Deliverable 6.1

Description of Food Water Energy EVs

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Introduction

In recent years, the Nexus approach has emerged as a key narrative to describe complex interlinkages between food, water, and energy (Hoff 2011; Allouche 2015). Both from an analytical and normative viewpoint, the Nexus concept is helpful to go beyond trade-offs and the identification of winners and losers (Weitz, Nilsson, and Davis 2014). This approach aims at moving resources management from silos to an implementation of integrated and cost-effective measures towards identification of shared benefits along specific value chains (Biggs et al. 2015).

Underlying the call to pursue a Nexus approach and the SDGs within the limits of planetary boundaries is the recognition that profound economic, societal and technical transformations are necessary. For example, much work remains to be done for economic indicators to reflect negative environmental externalities. The corresponding scientific challenges (Naeem et al. 2015) – gathering baseline data to document initial conditions, developing reliable metrics as indicators, monitoring essential variables, accounting for dynamic natural and human processes, incorporating trade-offs and synergies, etc. – are considerable and represent a central element of the Ecosystem Services (ES) framework of the Intergovernmental Science-Policy Platform on Biodiversity & Ecosystem Services (IPBES) and the Convention on Biological Diversity (CBD).

The concept of Essential Variables is increasingly used in Earth observation communities to identify those variables that have a high impact and should have priority in designing, deploying and maintaining observation systems and making data and products available. The concept of EVs assumes that there are a (small) number of variables that are essential to characterize the state and trends in a system without losing significant information. It is that set of variables that needs to be observed if past changes in the system have to be documented and if predictability of future changes is to be developed. Identifying this set of EVs allows for a commitment of inherently scarce resources to the essential observation needs. It also supports and eases the management of data and observations all along the chain from the measurement of raw data, through the processing and to the delivery of products, information and services needed by end users. The review of the set of EVs developed across several Group on Earth Observation (GEO) communities within the project ConnectinGEO (http://www.connectingeo.net/), revealed that there are different levels of maturity (with some communities well advanced and others in their infancy) and a considerable overlap between EVs already identified by different communities.

Essential Variables

In the context of the food, water and energy (FWE) nexus, WP6 will contribute to the GEOEssential knowledge base infrastructure with the determination of the required FWE EVs considering the related European policies, SDGs and modelling requirements. The workflow will be established from EVs derived via multiple EV Services (WP3). This will include multiple open data streams (e.g. remote sensing, in-situ, citizen science, social media, telecommunications, socioeconomic and more) obtained preferably via the GEO-DAB (discovery and access broker). One or more case studies will be selected for implementation across Europe, with the results being integrated into a nexus approach. Finally, the information will be transferred to the SDG dashboard (WP7), along with updating of the ConnectinGEO gap analysis and the ENEON (WP2).

By far the most established lists of essential variables to date are in the climate (Bojinski et al. 2014) and biodiversity (Pereira et al. 2013) domains (see Appendix). There is a significant amount of overlap between the EVs identified in climate and biodiversity, and many are broadly applicable across other domains.

The following sections broadly describe the basic EVs that have been identified across each of the FEW nexus domains. Much of this work borrows from previous efforts in the ConnectinGEO project (CREAF 2015), updated where possible.

Food

Within GEO, GEOGLAM (the global agricultural monitoring flagship) represents the international community's capacity to produce and disseminate relevant, timely and accurate projections of agricultural production at national, regional and global scales by using Earth Observation data. In GEOGLAM, EVs per se have not been defined, however they have been articulated in the form of monitoring needs to support policy and program development at the local, regional, national and global scales. The sector has been using a clear set of comparative measures that can be globally applied at different scales including global assessment, national capacity building and early warning for food insecure nations. These are also supported by Joint Experiments by R&D activities on sensors.

From the ConnectinGEO project, some food-agriculture-related EVs were identified (Table 1). In addition, the Crop Monitor (https://cropmonitor.org/) identifies some of the EO data that is required and has been added to the list. In particular:

Table 1. Provisional Essential Food Variables.

Essential Food Variables	Related EVs
Crop area: A mask of where there are crops (e.g. land cover/land use)	
Crop type: Crop type area extent and crop calendars	
[1]Crop condition: The health and growing condition of croplands. How the crops evolve thought the growing season. Here NDVI can be used.	

Crop phenology: A key issue that is in a research phase but will be a good instrument for yield forecasting. Here NDVI can be used.	
Crop yield (current and forecast): Derived cropland output (yield) is based on empirical information and crop growth information	
Crop management and agricultural practices (tillage, residue)	
Surface air temperature (temperature anomaly)	ECV
Precipitation	ECV
Solar surface irradiance and its components (global, direct, diffuse)	ECV
Soil moisture	ECV
Soil organic matter/Soil organic carbon	ECV
Soil mineral composition/grain size	
Evapotranspiration	
Water use demand (irrigation)	

[1] Crop Condition is a problematic term. At this stage we indicate NDVI as being a useful EO indicator for crop condition.

The following conclusions were extracted from the ConnectinGEO Project:

- There's some overlapping with EVs in other domains. The opportunity here should be to harmonize the needs of different domains to engage more users in using the agriculture essential variables.
- The priorities for EVs in the agriculture domain would be related to the agriculture monitoring, crop area, type, condition, phenology and yield; all of them, issues strongly related to food.
- EVs should be refocused to deal with the food sustainability context, in terms of crop management (tillage and residue) and with the link to other SBAs such as habitat biodiversity EVs, etc.
- Recommendations for GEO/GEOSS in a global context:

    - Develop a common approach to document EVs and their observation requirements. EVs are a way to share a common language and exchange information between domains.
    - Determine areas where EV/observation integration can occur. There is a strong bias to pursue some of the most fundamental EVs that cut across multiple domains in a multi-disciplinary/domain/SBA fashion. Linking different user communities together.

Water

The GEO Water Cycle Community of Practice has been engaged in identifying user needs and Essential Water Cycle Variables (EWVs). This work builds on the achievements of the IGOS-P Integrated Global Water Cycle Observation Theme and has resulted in the GEOSS Water Strategy (Lawford 2014) summarizing the most recent status.

The deliberations on EWVs are still in an early stage, with the following provisional EVs put forth (Table 2). The GEOSS Water Strategy defines EWVs as "water variables/parameters that address "user"-defined critical requirements for one or more of the following:

- Observational "monitoring" of key elements of the global and regional/local water cycle,
- Observations required by diagnostic and/or land surface/hydrological prediction models that are used to generate derived products for the end-user communities, and,
- Observational and model-derived variables and parameters required by users of water data/information products as applied to various inter-disciplinary decision support systems and tools".

Table 2. Provisional Essential Water Variables (GEOSS Water Strategy).

Essential Water Variables	Related EVs
Precipitation	ECV
Evaporation and evapotranspiration	
Snow cover	ECV
Soil moisture/temperature	ECV
Groundwater	ECV
Runoff/streamflow/river discharge	
Lakes, reservoir levels and aquifier volumetric change	
Glaciers/ice sheets	ECV
Water quality	
Water use/demand (agriculture, hydrology, energy, urbanization)	
Surface Meteorology	
Surface & Atmospheric Radiation Budget	
Cloud & Aerosols	
Land Cover & Vegetation, Land Use	
Permafrost	
Elevation/Topography and Geological Stratification	

Energy

Renewable Energy is a domain where no major dedicated EO network exists. No formal attempt by international bodies to define EVs has been undertaken. Nevertheless EVs have been established through several international projects involving stakeholders. In the following, we make a review of the renewable energy situation concerning EVs (Table 3).

The first formalized attempt from the Energy Community of Practices (Energy CoP) involved within GEO, to develop a set of area-specific EVs was linked with the GEO Task US-09-01a. This task entitled "Identify Critical Earth Observation Priorities for Societal Benefit Areas", aimed 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.

Table 3. Provisional Renewable Energy Variables.

Essential Renewable Energy Variables	Related EVs
Solar Surface Irradiance and its components (global, direct, diffuse)	ECV
Surface air temperature	ECV
Soil moisture	
Cloud cover	
Precipitation	ECV
Urbanization	
Land use, Land cover	ECV, EBV
Wind speed and direction	ECV
Land surface temperature	ECV
Surface atmospheric pressure	
Elevation	
Wave (height, direction, period)	
Tidal (min, max, sea surface elevation)	
Current (speed, direction)	
Temperature (sea-surface and sub-surface)	ECV
Bathymetry	
Water use demand	
Energy Production Kwh (e.g. bioenergy, hydro)	

Nexus

In the context of the nexus approach, we have consolidated the above three tables into a comparison table to highlight which essential variables are in fact cross-sectoral (Table 4). Furthermore, we indicate which of the EVs are ECVs. Essential nexus variables which span all three nexus variables and exist as ECVs should have the highest priority for application in the nexus approach.

Table 4. Essential nexus variables.

Essential Nexus Variables	Food	Water	Energy	ECV

Crop area	X			
Crop type	X			
Crop condition	X			
Crop phenology	X			
Crop yield (current and forecast)	X			
Crop management (tillage, residue)	X			
Surface air temperature (temperature anomaly)	X	X	X	X
Precipitation	X	X	X	X
Solar surface irradiance (global, direct, diffuse)	X		X	X
Soil moisture	X	X	X	X
Soil organic matter/Soil organic carbon	X			X
Soil mineral composition/grain size	X			
Evaporation and evapotranspiration	X	X		X
Water use demand (irrigation)	X	X	X	X
Groundwater		X		X
Runoff/streamflow/river discharge		X		X
Lakes, reservoir levels and aquifier volumetric change		X		X
Glaciers/ice sheets		X		
Water quality		X		
Surface Meteorology		X		
Surface & Atmospheric Radiation Budget		X		
Cloud & Aerosols		X		
Land Cover & Vegetation, Land Use	X	X	X	X
Permafrost		X		X
Elevation/Topography and Geological Stratification		X	X	
Solar Surface Irradiance and its components (global, direct, diffuse)			X	
Cloud cover			X	
Urbanization			X	
Wind speed and direction			X	
Surface atmospheric pressure			X	
Wave (height, direction, period)			X	
Tidal (min, max, sea surface elevation)			X	
Current (speed, direction)			X	
Temperature (sea-surface and sub-surface)			X	X
Bathymetry			X	
Energy Production Kwh (e.g. bioenergy, hydro)			X	

Data>EVs>Indicators>Policy tables

The EVs described above have been integrated in a broader table that will serve as a basis for linking Data, EVs, Indicators and environmental Policies to start building the GEOEssential knowledge base. This knowledge basis will allow the GEOEssential to browse across these different levels of information, to select adequate datasets, and to produce graphs and maps accordingly. The draft of this GEOEssential reference table is available as a Google Sheet document (see Appendix Table 3), which will be regularly updated.

Summary

This report presents an initial screening of the Food, Water and Energy nexus related essential variables. Wherever possible, care has been taken to identify the most up to date EVs in their respective domains. Three tables are presented which include the EVs identified across the three themes along with their related EVs. Even among just the three FWE themes we see overlaps in the EVs. Furthermore, overlaps exist with the established ECVs and EBVs. Hence it would seem wise to place additional emphasis on these variables which are deemed essential in more than one domain. Finally, some selection of EVs identified here will be used within WP6 based further on the modelling requirements.

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Appendix

Table A1. Examples of candidate EBVs (Pereira et al. 2013).

Examples of candidate Essential Biodiversity Variables					
EBV class	**EBV examples**	**Measurement and scalability**	**Temporal sensitivity**	**Feasibility**	**Relevance for CBD targets and indicators (*1,9*)**
Genetic composition	Allelic diversity	Genotypes of selected species (e.g., endangered, domesticated) at representative locations.	Generation time	Data available for many species and for several locations, but little global systematic sampling.	Targets: 12, 13. Indicators: Trends in genetic diversity of selected species and of domesticated animals and cultivated plants; RLI.
Species populations	Abundances and distributions	Counts or presence surveys for groups of species easy to monitor or important for ES, over an extensive network of sites, complemented with incidental data.	1 to >10 years	Standardized counts under way for some taxa but geographically restricted. Presence data collected for more taxa. Ongoing data integration efforts (Global Biodiversity Information Facility, Map of Life).	Targets: 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15. Indicators: LPI; WBI; RLI; population and extinction risk trends of target species, forest specialists in forests under restoration, and species that provide ES; trends in invasive alien species; trends in climatic impacts on populations.
Species traits	Phenology	Timing of leaf coloration by RS, with in situ validation.	1 year	Several ongoing initiatives (Phenological Eyes Network, PhenoCam, etc.)	Targets: 10, 15. Indicators: Trends in extent and rate of shifts of boundaries of vulnerable ecosystems.
Community composition	Taxonomic diversity	Consistent multitaxa surveys and metagenomics at select locations.	5 to >10 years	Ongoing at intensive monitoring sites (opportunities for expansion). Metagenomics and hyperspectral RS emerging.	Targets: 8, 10, 14. Indicators: Trends in condition and vulnerability of ecosystems; trends in climatic impacts on community composition.
Ecosystem structure	Habitat structure	RS of cover (or biomass) by height (or depth) globally or regionally.	1 to 5 years	Global terrestrial maps available with RS (e.g., Light Detection and Ranging). Marine and freshwater habitats mapped by combining RS and in situ data.	Targets: 5, 11, 14, 15. Indicators: Extent of forest and forest types; mangrove extent; seagrass extent; extent of habitats that provide carbon storage.
Ecosystem function	Nutrient retention	Nutrient output/input ratios measured at select locations. Combine with RS to model regionally.	1 year	Intensive monitoring sites exist for N saturation in acid-deposition areas and P retention in affected rivers.	Targets: 5, 8, 14. Indicators: Trends in delivery of multiple ES; trends in condition and vulnerability of ecosystems.

Table A2. Essential Climate Variables and related products (https://www.ncdc.noaa.gov/gosic/gcos-essential-climate-variable-ecv-data-access-matrix).

Top of Form

The Global Observing System for Climate (GCOS) Essential Climate Variable (ECV) Data Access Matrix provides key dataset links, definitions, associated networks and product requirements information for each of the ECVs.

ATMOSPHERE	OCEAN	LAND
SURFACE	PHYSICS	Above-Ground Biomass
Precipitation	Ocean Surface Heat Flux	Albedo
Pressure	Sea Ice	Anthropogenic Greenhouse Gas Fluxes
Surface Radiation Budget	Sea Level	Anthropogenic Water Use
Surface Wind Speed and Direction	Sea State	Fire
Temperature	Sea Surface Salinity	Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)
Water Vapour	Sea Surface Temperature	Glaciers
UPPER-ATMOSPHERE	Subsurface Currents	Groundwater
Earth Radiation Budget	Subsurface Salinity	Ice Sheets and Ice Shelves
Lightning	Subsurface Temperature	Lakes
Temperature	Surface Currents	Land Cover
Water Vapour	Surface Stress	Land Surface Temperature
Wind Speed and Direction	BIOGEOCHEMISTRY	Latent and Sensible Heat Fluxes
COMPOSITION	Inorganic Carbon	Leaf Area Index (LAI)
Aerosols Properties	Nitrous Oxide	Permafrost
Carbon Dioxide, Methane and other Greenhouse Gases	Nutrients	River Discharge
Cloud Properties	Ocean Colour	Snow
Ozone	Oxygen	Soil Carbon
Precursors (Supporting the Aerosols and Ozone ECVs)	Transient Tracers	Soil Moisture
	BIOLOGY/ECOSYSTEMS	
	Marine Habitat Properties	
	Plankton	

Table A3. Draft of GEOEssential Excel sheets of Data sources, Essential Variables, Indicators and Policies (for project partners only)
Available from owncloud at:
https://owncloud.unepgrid.ch/remote.php/webdav/GEOEssential/GEOEssential%20-%20SHARED/Deliverables/D_6.1/Draft0.1_GEOEssential_Data_EVs_Indicators_Policies.xlsx

EV	TYPE	EV-CODE	Similar EVs	EV-SHORT	CATEGORY	NAME	D
ECV	Climate	C_PRC	O_PRC, E_PRC	PRC	Atmosphere	Precipitation	P
ECV	Climate	C_PAS	O_PAS, E_PAS	PAS	Atmosphere	Pressure (surface)	S
ECV	Climate	C_SRB		SRB	Atmosphere	Surface Radiation Budget	T
ECV	Climate	C_WAS	E_WAS	WAS	Atmosphere	Surface Wind Speed and direction	S
ECV	Climate	C_TAS	E_TAS	TAS	Atmosphere	Temperature (surface)	S
ECV	Climate	C_WVAS		WVAS	Atmosphere	Water Vapour (surface)	T
ECV	Climate	C_ERB		ERB	Upper Atmosphere	Earth Radiation Budget	T
ECV	Climate	C_LIG		LIG	Upper Atmosphere	Lightning	L
ECV	Climate	C_TU		TU	Upper Atmosphere	Temperature (upper-air)	T
ECV	Climate	C_WVU		WVU	Upper Atmosphere	Water Vapour (upper air)	V
ECV	Climate	C_WNU		WNU	Upper Atmosphere	Wind speed and direction (upper-air)	T
ECV	Climate	C_AER		AER	Atmospheric Composition	Aerosols properties	A
ECV	Climate	C_CO2		CO2	Atmospheric Composition	Carbon Dioxide, Methane and other Greenhouse gases	C
ECV	Climate	C_CLD	E_CLD	CLD	Atmospheric Composition	Cloud Properties	T
ECV	Climate	C_O3A		O3A	Atmospheric Composition	Ozone	O
ECV	Climate	C_PRE		PRE	Atmospheric Composition	Precursors (supporting the Aerosol and Ozone ECVs)	P
ECV	Climate	C_AGB		AGB	Land	Above-ground biomass	V
ECV	Climate	C_ALB		ALB	Land	Albedo	T
ECV	Climate	C_GHG		GHG	Land	Anthropogenic Greenhouse Gas Fluxes	A
ECV	Climate	C_WTS	W_WTS	WTS	Land	Anthropogenic Water Use	D
ECV	Climate	C_FIRE		FIRE	Land	Fire	F
ECV	Climate	C_FAPR		FAPR	Land	Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)	S
ECV	Climate	C_GLA	W_GLA	GLA	Land	Glaciers	T
ECV	Climate	C_GWAT	W_GWAT	GWAT	Land	Groundwater	It
ECV	Climate	C_ICE	W_GLA	ICE	Land	Ice Sheets and ice shelves	T
ECV	Climate	C_LAK	W_LAK	LAK	Land	Lakes	Ir
ECV	Climate	C_LCV		LCV	Land	Land cover	L
ECV	Climate	C_LST		LST	Land	Land Surface Temperature	T
ECV	Climate	C_LSH		LSH	Land	Latent and Sensible Heat fluxes	L
ECV	Climate	C_LAI		LAI	Land	Leaf Area Index (LAI)	T
ECV	Climate	C_PFR		PFR	Land	Permafrost	T
ECV	Climate	C_RIV	W_RIV	RIV	Land	River Discharge	R
ECV	Climate	C_SNC	W_SNC	SNC	Land	Snow	S
ECV	Climate	C_SC		SC	Land	Soil Carbon	C
ECV	Climate	C_SM	W_SM	SM	Land	Soil Moisture	S
ECV	Climate	C_OSH		OSH	Ocean-Physical	Ocean Surface Heat Flux	S
ECV	Climate	C_SICE	O_SICE	SICE	Ocean-Physical	Sea Ice	S
ECV	Climate	C_SL	O_SL	SL	Ocean-Physical	Sea Level	T
ECV	Climate	C_SS	O_SS	SS	Ocean-Physical	Sea State	V
ECV	Climate	C_SSS	O_SSS	SSS	Ocean-Physical	Sea Surface Salinity	S
ECV	Climate	C_SST	O_SST	SST	Ocean-Physical	Sea Surface Temperature	T
ECV	Climate	C_SCUR	O_SCUR	SCUR	Ocean-Physical	Subsurface Curents	S
ECV	Climate	C_SALD	O_SALD	SALD	Ocean-Physical	Subsurface Salinity	S
ECV	Climate	C_COP	O_COP	COP	Ocean-Physical	Surface Carbon dioxide partial pressure	
ECV	Climate	C_SCOP	O_SCOP	SCOP	Ocean-Physical	Subsurface Carbon dioxide partial pressure	
ECV	Climate	C_TD	O_TD, E_TD	TD	Ocean-Physical	Subsurface Temperature	S
ECV	Climate	C_CUR	O_CUR, E_CUR	CUR	Ocean-Physical	Surface Currents	S
ECV	Climate	C_STR		STR	Ocean-Physical	Surface Stress	C
ECV	Climate	C_INC		INC	Ocean-Biogeochemical	Inorganic Carbon	T
ECV	Climate	C_NIO		NIO	Ocean-Biogeochemical	Nitrous Oxide	N
ECV	Climate	C_NUTD		NUTD	Ocean-Biogeochemical	Nutrients	N
ECV	Climate	C_COL	O_COL	COL	Ocean-Biogeochemical	Ocean Colour	C
ECV	Climate	C_OOD	O_OOD	OOD	Ocean-Biogeochemical	Oxygen	C
ECV	Climate	C_TRD		TRD	Ocean-Biogeochemical	Transient Tracers	T
ECV	Climate	C_HAB		HAB	Ocean-Biological	Marine Habitat Properties	M
ECV	Climate	C_PLK		PLK	Ocean-Biological	Plankton	P
EBV	Biodiversity	B_GCC		GCC	Genetic composition	Co-ancestry	
EBV	Biodiversity	B_GCA		GCA	Genetic composition	Allelic diversity	
EBV	Biodiversity	B_GCP		GCP	Genetic composition	Population genetic differentiation	
EBV	Biodiversity	B_GCB		GCB	Genetic composition	Breed and variety diversity	
EBV	Biodiversity	B_SPD		SPD	Species populations	Species distribution	
EBV	Biodiversity	B_SPA		SPA	Species populations	Population abundance	
EBV	Biodiversity	B_SPS		SPS	Species populations	Population structure by age/size class	
EBV	Biodiversity	B_STPH		STPH	Species traits	Phenology	
EBV	Biodiversity	B_STB		STB	Species traits	Body mass	
EBV	Biodiversity	B_STN		STN	Species traits	Natal dispersion distance	
EBV	Biodiversity	B_STM		STM	Species traits	Migratory behavior	
EBV	Biodiversity	B_STD		STD	Species traits	Demographic traits	
EBV	Biodiversity	B_STP		STP	Species traits	Physiological traits	
EBV	Biodiversity	B_CCT		CCT	Community composition	Taxonomic diversity	
EBV	Biodiversity	B_CCS		CCS	Community composition	Species interactions	
EBV	Biodiversity	B_EFNP		EFNP	Ecosystem function	Net primary productivity	
EBV	Biodiversity	B_EFSP		EFSP	Ecosystem function	Secondary productivity	
EBV	Biodiversity	B_EFNR		EFNR	Ecosystem function	Nutrient retention	

DATA | EVs | INDICATORS | POLICIES | +