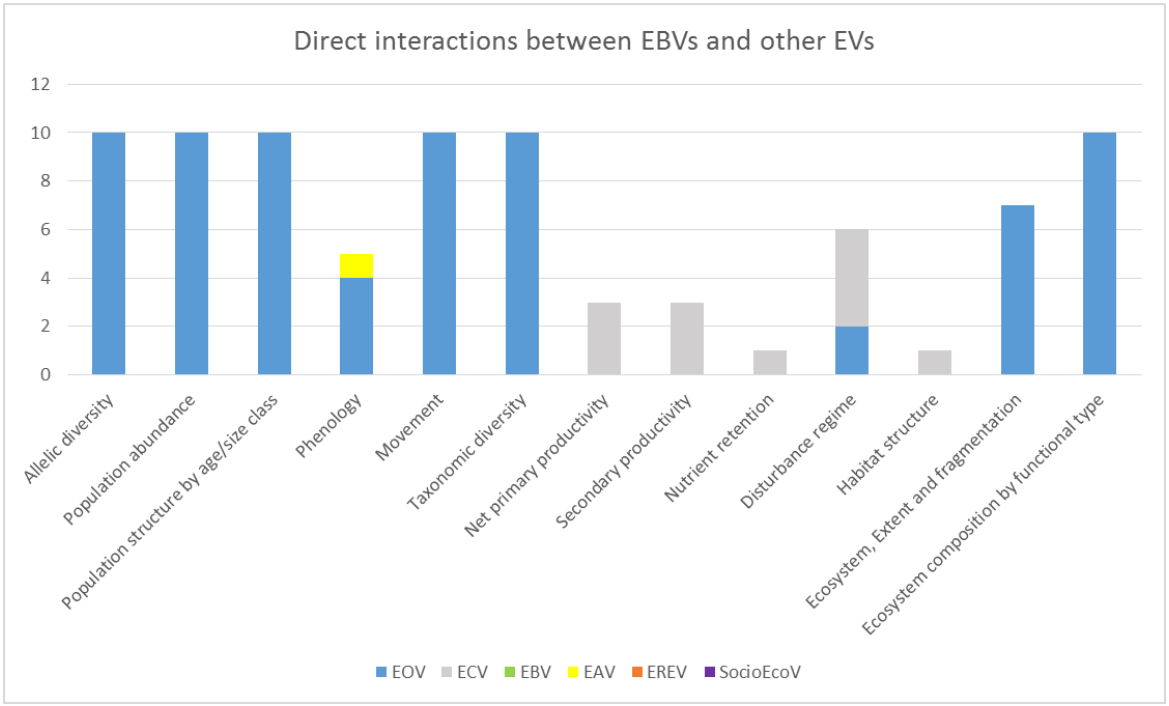


Figure 27. Number of interactions between EBVs and other EVs, per EBV

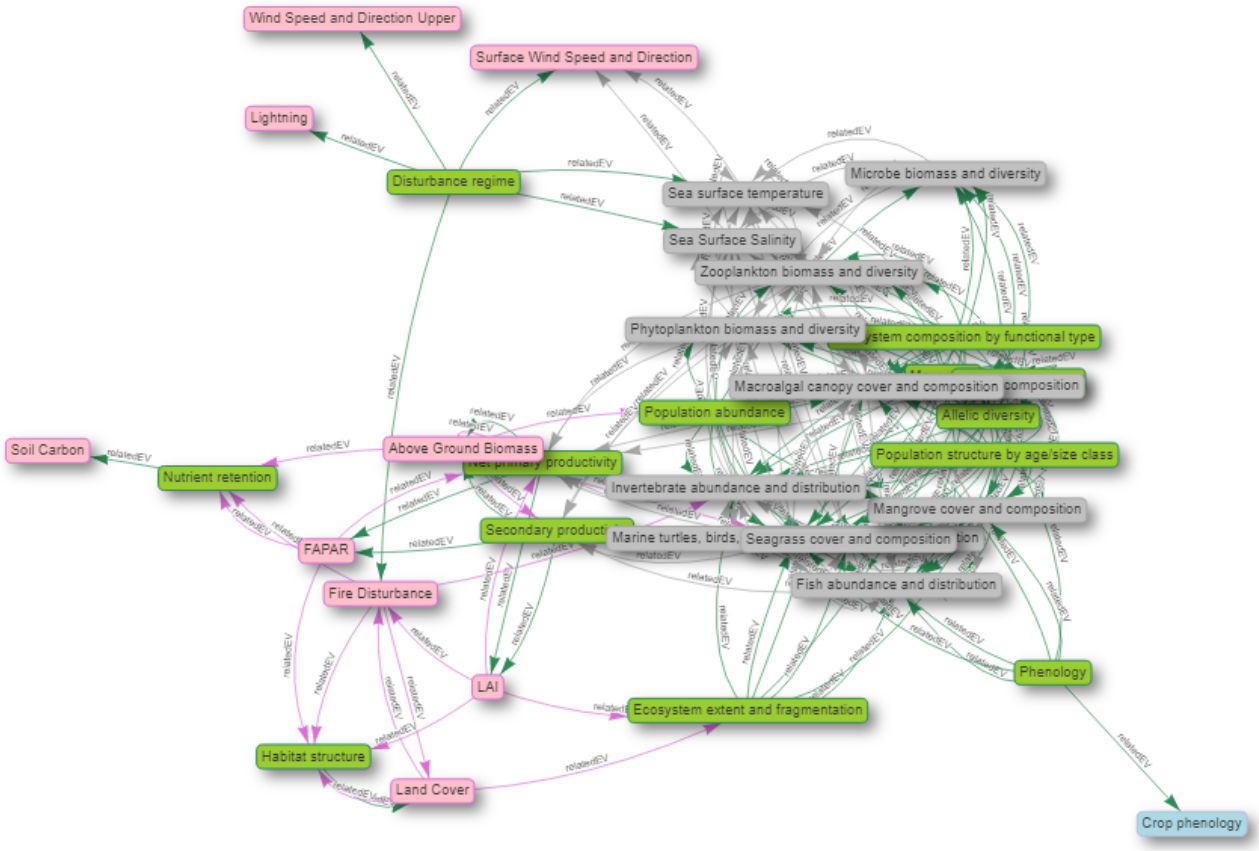


Figure 28. Screenshot from the ENEON graph showing the connections between EBVs and other EV

EAVs directly connected to other EVs

In the case of the emerging EAV only in one case exist a direct interaction with another EV, in this case the Land Cover ECV to derive Crop Area EAV.

EREVs directly connected to other EVs

In the case of the EREVs proposed in ConnectinGEO by the renewal energy community capitalised within GEO through the Mines Paris Tech group, these are equally related to EOVs and to ECVs (Figure 29 and Figure 30).

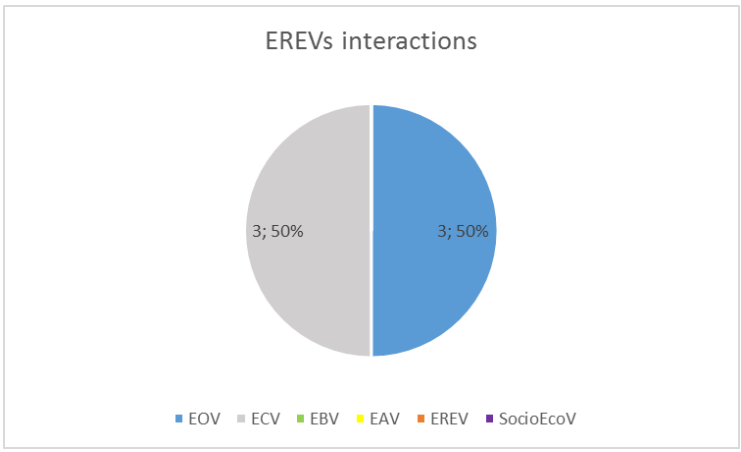


Figure 29. Overall number of connections between EREVs and other EVs

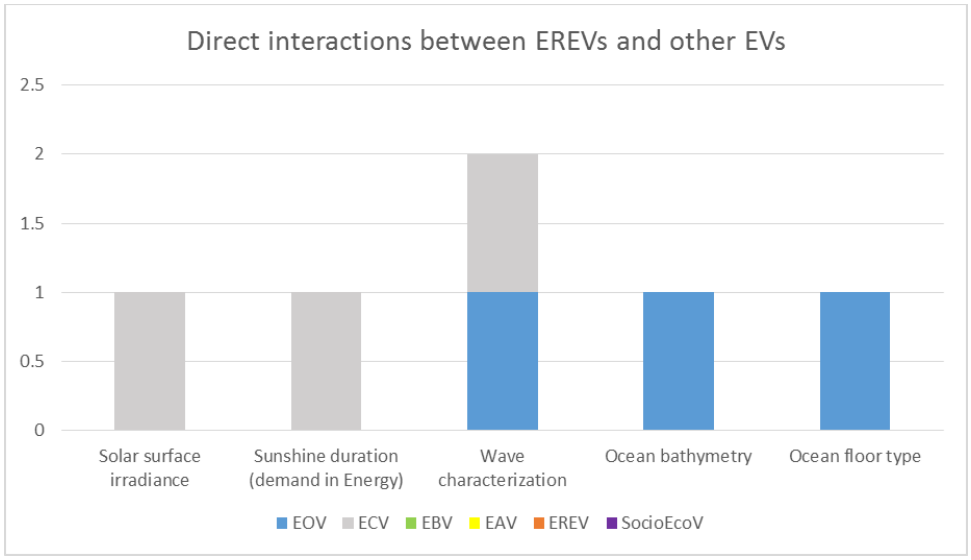


Figure 30. Number of interactions between EREVs and other EVs, per EREV

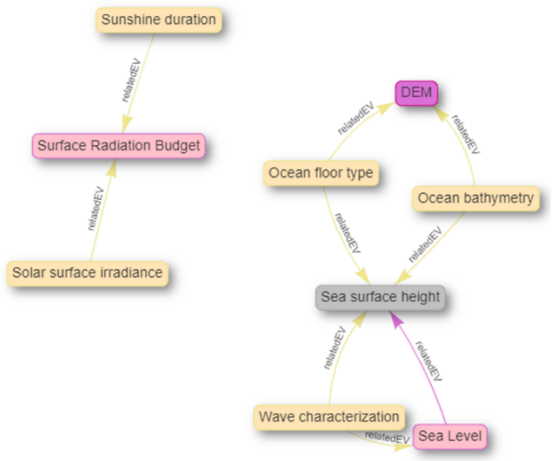


Figure 31. Screenshot from the ENEON graph showing the connections between EREVs and other EV

SocioEcoV directly connected to other EVs

No relations are established directly from SocioEcoV to other EVs but many EVs are related or based on the retrieval of these SocioEcoV.

Gaps prioritization

As said in the previous section, in this deliverable we have analysed gaps in terms of EVs existence and availability and their connection to SDGs indicators, instead of gaps in data which were studied within ConnectinGEO H2020 (ConnectinGEOb 2016). Proposal priorities will be then defined in terms of SDG interactions and EO networks behind.

Gaps in observing EO network

From Figure 12 we know that the most connected EV are "Anthropogenic water use" with 7 SDG indicators related, "Lakes" with 6 SDG indicators, "Land cover (Lakes)" with 5, and "River Discharge" with 4, all of them ECV. These could be then considered "strategic" EVs in terms of SDG monitoring and they should be properly connected with EO networks which could provide data. On the other hand, the only EVs which have no relation with some EO network are Lightning (ECV), Ocean surface stress (EOV), Microbe biomass and diversity (emerging) (EOV), Invertebrate abundance and distribution (emerging) (EOV), Solar surface irradiance (EREV), Sunshine duration (demand in energy) (EREV), Wave characterization (EREV), Ocean bathymetry (EREV), and Ocean floor type (EREV). So, it seems all SDG-"strategic" EVs are covered by EO networks, and the ones with no "cover" are less used EVs (not meaning they are not important EVs as well, since they are all defined as essential).

So we could consider there are no substantial gaps in terms of observing networks. However, the usefulness of these networks should be deeply studied in further studies, as for the moment, we can only say there's a related EO network behind, but we do not know anything on the availability of data. We should consider that, according to (Wetzel, et al. 2018), only around a third of the data-providers give unrestricted data access, and that particularly large geographic gaps exist in Eastern European countries as many datasets are not suitable for generating EBVs due to the absence of long-term data. This occurs in respect of EBVs but could be also applicable to other EVs.

From these analyses we can state that ECVs are the most connected EVs to SDGs indicators, and thus they play an important role. We also know that there are no major gaps regarding EO networks when it comes to ECVs. However, and according to (AtlantOS 2017), the IPCC Fifth Assessment Report notes that there are gaps in the current Global Climate Observing System on which the assessments it makes are based. More detailed climate observations are also needed for adaption planning to reduce risks from climate change and variability. It is, therefore, crucial to make further progress towards achieving a fully implemented, sustainable Global Climate Observing System.

Further analyses should be done in relation to the networks behind, as gaps could be better categorized in, for instance (AtlantOS 2017):

- Insufficient in-situ spatial coverage in relation to the phenomena (in particular, deep ocean is under-sampled in physics, biogeochemistry and biology).
- Gaps in baseline data.
- Gaps in observing infrastructure to allow for (near) real-time data transmission.
- Gaps in observations for validating satellite sensor data.
- Gaps in standardization and best practises for certain observing networks or certain variables.

So, regarding EO networks, we should prioritize those EVs with no data availability behind which, needs a more in-depth study and can't be inferred from the analysis of this deliverable.

Gaps in SDG indicators monitoring

There are some SDG indicators without any relation with EVs. In fact, some SDG goals have no indicators with relation with EVs. These are: *SDG 1. End poverty in all its forms everywhere*, *SDG 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all*, *SDG 5. Achieve gender equality and empower all women and girls*, *SDG 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all*, *SDG 10. Reduce inequality within and among countries*, *SDG 13. Take urgent action to combat climate change and its impacts*, *SDG 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels*, and *SDG 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development*.

This is because some SDG goals, and indicators, are mostly from a socioeconomic nature, but EVs are not currently defined in such terms. Regarding SDG indicators retrieval, thus, EVs have important gaps. In this sense, socioeconomic EVs could help to monitor these "orphan" SDG indicators. On the contrary, SDGs *6. Ensure availability and sustainable management of water and sanitation for all*, *14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development* and *15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss* are the ones with more interactions with EVs, as ECVs, EOVs, and EBVs are the most evolved EVs and are more close to EO observation indicators.

In this case, then, SDGs indicators without any corresponding EV, should be prioritize whether refocusing its definition in relation of its monitoring capacities, or defining new non existing EVs which could give answers to those orphan indicators.

Conclusions

It is a difficult task to analyse EVs in a rigorous manner as they are somehow intangible, broad and in some cases, they overlap with other EVs, which makes it difficult to know exactly what does intend to measure each EV. This overlapping is especially true between some ECV and EOVs (they even have the same EV name) and between "biospheric" EOVs and some EBVs.

This makes that the issue of relating EVs to EO networks may not be as complete and exhaustive as it could be, also because of the lifetime of this deliverable. This opens the door to the need of a more

in-depth study. Another point for this complexity is the EO networks panorama itself. It is an extremely complex environment as there are thousands on networks appearing and disappearing, consolidated or not, coming from a punctual project fund and being after discontinued after that, etc. The complexity of the networks is also in their same nature, as they are not always considered a network, but a system, or an infrastructure, or a catalogue, etc.

EVs and EO networks

Almost all EVs have EO networks that could provide data behind. The EVs with more connections with networks are the ECVs (41%), the EBVs (26%), and the EOVs (24%). This is completely logic as they are the 3 "historic" EVs with a strong network of communities behind.

This good connection between EVs and networks, suggests that EVs are well enough covered in terms of data or observations and thus they would be good candidates for Earth monitoring and, in particular, for SDG indicators monitoring.

SDGs and EVs correspondences

Regarding SDGs, in GEOEssential we still think EVs could become a good approach to retrieve SDG indicators. However, these are still vague and do not specify that much the matter and degree of monitoring. It is then a complicated task to properly relate SDG indicators with EVs.

SDGs indicators without any corresponding EV, should be prioritized to be redefined in relation to its monitoring capacities. Otherwise, new non existing EVs could give answer to these orphan SDG indicators.

From the work done in the GEO Community Activity on EVs, we know how difficult it is to stimulate the creation of new EVs in the SBA. On one side, there's the strong leadership of the "historic" EVs communities which do not see the need for these new EVs. On the other side, these other communities do not have enough steam to push for this process within their community. Finally, another important issue is the socioeconomic bias of most of the SDGs. In fact, H2020 ConnectinGEO concluded that 231 of the 240 SDG indicators could be calculated with socio-economic data, and only 30 could be extracted with the combination of socio-economic data and Earth observation (in-situ, airborne or remote sensing) and only 9 indicators by Earth observation alone (ConnectinGEO 2015). We think GEO should go for an in-depth analysis of the situation between SDG indicators, EO networks and EVs and try to solve the equation.

In this sense, the SBAs with a more mature development of EV lists are Climate, Ocean and Biodiversity. The Water SBA is also maturing a set of EVs in GEOSS. There are also SBAs that are working with a common set of variables that can be considered essential for them. In that sense, agricultural monitoring is conducted both by the USA and EU in a similar way; Crop Area, Crop Type, Crop Condition, etc., are obvious candidates for Agriculture EV's. More work is required for an agreement on other EVs for this SBA. Ecosystems is a cross-domain area that can make use of existing sets of EVs (such as ECVs, EOVs and EBVs) complemented by socioeconomic variables that can help to define ecosystem services to human societies. Renewable energy can also make use of the ECVs but there is a need for additional variables. For example, solar surface irradiance and wind at different

levels next to the ground are good candidates to explore. The Disaster SBA is one of the most heterogeneous areas dealing with disasters caused by a wide range of natural and anthropogenic hazards. Different sets of EVs are required for the different hazards, the vulnerability of exposed assets, and the impacts of the hazards on communities. In particular, socioeconomic EVs are required to characterize vulnerability and resilience (e.g., demographics, availability of public services, productive infrastructures, etc.) and to measure the extent of the hazard impacts on human societies leading to disasters.

This suggests that the use of EO data is completely new in some communities involved in the processes of facilitating progress towards the SDGs. For instance, the World Bank community has focused mainly on economic and social issues measured with aggregated socioeconomic data, even though a growing recognition remote sensing cannot be separated from monitoring progress. GEO can take an important role in supporting these communities with complementary indicators derived from EO data.

EVs interactions

Regarding the interactions (and possible overlapping) between EVs, most of EOVs interactions are with other EOVs (77%). This could suggest some redundancies among them or just that most of the EOVs are useful to retrieve other EOVs but are still all essential. Further analysis should be done in this direction to better differentiate this issue.

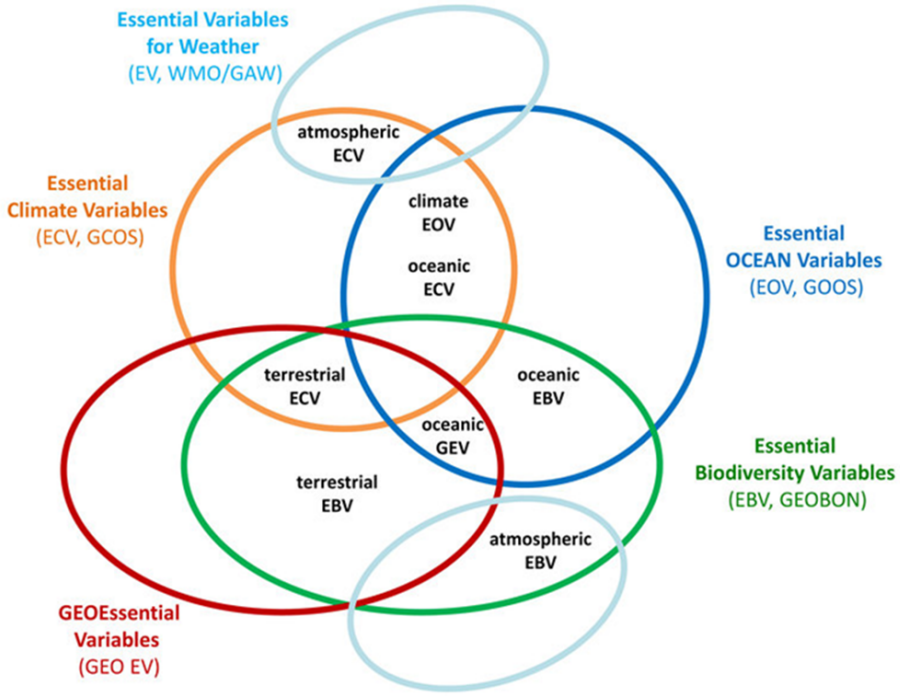


Figure 32. Conceptual overlap of Essential Variables (adapted figure from (Lausch, et al. 2018))

Many interactions coming from ECVs are with ECVs themselves or with EOVs (39% and 28%). In this case, a more in-depth analysis should be done in order to know whether the duplication of ECVs and EOVs are necessary, superfluous or could be redefined in terms of scales (temporal, spatial or geographic). In fact, there are 16 ECVs that have equal name to an equivalent EOV.

EBVs have a strong interconnection with EOVs (85%), especially the ones with a more biological component. However, EBVs are vaguer whereas biological EOVs are somehow more concrete, so in this case, it seems quite reasonable to maintain this "redundancy". Again, however, this should be analysed case by case. There is a natural connection between EBVs and ECVs but more in the sense of relation, not in terms of overlapping. Climatic parameters affect some EBVs but they are logically monitored through ECVs.

EAVs are only connected to ECVs, and in just one case: Crop Area is connected to ECV-Land Cover. On the contrary, 8% of ECVs are needed for some EAVs, suggesting that in this case there's a cross-benefit situation between ECVs and EAVs, and that there should be no need for more EAVs monitoring the same climatic parameters.

EREVs are equally connected to EOVs and ECVs, suggesting that many EREVs could be derived from these both (having into account the strong connection existing between ECVs and EOVs). EREVs have naturally strong dependency on climate parameters. In this case, a reflection should be done within the renewal energy community to detect whether all EREVs are needed or they could be derived from some variations on existing climatic EVs.

Finally, there are no relations established directly from SocioEcoV to other EVs but many EVs are related or based on the retrieval of these SocioEcoV. This is due to the fact that the SocioEcoV presented here are not really socioeconomic but only from a cartographic nature. These EVs come straight from ConnectinGEO and have been included here, but it is not the scope of GEOEssential to create new socioeconomic EVs.

To sum up, there is great uncertainty in the study of the interactions (and gaps) between **SDGs**, **EVs** and **EO networks**. In this deliverable we present the task done within GEOEssential, but we strongly encourage a comprehensive knowledge of this "triad" as it is capital in Earth monitoring and in the application of SDGs principles.

Glossary

Essential variables

EAV	Essential Agricultural Variables
EBV	Essential Biodiversity Variables
ECV	Essential Climate Variables
EESV	Essential Ecosystem Services Variables
EEV	Essential Ecosystem Variables
EOV	Essential Ocean Variables
EREV	Essential Renewable Energy Variables
ETV	Essential Transformation Variables
SocioEcoV	Essential SocioEconomic Variables

EO Networks

AERONET-OC	AErosol RObotic NETwork Ocean Color
AMAP	Arctic Monitoring and Assessment Programme
Anaee	Infrastructure for Analysis and Experimentation on Ecosystems
ArcticCouncil	Arctic Council
Argo	Argo
BirdLife	BirdLife International
BOUSSOLE	Buoy for the acquisition of long-term optical time series (BOUée pour l'acquiSition d'une Série Optique à Long termE)
CAFF	Conservation of Arctic Flora and Fauna
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CEOS-LPV	CEOS Land Product Validation - LPV
CETAF	Consortium of European Taxonomic Facilities
COPEPOD	Coastal & Oceanic Plankton Ecology, Production, & Observation Database
CopernicusClimateChange	Copernicus Climate Change Service
CopernicusLand	Copernicus Land Monitoring Service
DBCP	Data Buoy Cooperation Panel
DOPA	Digital Observatory for Protected Areas
ECOSCOPE	ECOSCOPE - A national forum for biodiversity research observatories
ECSA	European Citizen Science Association
EFFIS	European Forest Fire Information System
EGO	Everyone's Gliding Observatories
EIONET	European Environment Information and Observation Network
Elixir	European Life-science Infrastructure for Biological Information
ENEON	European Observatory of Earth Observation Networks
ENSA	European Network on Soil Awareness
ESBN	European Soil Bureau Network
ESDAC	European Soil Data Centre
ESP	European Soil Partnership
Euro-Argo	European infrastructure for Argo
FLUXNET	FLUXNET
FOS	Forest Observation System
GACS	Global Alliance of Continuous Plankton Recorder Surveys
GBIF	Global Biodiversity Information Facility
GCOS	Global Climate Observation System
GEO-GNOME	GEO Global Network for Observation and Information in Mountain Environments
GFOI	Global Forest Observations Initiative
GLOSS	Global Sea Level Observing System
GOFC-GOLD	Global Observation for Forest Cover and Land Dynamics
GOOS	Global Ocean Observing System
GO-SHIP	The Global Ocean Ship-Based Hydrographic Investigations Program
GRUAN	GCOS Reference Upper-Air Network
GSEO	Global System of Ecosystem Observatories

GTN	Global Terrestrial Network
GUAN	GCOS Upper-Air Network
GWOS	Global Wetland Observing System
GWOS	Global Wetland Observing System
HAEDAT	Harmful Algal Information System
IGMETS	International Group for Marine Ecological Time Series
ILTER	International Long-Term Ecosystem Research in Europe
IMOS	Integrated Marine Observing System
INSPIRE	Infrastructure for Spatial Information in the European Community
Interact	International Network for Terrestrial Research and Monitoring in the Arctic
ISMN	International Soil Moisture Network
JFRA	Japan Fisheries Research and Education Agency
KEEN	Kelp Ecosystem Ecology Network
LUCAS	Land use and land cover survey
MEOP	Marine Mammals Exploring the Oceans Pole to Pole
MOBY	Marine Optical Buoy
NDBC	National Data Buoy Center
OceanSITES	OceanSITES
OCR-VC	Ocean Colour Radiometry-Virtual Constellation
OSTST	OCEAN SURFACE TOPOGRAPHY SCIENCE TEAM
PESI	Pan-European Species directories Infrastructure
PISCO	Partnership for Interdisciplinary Studies of Coastal Oceans
Rainfor	Amazon Forest Inventory Network
SAON	Sustaining Arctic Observing Networks
Sios	Svalbard Integrated Earth Observing System
SWOS	Satellite-based Wetland Observation Service
SYNTHESYS	Synthesis of Systematic Resources
TrendsPO	Trends of Phytoplankton in the Ocean

Other

CBD	Convention on Biological Diversity
EO	Earth Observation
FAPAR	Absorbed Photosynthetically Active Radiation
FRP	Fire Radiated Power
HTE	High-Temperature Events
LAI	Leaf Area Index
SDG	Sustainable Development Goal
UNFCCC	UN Framework Convention on Climate Change

Bibliography

Ambrosone, M., G. Giuliani, B. Chatenoux, D. Rodila, and P. Lacroix. “Definition of candidate Essential Variables for the monitoring of mineral resources exploitation.” *Geo-spatial Information Science*, 2019: 265-278.

AtlantOS. “Capacities and Gap analysis.” deliverable, 2017.

ConnectinGEO. “EVs current status in different communities and way to move forward.” deliverable, 2015.

ConnectinGEOa. “Proposal of EVs for selected themes.” deliverable, 2016.

ConnectinGEOb. “Report on observations, measurements and gaps in observation systems reported by the communities.” deliverable, 2016.

Dantas de Paula, M., M. Gómez Giménez, A. Niamir, M. Thurner, and T. Hickler. “Combining European Earth Observation products with Dynamic Global Vegetation Models for estimating Essential Biodiversity Variables.” *International Journal of Digital Earth*, 2019: 262-277.

Fang, K., R. Heijungs, and G.R. De Snoo. “Understanding the complementary linkages between environmental footprints and planetary boundaries in a footprint–boundary environmental sustainability assessment framework.” *Ecological Economics*, 2015: 218-226.

GEO. *GEO Community Activities and Candidate Community Activities.* 2019. https://www.earthobservations.org/documents/gwp20_22/geo_essential_variables_ip.pdf (accessed 2019).

GEOEssential. “D4.1 EVs for Biodiversity and Ecosystems.” Deliverable, 2019.

GEOGLAM. *Towards Essential Agricultural Variables.* 2019. https://slideplayer.com/slide/15856616 (accessed July -, 2019).

Giampietro, M., K. Mayumi, and J. Ramos-Martin. “Multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM): Theoretical concepts and basic rationale.” *Energy 34 (3)*, 2009: 313-22.

Hardisty, A.R. , et al. “The Bari Manifesto: An interoperability framework for essential biodiversity variables,.” *Ecological Informatics*, 2019: 22-31.

Kissling, W.D. , et al. “Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale.” *Biological Reviews*, 2018: 600-625.

Kissling, W.D., et al. “Towards global interoperability for supporting biodiversity research on essential biodiversity variables (EBVs).” *Biodiversity*, 2015: 99-107.

Kolotii, A., et al. “Essential Variables on Air Quality Estimation within ERA-PLANET Project.” *International Journal of Digital Earth*, 2019: 278-298.

Kussul, Nataliia, Mykola Lavreniuk, Andrii Kolotii, Sergii Skakun, Olena Rakoid, and Leonid Shumilo. “A workflow for Sustainable Development Goals indicators assessment based on high-resolution satellite data.” *International Journal of Digital Earth*, 2019.

Lausch, A., et al. “Understanding Forest Health with Remote Sensing, Part III: Requirements for a Scalable Multi-Source Forest Health Monitoring Network Based on Data Science Approaches.” *Remote Sensing*, 2018: 1120.

Lavreniuk, M., N. Kussul, A. Kolotii, S. Skakun, O. Rakoid, and L. Shumilo. “A workflow for Sustainable Development Goals Indicators Assessment Based on High Resolution Satellite Data.” *International Journal of Digital Earth*, 2019: 309-321.

Lehmann, A., et al. “GEOEssential – mainstreaming workflows from data sources to environment policy indicators with essential variables.” *International Journal of Digital Earth*, 2019: 322-338.

Lehmann, A., J. Masó, S. Nativi, and G. Giuliani. “Towards integrated essential variables for sustainability.” *International Journal of Digital Earth*, 2020: 158-165.

Lindstrom, E., J. Gunn, A. Fischer, A. McCurdy, L.K. Glover, and T.T. Members. *A Framework for Ocean Observing.* IOC/INF-1284, UNESCO, 2012.

Masó, J., I. Serral, C. Domingo-Marimon, and A. Zabala. “Earth observations for sustainable development goals monitoring based on essential variables and driver-pressure-state-impact-response indicators.” *International Journal of Digital Earth*, 2019: 217-235.

McCallum, I., et al. “Addressing the food water energy nexus with Earth observation.” *International Journal of Digital Earth*, 2019: 299-308.

Miranda Espinosa, M.T., G. Giuliani, and N. Ray. “Essential Climate Variables: Reviewing the accessibility to data and information product.” *International Journal of Digital Earth*, 2019: 236-252.

Muller-Karger Frank E., Miloslavich Patricia, Bax Nicholas J., Simmons Samantha, Costello Mark J., Sousa Pinto Isabel, Canonico Gabrielle, Turner Woody, Gill Michael, Montes Enrique, Best Benjamin D., Pearlman Jay, Halpin Patrick, Dunn Daniel, Benson Abig. “Advancing Marine Biological Observations and Data Requirements of the Complementary Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs) Frameworks.” *Frontiers in Marine Science*, 2018: 211.

Muller-Karger, F.E., et al. “Advancing Marine Biological Observations and Data Requirements of the Complementary Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs) Frameworks.” *Frontiers in Marine Science*, 2018: 211.

Nativi, S., M. Santoro, G. Giuliani, and P. Mazzetti. “Towards a Knowledge Base to support Global Change Policy Goals.” *International Journal of Digital Earth*, 2019: 188-216.

Pereira, H.M., et al. “Essential Biodiversity Variables.” *Science*, 2013: 277-278.

Plag, H.P, and S. Jules-Plag. “A Goal-Based Approach to the Identification of Essential Transformation Variables in Support of the Implementation of the 2030 Agenda for Sustainable Development.” *International Journal of Digital Earth*, 2019: 166-187.

Ramirez-Reyes, C., et al. “Reimagining the potential of Earth observations for ecosystem service assessments.” *Science of The Total Environment*, 2019: 1053-1063.

Ranchin, T., M. Trolliet, L. Ménard, and L. Wald. “Which variables are essential for renewable energies?” *International Journal of Digital Earth*, 2019: 253-261.

Ranchin, Thierry, Mélodie Trolliet, Lionel Ménard, and Lucien Wald. “On the Essential Renewable Energies Variables.” *European Geosciences Union General Assembly.* Vienna, 2018.

Reyers, Belinda, Mark Stafford-Smith, Karl-Heinz Erb, Robert J Scholes, and Odirilwe Selomane. “Essential Variables help to focus Sustainable Development Goals monitoring.” *Current Opinion in Environmental Sustainability* 26–27 (2017): 97-105.

W.D. Kissling, R. Walls, A. Bowser, M.O. Jones, J. Kattge, D. Agosti, J. Amengual, A. Basset, P.M. van Bodegom, J.H.C. Cornelissen, E.G. Denny, S. Deudero, W. Egloff, S.C. Elmendorf, E. Alonso García, K.D. Jones, O.R. Jones, S. Lavorel, D. Lear, L.M. Nava. “Towards global data products of Essential Biodiversity Variables (EBVs) on species traits.” *Nature Ecology & Evolution*, 2018: 1531-1540.

Wetzel, F.T. , et al. “Unlocking biodiversity data: Prioritization and filling the gaps in biodiversity observation data in Europe.” *Biological Conservation* 221 (2018): 78-85.

Wilkinson, M.D. , et al. “The FAIR Guiding Principles for scientific data management and stewardship.” *Scientific Data*, 2016.

Annexes

Annex 1. List of the complete interactions for each EV

- Allelic diversity (Allelic diversity) Type: EBV Connected to: Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Population abundance (Population abundance) Type: EBV Connected to: Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Population structure by age/size class (Population structure by age/size class) Type: EBV Connected to: Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Phenology (Phenology) Type: EBV Connected to: Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Crop phenology EAV (Crop phenology)
- Movement (Movement) Type: EBV Connected to: Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Taxonomic diversity (Taxonomic diversity) Type: EBV Connected to: Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Net primary productivity (Net primary productivity) Type: EBV Connected to: Above Ground Biomass ECV (Above Ground Biomass), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) ECV (FAPAR), Leaf Area Index (LAI) ECV (LAI)
- Secondary productivity (Secondary productivity) Type: EBV Connected to: Above Ground Biomass ECV (Above Ground Biomass), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) ECV (FAPAR), Leaf Area Index (LAI) ECV (LAI)
- Nutrient retention (Nutrient retention) Type: EBV Connected to: Soil Carbon ECV (Soil Carbon)
- Disturbance regime (Disturbance regime) Type: EBV Connected to: Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Lightning ECV (Lightning), Wind Speed and Direction Upper ECV (Wind Speed and Direction Upper), Fire Disturbance ECV (Fire Disturbance), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity)
- Habitat structure (Habitat structure) Type: EBV Connected to: Land Cover ECV (Land Cover)

- Ecosystem extent and fragmentation (Ecosystem extent and fragmentation) Type: EBV Connected to: Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Ecosystem composition by functional type (Ecosystem composition by functional type) Type: EBV Connected to: Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Ocean Surface Heat Flux (Ocean Surface Heat Flux - ECV) Type: ECV Connected to: Ocean surface heat flux EOV (Ocean surface heat flux)
- Sea Ice (Sea Ice - ECV) Type: ECV Connected to: Sea ice EOV (Sea Ice)
- Sea Level (Sea Level) Type: ECV Connected to: Sea surface height EOV (Sea surface height)
- Sea State (Sea State - ECV) Type: ECV Connected to: Sea state EOV (Sea state)
- Sea Surface Salinity (Sea Surface Salinity - ECV) Type: ECV Connected to: Sea Surface Salinity EOV (Sea Surface Salinity)
- Sea Surface Temperature (Sea surface temperature - ECV) Type: ECV Connected to: Sea surface temperature (SST) EOV (Sea surface temperature)
- Subsurface Currents (Subsurface Currents - ECV) Type: ECV Connected to: Subsurface currents EOV (Subsurface currents)
- Subsurface Salinity (Subsurface Salinity - ECV) Type: ECV Connected to: Subsurface salinity EOV (Subsurface salinity)
- Subsurface Temperature (Subsurface Temperature - ECV) Type: ECV Connected to: Subsurface temperature EOV (Subsurface temperature)
- Surface Current (Surface Current - ECV) Type: ECV Connected to: Surface currents EOV (Surface currents)
- Ocean Surface Stress (Ocean Surface Stress - ECV) Type: ECV Connected to: Ocean surface stress EOV (Ocean surface stress)
- Inorganic Carbon (Inorganic Carbon - ECV) Type: ECV Connected to: Inorganic carbon EOV (Inorganic carbon)
- Nitrous Oxide (Nitrous Oxide - ECV) Type: ECV Connected to: Nitrous oxide EOV (Nitrous oxide)
- Nutrients (Nutrients - ECV) Type: ECV Connected to: Nutrients EOV (Nutrients)
- Ocean Color (Ocean Color - ECV) Type: ECV Connected to: Ocean colour EOV (Ocean colour)
- Oxygen (Oxygen - ECV) Type: ECV Connected to: Oxygen EOV (Oxygen)
- Transient Tracers (Transient Tracers - ECV) Type: ECV Connected to: Transient tracers EOV (Transient tracers)
- Marine Habitat Properties (Marine Habitat Properties) Type: ECV Connected to: Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition)
- Plankton (Plankton) Type: ECV Connected to: Species distribution EBV (Species distribution), Population abundance EBV (Population abundance), Net primary productivity EBV (Net primary productivity), Nutrient retention EBV (Nutrient retention), Nutrients ECV (Nutrients - ECV), Oxygen ECV (Oxygen - ECV), Nutrients EOV (Nutrients), Particulate matter EOV (Particulate matter), Nitrous oxide EOV (Nitrous oxide), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Ocean colour EOV (Ocean colour)
- Above Ground Biomass (Above Ground Biomass) Type: ECV Connected to: Species distribution EBV (Species distribution), Population abundance EBV (Population abundance), Net primary productivity EBV (Net primary productivity), Secondary productivity EBV (Secondary productivity), Nutrient retention EBV (Nutrient retention), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution)
- Albedo (Albedo) Type: ECV Connected to: Aerosols Properties ECV (Aerosols Properties), Carbon Dioxide, Methane and other Greenhouse Gases ECV (Carbon Dioxide, Methane and other Greenhouse Gases), Ozone ECV (Ozone), Precursors (supporting the Aerosol and Ozone ECVs) ECV (Precursors), Sea Ice ECV (Sea Ice - ECV), Sea ice EOV (Sea Ice)
- Fire Disturbance (Fire Disturbance) Type: ECV Connected to: Nutrient retention EBV (Nutrient retention), Habitat structure EBV (Habitat structure), Aerosols Properties ECV (Aerosols Properties), Carbon Dioxide, Methane and other Greenhouse Gases ECV (Carbon Dioxide, Methane and other Greenhouse Gases), Ozone ECV (Ozone), Precursors (supporting the Aerosol and Ozone ECVs) ECV (Precursors), Land Cover ECV (Land Cover), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution), Protected areas SocioEcoV (Protected areas)
- Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) (FAPAR) Type: ECV Connected to: Net primary productivity EBV (Net primary productivity), Nutrient retention EBV (Nutrient retention), Habitat structure EBV (Habitat structure), Carbon Dioxide, Methane and other Greenhouse Gases ECV (Carbon Dioxide, Methane and other Greenhouse Gases), Cloud Properties ECV (Cloud Properties)
- Glaciers (Glaciers) Type: ECV Connected to: Ocean Surface Heat Flux ECV (Ocean Surface Heat Flux - ECV), Sea Level ECV (Sea Level), Ocean surface heat flux EOV (Ocean surface heat flux)
- Groundwater (Groundwater) Type: ECV Connected to: Species distribution EBV (Species distribution), Population abundance EBV (Population abundance), Sea Level ECV (Sea Level), Crop Area EAV (Crop area), Crop type EAV (Crop type), Crop Yield EAV (Crop yield), Crop condition EAV (Crop condition)
- Ice Sheets and Ice Shelves (Ice Sheets) Type: ECV Connected to: Ocean Surface Heat Flux ECV (Ocean Surface Heat Flux - ECV), Sea Level ECV (Sea Level), Ocean surface heat flux EOV (Ocean surface heat flux)

- Lakes (Lakes) Type: ECV Connected to: Species distribution EBV (Species distribution), Population abundance EBV (Population abundance), Habitat structure EBV (Habitat structure), Ecosystem extent and fragmentation EBV (Ecosystem extent and fragmentation), Precipitation ECV (Precipitation), Land Cover ECV (Land Cover), Snow Cover ECV (Snow Cover)
- Land Cover (Land Cover) Type: ECV Connected to: Species distribution EBV (Species distribution), Habitat structure EBV (Habitat structure), Ecosystem extent and fragmentation EBV (Ecosystem extent and fragmentation), Fire Disturbance ECV (Fire Disturbance), Lakes ECV (Lakes), Land Cover (category forest) ECV (Forest (LC)), Snow Cover ECV (Snow Cover), Crop Area EAV (Crop area), Crop type EAV (Crop type)
- Land Cover (category forest) (Forest (LC)) Type: ECV Connected to: Land Cover ECV (Land Cover)
- Land Surface Temperature (Land Surface Temperature) Type: ECV Connected to: Habitat structure EBV (Habitat structure), Ecosystem extent and fragmentation EBV (Ecosystem extent and fragmentation), Albedo ECV (Albedo), Fire Disturbance ECV (Fire Disturbance), Land Cover (category forest) ECV (Forest (LC)), Soil Carbon ECV (Soil Carbon), Soil Moisture ECV (Soil Moisture)
- Leaf Area Index (LAI) (LAI) Type: ECV Connected to: Net primary productivity EBV (Net primary productivity), Habitat structure EBV (Habitat structure), Ecosystem extent and fragmentation EBV (Ecosystem extent and fragmentation), Carbon Dioxide, Methane and other Greenhouse Gases ECV (Carbon Dioxide, Methane and other Greenhouse Gases), Fire Disturbance ECV (Fire Disturbance), Land Cover (category forest) ECV (Forest (LC))
- Permafrost (Permafrost) Type: ECV Connected to: Ocean Surface Heat Flux ECV (Ocean Surface Heat Flux - ECV), Glaciers ECV (Glaciers), Ice Sheets and Ice Shelves ECV (Ice Sheets), Snow Cover ECV (Snow Cover), Ocean surface heat flux EOV (Ocean surface heat flux)
- River Discharge (River Discharge) Type: ECV Connected to: Precipitation ECV (Precipitation), Sea Level ECV (Sea Level), Sea Surface Salinity ECV (Sea Surface Salinity - ECV), Subsurface Salinity ECV (Subsurface Salinity - ECV), Snow Cover ECV (Snow Cover), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity)
- Snow Cover (Snow Cover) Type: ECV Connected to: Precipitation ECV (Precipitation), Land Cover ECV (Land Cover)
- Soil Moisture (Soil Moisture) Type: ECV Connected to: Nutrient retention EBV (Nutrient retention), Land Cover (category forest) ECV (Forest (LC)), Crop Area EAV (Crop area), Crop type EAV (Crop type), Crop Yield EAV (Crop yield), Crop condition EAV (Crop condition)
- Sea state (Sea state) Type: EOV Connected to: Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Surface currents EOV (Surface currents), Wave characterization EREV (Wave characterization)
- Ocean surface stress (Ocean surface stress) Type: EOV Connected to: Pressure ECV (Pressure), Sea state EOV (Sea state), Sea surface temperature (SST) EOV (Sea surface temperature), Surface currents EOV (Surface currents)
- Sea ice (Sea Ice) Type: EOV Connected to: Precipitation ECV (Precipitation), Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Sea Ice ECV (Sea Ice - ECV), Glaciers ECV (Glaciers), Ice Sheets and Ice Shelves ECV (Ice Sheets), Snow Cover ECV (Snow Cover), Sea surface temperature (SST) EOV (Sea surface temperature), Surface currents EOV (Surface currents), Wave characterization EREV (Wave characterization)
- Sea surface height (Sea surface height) Type: EOV Connected to: Pressure ECV (Pressure), Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Sea state EOV (Sea state), Subsurface temperature EOV (Subsurface temperature), Subsurface salinity EOV (Subsurface salinity)
- Sea surface temperature (SST) (Sea surface temperature) Type: EOV Connected to: Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Cloud Properties ECV (Cloud Properties), Ocean surface heat flux EOV (Ocean surface heat flux)
- Subsurface temperature (Subsurface temperature) Type: EOV Connected to: Surface currents EOV (Surface currents), Subsurface currents EOV (Subsurface currents), Ocean surface heat flux EOV (Ocean surface heat flux)
- Surface currents (Surface currents) Type: EOV Connected to: Sea surface height EOV (Sea surface height), Subsurface temperature EOV (Subsurface temperature), Subsurface salinity EOV (Subsurface salinity), Wave characterization EREV (Wave characterization)
- Subsurface currents (Subsurface currents) Type: EOV Connected to: Pressure ECV (Pressure), Subsurface temperature EOV (Subsurface temperature), Subsurface salinity EOV (Subsurface salinity), Ocean bathymetry EREV (Ocean bathymetry)
- Sea Surface Salinity (Sea Surface Salinity) Type: EOV Connected to: Precipitation ECV (Precipitation), Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Ice Sheets and Ice Shelves ECV (Ice Sheets), River Discharge ECV (River Discharge), Sea surface temperature (SST) EOV (Sea surface temperature), Inorganic carbon EOV (Inorganic carbon)
- Subsurface salinity (Subsurface salinity) Type: EOV Connected to: Precipitation ECV (Precipitation), Sea Level ECV (Sea Level), Sea Surface Salinity ECV (Sea Surface Salinity - ECV), Subsurface Salinity ECV (Subsurface Salinity - ECV), River Discharge ECV (River Discharge), Snow Cover ECV (Snow Cover), Sea Surface Salinity EOV (Sea Surface Salinity)
- Ocean surface heat flux (Ocean surface heat flux) Type: EOV Connected to: Pressure ECV (Pressure), Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Sea state EOV (Sea state), Ocean surface stress EOV (Ocean surface stress), Sea ice EOV (Sea Ice), Sea surface temperature (SST) EOV (Sea surface temperature), Surface currents EOV (Surface currents), Sea Surface Salinity EOV (Sea Surface Salinity), Ocean colour EOV (Ocean colour)
- Oxygen (Oxygen) Type: EOV Connected to: Ocean surface stress EOV (Ocean surface stress), Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity)
- Nutrients (Nutrients) Type: EOV Connected to: Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity), Oxygen EOV (Oxygen), Transient tracers EOV (Transient tracers)
- Inorganic carbon (Inorganic carbon) Type: EOV Connected to: Ocean surface stress EOV (Ocean surface stress), Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity), Oxygen EOV (Oxygen), Transient tracers EOV (Transient tracers)
- Transient tracers (Transient tracers) Type: EOV Connected to: Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity)

- Particulate matter (Particulate matter) Type: EOV Connected to: Ocean surface stress EOV (Ocean surface stress), Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity), Oxygen EOV (Oxygen), Nutrients EOV (Nutrients), Inorganic carbon EOV (Inorganic carbon), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Ocean colour EOV (Ocean colour)
- Nitrous oxide (Nitrous oxide) Type: EOV Connected to: Pressure ECV (Pressure), Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity)
- Stable carbon isotopes (Stable carbon isotopes) Type: EOV Connected to: Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity), Inorganic carbon EOV (Inorganic carbon)
- Dissolved organic carbon (Dissolved organic carbon) Type: EOV Connected to: Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity), Oxygen EOV (Oxygen), Nutrients EOV (Nutrients), Inorganic carbon EOV (Inorganic carbon), Transient tracers EOV (Transient tracers), Particulate matter EOV (Particulate matter), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity)
- Phytoplankton biomass and diversity (Phytoplankton biomass and diversity) Type: EOV Connected to: Net primary productivity EBV (Net primary productivity), Secondary productivity EBV (Secondary productivity), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Oxygen EOV (Oxygen), Nutrients EOV (Nutrients), Inorganic carbon EOV (Inorganic carbon), Particulate matter EOV (Particulate matter), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Ocean colour EOV (Ocean colour)
- Zooplankton biomass and diversity (Zooplankton biomass and diversity) Type: EOV Connected to: Net primary productivity EBV (Net primary productivity), Secondary productivity EBV (Secondary productivity), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Oxygen EOV (Oxygen), Nutrients EOV (Nutrients), Inorganic carbon EOV (Inorganic carbon), Particulate matter EOV (Particulate matter), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Ocean colour EOV (Ocean colour)
- Fish abundance and distribution (Fish abundance and distribution) Type: EOV Connected to: Secondary productivity EBV (Secondary productivity), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity)
- Marine turtles, birds, mammals abundance and distribution (Marine turtles, birds, mammals abundance and distribution) Type: EOV Connected to: Secondary productivity EBV (Secondary productivity), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity), Oxygen EOV (Oxygen), Particulate matter EOV (Particulate matter), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution), Ocean colour EOV (Ocean colour)
- Hard coral cover and composition (Hard coral cover and composition) Type: EOV Connected to: Net primary productivity EBV (Net primary productivity), Inorganic Carbon ECV (Inorganic Carbon - ECV), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Nutrients EOV (Nutrients), Inorganic carbon EOV (Inorganic carbon), Ocean colour EOV (Ocean colour)
- Seagrass cover and composition (Seagrass cover and composition) Type: EOV Connected to: Net primary productivity EBV (Net primary productivity), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Nutrients EOV (Nutrients), Fish abundance and distribution EOV (Fish abundance and distribution), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution), Ocean colour EOV (Ocean colour)
- Macroalgal canopy cover and composition (Macroalgal canopy cover and composition) Type: EOV Connected to: Net primary productivity EBV (Net primary productivity), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Nutrients EOV (Nutrients), Fish abundance and distribution EOV (Fish abundance and distribution), Ocean colour EOV (Ocean colour)
- Mangrove cover and composition (Mangrove cover and composition) Type: EOV Connected to: Precipitation ECV (Precipitation), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Fish abundance and distribution EOV (Fish abundance and distribution), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Microbe biomass and diversity (emerging) (Microbe biomass and diversity) Type: EOV Connected to: Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity)
- Invertebrate abundance and distribution (emerging) (Invertebrate abundance and distribution) Type: EOV Connected to: Net primary productivity EBV (Net primary productivity), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution)
- Ocean colour (Ocean colour) Type: EOV Connected to: Ocean surface stress EOV (Ocean surface stress), Sea ice EOV (Sea Ice), Sea surface height EOV (Sea surface height), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Inorganic carbon EOV (Inorganic carbon), Particulate matter EOV (Particulate matter), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Ocean bathymetry EREV (Ocean bathymetry)

- Ocean sound (Ocean sound) Type: EOV Connected to: Surface currents EOV (Surface currents), Ocean bathymetry EREV (Ocean bathymetry), Ocean floor type EREV (Ocean floor type)
- Crop Area (Crop area) Type: EAV Connected to: Land Cover ECV (Land Cover)
- Solar surface irradiance (Solar surface irradiance) Type: EREV Connected to: Surface Radiation Budget ECV (Surface Radiation Budget)
- Sunshine duration (demand in energy) (Sunshine duration) Type: EREV Connected to: Surface Radiation Budget ECV (Surface Radiation Budget)
- Wave characterization (Wave characterization) Type: EREV Connected to: Sea Level ECV (Sea Level), Sea surface height EOV (Sea surface height)
- Ocean bathymetry (Ocean bathymetry) Type: EREV Connected to: Sea surface height EOV (Sea surface height), Digital Elevation Model SocioEcoV (DEM)
- Ocean floor type (Ocean floor type) Type: EREV Connected to: Sea surface height EOV (Sea surface height), Digital Elevation Model SocioEcoV (DEM)

Annex 2. List of the complete interactions for each EOV

- Sea state (Sea state) Type: EOV Connected to: Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Surface currents EOV (Surface currents), Wave characterization EREV (Wave characterization)
- Ocean surface stress (Ocean surface stress) Type: EOV Connected to: Pressure ECV (Pressure), Sea state EOV (Sea state), Sea surface temperature (SST) EOV (Sea surface temperature), Surface currents EOV (Surface currents)
- Sea ice (Sea Ice) Type: EOV Connected to: Precipitation ECV (Precipitation), Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Sea Ice ECV (Sea Ice - ECV), Glaciers ECV (Glaciers), Ice Sheets and Ice Shelves ECV (Ice Sheets), Snow Cover ECV (Snow Cover), Sea surface temperature (SST) EOV (Sea surface temperature), Surface currents EOV (Surface currents), Wave characterization EREV (Wave characterization)
- Sea surface height (Sea surface height) Type: EOV Connected to: Pressure ECV (Pressure), Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Sea state EOV (Sea state), Subsurface temperature EOV (Subsurface temperature), Subsurface salinity EOV (Subsurface salinity)
- Sea surface temperature (SST) (Sea surface temperature) Type: EOV Connected to: Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Cloud Properties ECV (Cloud Properties), Ocean surface heat flux EOV (Ocean surface heat flux)
- Subsurface temperature (Subsurface temperature) Type: EOV Connected to: Surface currents EOV (Surface currents), Subsurface currents EOV (Subsurface currents), Ocean surface heat flux EOV (Ocean surface heat flux)
- Surface currents (Surface currents) Type: EOV Connected to: Sea surface height EOV (Sea surface height), Subsurface temperature EOV (Subsurface temperature), Subsurface salinity EOV (Subsurface salinity), Wave characterization EREV (Wave characterization)
- Subsurface currents (Subsurface currents) Type: EOV Connected to: Pressure ECV (Pressure), Subsurface temperature EOV (Subsurface temperature), Subsurface salinity EOV (Subsurface salinity), Ocean bathymetry EREV (Ocean bathymetry)
- Sea Surface Salinity (Sea Surface Salinity) Type: EOV Connected to: Precipitation ECV (Precipitation), Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Ice Sheets and Ice Shelves ECV (Ice Sheets), River Discharge ECV (River Discharge), Sea surface temperature (SST) EOV (Sea surface temperature), Inorganic carbon EOV (Inorganic carbon)
- Subsurface salinity (Subsurface salinity) Type: EOV Connected to: Precipitation ECV (Precipitation), Sea Level ECV (Sea Level), Sea Surface Salinity ECV (Sea Surface Salinity - ECV), Subsurface Salinity ECV (Subsurface Salinity - ECV), River Discharge ECV (River Discharge), Snow Cover ECV (Snow Cover), Sea Surface Salinity EOV (Sea Surface Salinity)
- Ocean surface heat flux (Ocean surface heat flux) Type: EOV Connected to: Pressure ECV (Pressure), Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Sea state EOV (Sea state), Ocean surface stress EOV (Ocean surface stress), Sea ice EOV (Sea Ice), Sea surface temperature (SST) EOV (Sea surface temperature), Surface currents EOV (Surface currents), Sea Surface Salinity EOV (Sea Surface Salinity), Ocean colour EOV (Ocean colour)
- Oxygen (Oxygen) Type: EOV Connected to: Ocean surface stress EOV (Ocean surface stress), Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity)
- Nutrients (Nutrients) Type: EOV Connected to: Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity), Oxygen EOV (Oxygen), Transient tracers EOV (Transient tracers)
- Inorganic carbon (Inorganic carbon) Type: EOV Connected to: Ocean surface stress EOV (Ocean surface stress), Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity), Oxygen EOV (Oxygen), Transient tracers EOV (Transient tracers)
- Transient tracers (Transient tracers) Type: EOV Connected to: Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity)
- Particulate matter (Particulate matter) Type: EOV Connected to: Ocean surface stress EOV (Ocean surface stress), Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity), Oxygen EOV (Oxygen), Nutrients EOV (Nutrients), Inorganic carbon EOV (Inorganic carbon), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Ocean colour EOV (Ocean colour)
- Nitrous oxide (Nitrous oxide) Type: EOV Connected to: Pressure ECV (Pressure), Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity)
- Stable carbon isotopes (Stable carbon isotopes) Type: EOV Connected to: Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity), Inorganic carbon EOV (Inorganic carbon)

- Dissolved organic carbon (Dissolved organic carbon) Type: EOV Connected to: Sea surface temperature (SST) EOV (Sea surface temperature), Subsurface temperature EOV (Subsurface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity), Oxygen EOV (Oxygen), Nutrients EOV (Nutrients), Inorganic carbon EOV (Inorganic carbon), Transient tracers EOV (Transient tracers), Particulate matter EOV (Particulate matter), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity)
- Phytoplankton biomass and diversity (Phytoplankton biomass and diversity) Type: EOV Connected to: Net primary productivity EBV (Net primary productivity), Secondary productivity EBV (Secondary productivity), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Oxygen EOV (Oxygen), Nutrients EOV (Nutrients), Inorganic carbon EOV (Inorganic carbon), Particulate matter EOV (Particulate matter), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Ocean colour EOV (Ocean colour)
- Zooplankton biomass and diversity (Zooplankton biomass and diversity) Type: EOV Connected to: Net primary productivity EBV (Net primary productivity), Secondary productivity EBV (Secondary productivity), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Oxygen EOV (Oxygen), Nutrients EOV (Nutrients), Inorganic carbon EOV (Inorganic carbon), Particulate matter EOV (Particulate matter), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Ocean colour EOV (Ocean colour)
- Fish abundance and distribution (Fish abundance and distribution) Type: EOV Connected to: Secondary productivity EBV (Secondary productivity), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity)
- Marine turtles, birds, mammals abundance and distribution (Marine turtles, birds, mammals abundance and distribution) Type: EOV Connected to: Secondary productivity EBV (Secondary productivity), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity), Oxygen EOV (Oxygen), Particulate matter EOV (Particulate matter), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution), Ocean colour EOV (Ocean colour)
- Hard coral cover and composition (Hard coral cover and composition) Type: EOV Connected to: Net primary productivity EBV (Net primary productivity), Inorganic Carbon ECV (Inorganic Carbon - ECV), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Nutrients EOV (Nutrients), Inorganic carbon EOV (Inorganic carbon), Ocean colour EOV (Ocean colour)
- Seagrass cover and composition (Seagrass cover and composition) Type: EOV Connected to: Net primary productivity EBV (Net primary productivity), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Nutrients EOV (Nutrients), Fish abundance and distribution EOV (Fish abundance and distribution), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution), Ocean colour EOV (Ocean colour)
- Macroalgal canopy cover and composition (Macroalgal canopy cover and composition) Type: EOV Connected to: Net primary productivity EBV (Net primary productivity), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Nutrients EOV (Nutrients), Fish abundance and distribution EOV (Fish abundance and distribution), Ocean colour EOV (Ocean colour)
- Mangrove cover and composition (Mangrove cover and composition) Type: EOV Connected to: Precipitation ECV (Precipitation), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Fish abundance and distribution EOV (Fish abundance and distribution), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Microbe biomass and diversity (emerging) (Microbe biomass and diversity) Type: EOV Connected to: Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity)
- Invertebrate abundance and distribution (emerging) (Invertebrate abundance and distribution) Type: EOV Connected to: Net primary productivity EBV (Net primary productivity), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution)
- Ocean colour (Ocean colour) Type: EOV Connected to: Ocean surface stress EOV (Ocean surface stress), Sea ice EOV (Sea Ice), Sea surface height EOV (Sea surface height), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity), Inorganic carbon EOV (Inorganic carbon), Particulate matter EOV (Particulate matter), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Ocean bathymetry EREV (Ocean bathymetry)
- Ocean sound (Ocean sound) Type: EOV Connected to: Surface currents EOV (Surface currents), Ocean bathymetry EREV (Ocean bathymetry), Ocean floor type EREV (Ocean floor type)

Annex 3. List of the complete interactions for each ECV

- Ocean Surface Heat Flux (Ocean Surface Heat Flux - ECV) Type: ECV Connected to: Ocean surface heat flux EOV (Ocean surface heat flux)
- Sea Ice (Sea Ice - ECV) Type: ECV Connected to: Sea ice EOV (Sea Ice)
- Sea Level (Sea Level) Type: ECV Connected to: Sea surface height EOV (Sea surface height)
- Sea State (Sea State - ECV) Type: ECV Connected to: Sea state EOV (Sea state)
- Sea Surface Salinity (Sea Surface Salinity - ECV) Type: ECV Connected to: Sea Surface Salinity EOV (Sea Surface Salinity)
- Sea Surface Temperature (Sea surface temperature - ECV) Type: ECV Connected to: Sea surface temperature (SST) EOV (Sea surface temperature)
- Subsurface Currents (Subsurface Currents - ECV) Type: ECV Connected to: Subsurface currents EOV (Subsurface currents)
- Subsurface Salinity (Subsurface Salinity - ECV) Type: ECV Connected to: Subsurface salinity EOV (Subsurface salinity)
- Subsurface Temperature (Subsurface Temperature - ECV) Type: ECV Connected to: Subsurface temperature EOV (Subsurface temperature)

- Surface Current (Surface Current - ECV) Type: ECV Connected to: Surface currents EOV (Surface currents)
- Ocean Surface Stress (Ocean Surface Stress - ECV) Type: ECV Connected to: Ocean surface stress EOV (Ocean surface stress)
- Inorganic Carbon (Inorganic Carbon - ECV) Type: ECV Connected to: Inorganic carbon EOV (Inorganic carbon)
- Nitrous Oxide (Nitrous Oxide - ECV) Type: ECV Connected to: Nitrous oxide EOV (Nitrous oxide)
- Nutrients (Nutrients - ECV) Type: ECV Connected to: Nutrients EOV (Nutrients)
- Ocean Color (Ocean Color - ECV) Type: ECV Connected to: Ocean colour EOV (Ocean colour)
- Oxygen (Oxygen - ECV) Type: ECV Connected to: Oxygen EOV (Oxygen)
- Transient Tracers (Transient Tracers - ECV) Type: ECV Connected to: Transient tracers EOV (Transient tracers)
- Marine Habitat Properties (Marine Habitat Properties) Type: ECV Connected to: Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition)
- Plankton (Plankton) Type: ECV Connected to: Species distribution EBV (Species distribution), Population abundance EBV (Population abundance), Net primary productivity EBV (Net primary productivity), Nutrient retention EBV (Nutrient retention), Nutrients ECV (Nutrients - ECV), Oxygen ECV (Oxygen - ECV), Nutrients EOV (Nutrients), Particulate matter EOV (Particulate matter), Nitrous oxide EOV (Nitrous oxide), Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Ocean colour EOV (Ocean colour)
- Above Ground Biomass (Above Ground Biomass) Type: ECV Connected to: Species distribution EBV (Species distribution), Population abundance EBV (Population abundance), Net primary productivity EBV (Net primary productivity), Secondary productivity EBV (Secondary productivity), Nutrient retention EBV (Nutrient retention), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution)
- Albedo (Albedo) Type: ECV Connected to: Aerosols Properties ECV (Aerosols Properties), Carbon Dioxide, Methane and other Greenhouse Gases ECV (Carbon Dioxide, Methane and other Greenhouse Gases), Ozone ECV (Ozone), Precursors (supporting the Aerosol and Ozone ECVs) ECV (Precursors), Sea Ice ECV (Sea Ice - ECV), Sea ice EOV (Sea Ice)
- Fire Disturbance (Fire Disturbance) Type: ECV Connected to: Nutrient retention EBV (Nutrient retention), Habitat structure EBV (Habitat structure), Aerosols Properties ECV (Aerosols Properties), Carbon Dioxide, Methane and other Greenhouse Gases ECV (Carbon Dioxide, Methane and other Greenhouse Gases), Ozone ECV (Ozone), Precursors (supporting the Aerosol and Ozone ECVs) ECV (Precursors), Land Cover ECV (Land Cover), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution), Protected areas SocioEcoV (Protected areas)
- Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) (FAPAR) Type: ECV Connected to: Net primary productivity EBV (Net primary productivity), Nutrient retention EBV (Nutrient retention), Habitat structure EBV (Habitat structure), Carbon Dioxide, Methane and other Greenhouse Gases ECV (Carbon Dioxide, Methane and other Greenhouse Gases), Cloud Properties ECV (Cloud Properties)
- Glaciers (Glaciers) Type: ECV Connected to: Ocean Surface Heat Flux ECV (Ocean Surface Heat Flux - ECV), Sea Level ECV (Sea Level), Ocean surface heat flux EOV (Ocean surface heat flux)
- Groundwater (Groundwater) Type: ECV Connected to: Species distribution EBV (Species distribution), Population abundance EBV (Population abundance), Sea Level ECV (Sea Level), Crop Area EAV (Crop area), Crop type EAV (Crop type), Crop Yield EAV (Crop yield), Crop condition EAV (Crop condition)
- Ice Sheets and Ice Shelves (Ice Sheets) Type: ECV Connected to: Ocean Surface Heat Flux ECV (Ocean Surface Heat Flux - ECV), Sea Level ECV (Sea Level), Ocean surface heat flux EOV (Ocean surface heat flux)
- Lakes (Lakes) Type: ECV Connected to: Species distribution EBV (Species distribution), Population abundance EBV (Population abundance), Habitat structure EBV (Habitat structure), Ecosystem extent and fragmentation EBV (Ecosystem extent and fragmentation), Precipitation ECV (Precipitation), Land Cover ECV (Land Cover), Snow Cover ECV (Snow Cover)
- Land Cover (Land Cover) Type: ECV Connected to: Species distribution EBV (Species distribution), Habitat structure EBV (Habitat structure), Ecosystem extent and fragmentation EBV (Ecosystem extent and fragmentation), Fire Disturbance ECV (Fire Disturbance), Lakes ECV (Lakes), Land Cover (category forest) ECV (Forest (LC)), Snow Cover ECV (Snow Cover), Crop Area EAV (Crop area), Crop type EAV (Crop type)
- Land Cover (category forest) (Forest (LC)) Type: ECV Connected to: Land Cover ECV (Land Cover)
- Land Surface Temperature (Land Surface Temperature) Type: ECV Connected to: Habitat structure EBV (Habitat structure), Ecosystem extent and fragmentation EBV (Ecosystem extent and fragmentation), Albedo ECV (Albedo), Fire Disturbance ECV (Fire Disturbance), Land Cover (category forest) ECV (Forest (LC)), Soil Carbon ECV (Soil Carbon), Soil Moisture ECV (Soil Moisture)
- Leaf Area Index (LAI) (LAI) Type: ECV Connected to: Net primary productivity EBV (Net primary productivity), Habitat structure EBV (Habitat structure), Ecosystem extent and fragmentation EBV (Ecosystem extent and fragmentation), Carbon Dioxide, Methane and other Greenhouse Gases ECV (Carbon Dioxide, Methane and other Greenhouse Gases), Fire Disturbance ECV (Fire Disturbance), Land Cover (category forest) ECV (Forest (LC))
- Permafrost (Permafrost) Type: ECV Connected to: Ocean Surface Heat Flux ECV (Ocean Surface Heat Flux - ECV), Glaciers ECV (Glaciers), Ice Sheets and Ice Shelves ECV (Ice Sheets), Snow Cover ECV (Snow Cover), Ocean surface heat flux EOV (Ocean surface heat flux)
- River Discharge (River Discharge) Type: ECV Connected to: Precipitation ECV (Precipitation), Sea Level ECV (Sea Level), Sea Surface Salinity ECV (Sea Surface Salinity - ECV), Subsurface Salinity ECV (Subsurface Salinity - ECV), Snow Cover ECV (Snow Cover), Sea Surface Salinity EOV (Sea Surface Salinity), Subsurface salinity EOV (Subsurface salinity)
- Snow Cover (Snow Cover) Type: ECV Connected to: Precipitation ECV (Precipitation), Land Cover ECV (Land Cover)
- Soil Moisture (Soil Moisture) Type: ECV Connected to: Nutrient retention EBV (Nutrient retention), Land Cover (category forest) ECV (Forest (LC)), Crop Area EAV (Crop area), Crop type EAV (Crop type), Crop Yield EAV (Crop yield), Crop condition EAV (Crop condition)

Annex 4. List of the complete interactions for each EBV

- Allelic diversity (Allelic diversity) Type: EBV Connected to: Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and

composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)

- Population abundance (Population abundance) Type: EBV Connected to: Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Population structure by age/size class (Population structure by age/size class) Type: EBV Connected to: Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Phenology (Phenology) Type: EBV Connected to: Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Crop phenology EAV (Crop phenology)
- Movement (Movement) Type: EBV Connected to: Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Taxonomic diversity (Taxonomic diversity) Type: EBV Connected to: Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Net primary productivity (Net primary productivity) Type: EBV Connected to: Above Ground Biomass ECV (Above Ground Biomass), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) ECV (FAPAR), Leaf Area Index (LAI) ECV (LAI)
- Secondary productivity (Secondary productivity) Type: EBV Connected to: Above Ground Biomass ECV (Above Ground Biomass), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) ECV (FAPAR), Leaf Area Index (LAI) ECV (LAI)
- Nutrient retention (Nutrient retention) Type: EBV Connected to: Soil Carbon ECV (Soil Carbon)
- Disturbance regime (Disturbance regime) Type: EBV Connected to: Surface Wind Speed and Direction ECV (Surface Wind Speed and Direction), Lightning ECV (Lightning), Wind Speed and Direction Upper ECV (Wind Speed and Direction Upper), Fire Disturbance ECV (Fire Disturbance), Sea surface temperature (SST) EOV (Sea surface temperature), Sea Surface Salinity EOV (Sea Surface Salinity)
- Habitat structure (Habitat structure) Type: EBV Connected to: Land Cover ECV (Land Cover)
- Ecosystem extent and fragmentation (Ecosystem extent and fragmentation) Type: EBV Connected to: Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)
- Ecosystem composition by functional type (Ecosystem composition by functional type) Type: EBV Connected to: Phytoplankton biomass and diversity EOV (Phytoplankton biomass and diversity), Zooplankton biomass and diversity EOV (Zooplankton biomass and diversity), Fish abundance and distribution EOV (Fish abundance and distribution), Marine turtles, birds, mammals abundance and distribution EOV (Marine turtles, birds, mammals abundance and distribution), Hard coral cover and composition EOV (Hard coral cover and composition), Seagrass cover and composition EOV (Seagrass cover and composition), Macroalgal canopy cover and composition EOV (Macroalgal canopy cover and composition), Mangrove cover and composition EOV (Mangrove cover and composition), Microbe biomass and diversity (emerging) EOV (Microbe biomass and diversity), Invertebrate abundance and distribution (emerging) EOV (Invertebrate abundance and distribution)

Annex 5. List of the complete interactions for each EREV

- Solar surface irradiance (Solar surface irradiance) Type: EREV Connected to: Surface Radiation Budget ECV (Surface Radiation Budget)
- Sunshine duration (demand in energy) (Sunshine duration) Type: EREV Connected to: Surface Radiation Budget ECV (Surface Radiation Budget)

- Wave characterization (Wave characterization) Type: EREV Connected to: Sea Level ECV (Sea Level), Sea surface height EOV (Sea surface height)
- Ocean bathymetry (Ocean bathymetry) Type: EREV Connected to: Sea surface height EOV (Sea surface height), Digital Elevation Model SocioEcoV (DEM)
- Ocean floor type (Ocean floor type) Type: EREV Connected to: Sea surface height EOV (Sea surface height), Digital Elevation Model SocioEcoV (DEM)