

Deliverable 6.2

Description of nexus workflow and case study

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Table of Contents

| | |
|------------------------------------------------------------------|-----------|
| TABLE OF CONTENTS | 2 |
| INTRODUCTION | 3 |
| MODELS | 4 |
| TERRSYSMP | 4 |
| SWAT | 4 |
| GLOBIOM | 4 |
| WOFOST..... | 5 |
| WORKFLOWS | 6 |
| DROUGHT: AGRICULTURE AND ENERGY | 6 |
| AGRICULTURAL YIELD: PRODUCTIVE AND SUSTAINABLE AGRICULTURE | 7 |
| WATER: FOOD, HYDROPOWER | 8 |
| LAND USE: FOOD PRICE NEXUS | 9 |
| SUMMARY | 10 |
| REFERENCES | 11 |

Introduction

This deliverable aims to establish the Food, Water and Energy (FWE) workflows outlining how the essential variables (EVs) required will be derived via multiple EV services. This deliverable builds upon the report D6.1 a description of food water energy EVs (McCallum et al., 2018a) and the research article addressing the food, water and energy nexus with Earth observation data – a modeling perspective (McCallum et al., 2018b).

In this study we investigate four models which can be used as part of a nexus framework (but which differ in the amount of EO data that they ingest). In particular, we wish to understand to what extent they can incorporate EO data and provide new insight in a nexus approach. They include the Terrestrial System Modeling Platform (TerrSysMP) (Shrestha et al. 2014a; Gasper et al. 2014) the Soil and Water Assessment Tool (SWAT) (Arnold et al. 1998), the Global Biosphere Management Model (GLOBIOM) (Havlik et al. 2014) and the (WOFOST) (Ceglar et al. 2018) model.

In analyzing the above-mentioned model platforms, our aim is to derive a common set of nexus Essential Variables (EVs) which either feed into or are derived from the models, leverage the potential to ingest this data via the above mentioned EO services and the potential for new EO data to be taken up by the models. Furthermore, we aim to describe how this could be achieved via workflows demonstrating operationally the entire process from data acquisition through to SDG indicator provision.

Models

Four nexus capable models are considered for this study: namely TerrSysMP, SWAT, GLOBIOM and WOFOST. Each of these models addresses one or more of the nexus thematic areas. All four models incorporate EO data to varying degrees and are described below in further detail.

TerrSysMP

The Terrestrial Systems Modeling Platform (TerrSysMP), closes the terrestrial water and energy cycles and also biogeochemical cycles from groundwater across the land surface into the atmosphere (Shrestha et al. 2014b). TerrSysMP allows for a physically-based representation of transport processes across scales down to sub-km resolution with explicit feedbacks between the individual compartments. TerrSysMP consists of three component models that are COSMO for the atmosphere (Baldauf et al. 2011; Doms and Schättler 2002), the Community Land Model (CLM) for the land surface (Oleson et al. 2008) and ParFlow for the surface-subsurface (Kollet and Maxwell 2006; Jones and Woodward 2001).

The component models are coupled in a modular fashion using OASIS3-MCT (Valcke 2013), which allows to remove different components in a plug-and-play fashion and perform e.g. offline hydrologic simulations replacing the dynamics of the atmosphere with an atmospheric forcing time series. More information is available at <http://terrsysmp.org/>

SWAT

The Soil and Water Assessment Tool (SWAT) has been applied in studies ranging from catchment to continental scales. The SWAT program is a comprehensive, semi-distributed, continuous-time, process-based model (Arnold, 1998, 2015). The calibrated model and results provide information support to the European Water Framework Directive and lay the basis for further assessment of the impact of climate change on water availability and quality. The approach and methods developed are general and can be applied to any large region around the world. Among other impediments to the SWAT model, a lack of data on soil moisture and/or deep aquifer percolation prevents calibration/validation of these components (Abbaspour et al. 2015). SWAT will be used to demonstrate the workflow towards useful FWE indicators, creating outputs on water quality and quantity, food productivity and hydropower potential using the SWAT model developed for Europe in Abbaspour et al. (2015).

GLOBIOM

The Global Biosphere Management Model (GLOBIOM) is a global, recursively dynamic, and partial equilibrium model. It integrates the agricultural, bioenergy, and forestry sectors and draws on comprehensive socioeconomic and geospatial data. It accounts for the 18 most globally important crops, a range of livestock production activities, forestry commodities, first- and second-generation bioenergy, and water. Production is spatially explicit and takes into account land, management, and weather characteristics (Havlik et al. 2014). More information is available at <http://globiom.org/>.

WOFOST

WOFOST (World FOod STudies) is a simulation model for the quantitative analysis of the growth and production of annual field crops. It is a mechanistic and dynamic model that explains crop growth on the basis of the underlying processes, such as photosynthesis, respiration and how these processes are influenced by environmental conditions (Ceglar et al. 2018). With WOFOST, you can calculate attainable crop production, biomass, water use, etc. for a location given knowledge about soil type, crop type, weather data and crop management factors (e.g. sowing date). More information available at <https://www.wur.nl/en/Expertise-Services/Research-Institutes/Environmental-Research/Facilities-Products/Software-and-models/WOFOST.htm>.

Workflows

In order to address some of the indicators required for the FWE SDG nexus, the following workflows have been designed. As there is a lack of integrated nexus models and coupling of sector-specific models is extremely difficult, the aim here is to propose nexus workflows which ultimately generate SDG related nexus indicators which can then be used for integrated analysis.

- Drought: agriculture and energy
- Agricultural yield: productive and sustainable agriculture
- Water: food, hydropower
- Land use: food price nexus

Drought: agriculture and energy

Addressing **Indicator 15.3.1**: Proportion of land that is degraded over total land area and **Indicator 2.4.1**: Proportion of agricultural area under productive and sustainable agriculture. Here we focus on temporal degradation due to water-related drought and sustainable agriculture in terms of sustainable water use.

Crop yield as well as energy production is severely affected during drought conditions. Crops in an early stage of drought stress may show reduced yield, in a later stage they may change over to early senescence. The cooling of coal and atomic power plants is typically performed by river water, where the discharge may be limited during droughts. Both phenomena are linked by the terrestrial water cycle, where water fluxes from one component to another via natural processes are altered by human activities.

Groundwater abstraction and river basin management are strategies to mitigate crop and energy production constraints, but the issue of sustainability is largely not considered. EO can observe important compartments of the water cycle, e.g. groundwater storage change by the Gravity Recovery and Climate Experiment (GRACE), (Rodell et al. 2007), soil moisture estimation by the Soil Moisture Ocean Salinity (SMOS) mission (Kerr et al. 2010), river discharge by the TOPEX/Poseidon mission (Zakharova et al. 2006), and crop yield by JECAM (Kussul et al. 2015). However, each observation and retrieval method has its own limitations leading to uncertainties in the final product. Especially the relationships between the observables are often biased, so that nexus studies may lead to biased SDG evaluations. Here model frameworks representing the full system such as TerrSysMP can help to set the observables back into their proper relationship. Two main approaches are available to perform the adaptation: (i) individual correction of the observables, e.g. by cumulative distribution function (CDF) matching, and (ii) by multi-source data assimilation of the observables into the model framework, e.g. by the Kalman filter (Montzka et al. 2012). The latter approach is especially innovative in the context of groundwater-to-atmosphere simulations utilizing TerrSysMP, because compartmental feedbacks provide additional strong physical constraints in the assimilation process.

The output of the workflow is a number representing the change in drought extent as compared to a reference period. Moreover, another output is a number representing the

change in area fraction of sustainable water use in agriculture. With full implementation of the FWE also energy targets can be addressed, e.g. **Target 7.1:** By 2030, ensure universal access to affordable, reliable and modern energy services. However, the respective indicators are mainly of a socio-economic nature with a focus on energy access and efficiency. Indicators are missing which adequately address energy production sustainability aside from the main energy source (renewable, coal, etc.), such as cooling water or air pollution.

Agricultural yield: productive and sustainable agriculture

Addressing **Indicator 2.4.1:** Proportion of agricultural area under productive and sustainable agriculture. Two methods for indicator 2.4.1 calculation for the territory of Ukraine were developed. The first method is close to the classical approach to land productivity estimation based on the NDVI index trend change as a proxy of land productivity. Using the classification map, we estimate the total area of agricultural land (namely cropland mask) and the trend of the NDVI index change over cropland. We define productive and sustainable land as the cropland that has a non-negative trend of NDVI index change. The final output of this method is a proportion of the cropland area with a non-negative NDVI trend compared to all area of agricultural land in percentage [0-100]. The second method is based on the essential variables derived from land cover and land use classification maps (LULC) as well as outputs from the biophysical model WOFOST.

For each point over the regular grid, that covers the territory of interest, the WOFOST model is used for crop state simulation, taking into account type of crop. Using outputs from the model (namely LAI, total biomass and integral characteristics of these parameters) clusters of points with the biggest mean value of all the criteria for each crop type are identified, then the centroid of this productivity cluster is indexed with this value. After that, the productivity index for other points is estimated through calculation of the difference between the value of each point. Using the crop classification map, it's possible to calculate a productivity index for every agricultural field and produce a whole productivity map. Analyzing such maps for FWE years, it's feasible to estimate the productivity trend for each point. Thus, productive and sustainable agriculture areas could be considered as areas with a positive productivity trend.

Furthermore, the workflow will focus on the temporal dynamics of soil surface organic matter (OM) content as a crucial soil property for soil fertility and productivity. Currently this parameter is not directly listed as an SDG indicator, but it has a strong regulating and stabilizing influence on the quality of many soil functions such as storage and buffering of water, nutrients, and pollutants (Balduck, 2012; Bot and Bernites, 2005). OM is affecting the 2.4.1 Proportion of agricultural area under productive and sustainable agriculture and loss of OM leads to degradation (link to indicator 15.3.1). The workflow outlines a method that is based on multitemporal soil pattern analysis (MSPA) (Blasch et al. 2015) originally developed for RapidEye data and easily extendable to Copernicus data. The method uses multitemporal optical remote sensing data sets for the creation of a synthetic bare soil composite of the agricultural fields. Through combination of the multitemporal bare soil spectral information and in combination with laboratory analysis that are based on field sampling, the estimation of the surface organic matter content at regional scale will be possible. The workflow will be validated for the usability of Sentinel-2 data at the German JECAM site DEMMIN and optionally at other regions where validation data for surface OM

content are available. Comparing different acquisition periods enables us to calculate change rates of top soil organic matter content.

The output of the workflow is the proportion of agricultural area under productive and sustainable agriculture as a percentage and a number representing the change rates of soil surface organic matter content for specific areas in percentage. It represents the degradation development of organic rich top soil and the proportion of agricultural area under production.

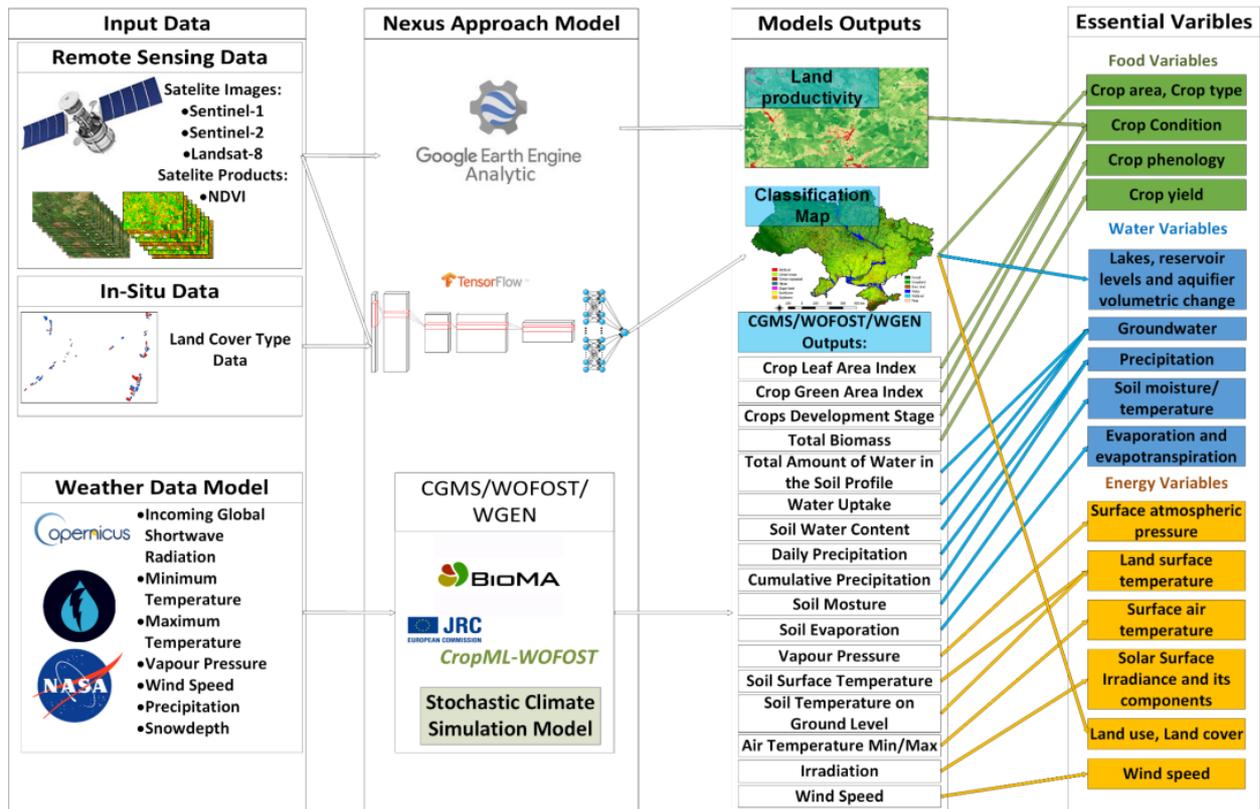


Fig. 1. Schematic diagram of the agricultural yield workflow.

Water: food, hydropower

Addressing **Indicator 6.6.1**: Change in the extent of water-related ecosystems over time. Each of the sub-indicators in this 6.6.1 Indicator sets out to determine the percentage of change in a water-related ecosystem. This can only be done if there is some point of reference. The ideal situation is that reporting is done using the “natural” situation as the reference, however this “natural” situation is sometimes difficult to determine and instead an alternative “reference” condition can be used. Measurement of spatial extent is important as this provides an indication of the availability of these ecosystems and the potential they have to provide ecosystem services. Both Earth Observation (EO), ground-based surveys and models provide data that are used to determine the change in the spatial extent of water-related ecosystems over time.

The SWAT model will be used to demonstrate the workflow towards useful FWE indicators, creating outputs on water quality and quantity, food productivity and hydropower potential at the scale of Europe. Many of the difficulties and limitations with continental modeling using SWAT arose from data related issues and included among others a lack of data on soil moisture making cal/val of these components impossible. EO meanwhile provides globally

consistent soil moisture datasets over a long time-series which could be used in SWAT. This workflow will test the inclusion of additional EO datasets (e.g. soil moisture) derived from EO in SWAT.

Output: a number representing the total area in km² of water extent lost, gained and unchanged between the years 1984 and 2015. This workflow is already described on <https://github.com/irmccallum/GeoEssential>.

Land use: Food price nexus

Addressing Target 12.2: Achieving sustainable management and efficient use of natural resources.

This workflow examines the pressure that conservation policies can place on agricultural systems and, by extension, food security e.g., land-use change restrictions in support of biodiversity and emissions mitigation can increase pressure on food production systems by limiting their capacity to expand in response to market shifts, climate change, or soil degradation (Obersteiner et al. 2016).

This workflow will take advantage of the GLOBIOM model. From the initial conditions, the model calculates demand for commodities within each region and bilateral trade flows among them endogenously on the basis of population, per capita income, production costs, and equilibrium prices (including tariffs and transportation costs and capacity constraints) (Obersteiner et al. 2016). Finally we examine the GLOBIOM scenario results for a relationship between global food prices and five planetary boundaries, which collectively serve as dynamic indicators of trade-offs between global agricultural and environmental systems (Obersteiner et al. 2016).

Output: quantities and locations of land available for biodiversity, food production and energy production under various scenarios.

Summary

This study lays out the framework for an earth observation model driven approach to the FWE nexus. We have reviewed a suite of four models (GLOBIOM, SWAT, TerrSysMP and WOFOST) performing an appraisal in terms of their applicability to the FWE nexus. No single model or approach can completely address all aspects of the FWE nexus. Hence the optimal solution is to capitalize on the strengths of each of the different approaches producing essential nexus variables. We have designed a suite of workflows which when applied could act as a roadmap to reach nexus informed decisions. Going forward, the aim will be to determine the required EVs which can be combined in a new FWE nexus to address the relevant SDGs.

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