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WATER-ECOSYSTEM-FOOD

ASSESSMENT OF ECOSYSTEM SERVICES

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List of Acronyms

Abbreviations

BEA	Bilateral Environmental Agreement
CICES	Common International Classification of Ecosystem Services
EEA	European Environment Agency
ES	Ecosystem Services
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
IEA	International Environmental Agreement
MAWG	Multi-Actor Working Group
MEA	Multilateral Environmental Agreement
MPV	Market Price Valuation
NRB	Nile River Basin
OECD	Organisation for Economic Co-operation and Development
PPP	Power Purchasing Parity
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goals
SSP	Shared Socioeconomic Pathway
TEV	Total Economic Value
UN	United Nations
USD	United States Dollar
VT	Value Transfer
WB	World Bank
WEFE	Water, Energy, Food and Ecosystems
WP	Work Package

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EXECUTIVE SUMMARY

In this report relevant Ecosystem Services (ES) at the meso scale level for the main basin of river Nile (including Egypt, Ethiopia and Sudan) are identified and prioritized in cross-reference with the results provided by WP6 (Deliverable 6.1 [3]) where ES were identified at case study level. Then, for the key ES of the list, economic valuation methods are applied to quantify their Total Economic Value (TEV) for the region of interest. The relevant analysis relies mainly on a mixed methodology combining the Market Price valuation approach and the Value Transfer method depending on the type of the ES and data availability. In addition, in collaboration with WP7, an updated list of applicable international policies related to environmental protection is compiled (e.g. Mediterranean Action Plan, European Neighbourhood Policy, Barcelona Convention) and discussed within the context of the AWESOME's meso-scale model.

1 INTRODUCTION

The aim of this report is to provide economic valuation for Ecosystem Services (ES) in the AWESOME case study, which covers the main countries of the Nile River Basin (NRB), i.e., Egypt, Ethiopia and Sudan. Employing the results provided by WP6 (Task 6.1), a list of key ES have been identified after a prioritization process/method performed during the sessions that took place within the project's Multi-Actor Working Groups (MAWGs) constituted by selected regional stakeholders. The final list with the key ES is constituted by services that are considered crucial for the region under study, and their economic evaluation is performed with the aim of representing the level of impact of various ES related to the river Nile to the economy of the region under study.

This report is structured as follows. In Section 2, the methodologies adopted for the ES valuation tasks are presented and several issues related to data management and availability as well as implementation are discussed. Depending on the type of the ES studied and the availability of accessible and reliable data, two main valuation strategies are adopted. For the case of ES that official market data are regularly recording (primarily provisioning services), the Market Price valuation approach is adopted, using as an intermediate step the estimation of production functions, as well as statistical modeling of the relevant ES in the GDP of the region, subject to the available historic data (see Section 2.2.1). For such services we also provide probabilistic projections for their economic values under the combined framework of socio-economic and climate scenarios (SSPs and RCPs framework, see Section 2.2.3) for the period 2019-2050. This provides a more clear picture of the value of the services and their dependence on the evolution of key drivers for these economies such as population, labour, income and of course key drivers for the environment, like temperature and precipitation. The scenario generation approach for these ES builds on the relevant socio-economic scenarios that were developed in D2.1 [2] of the project, as well as, yearly aggregate climate scenarios in country scale available from WB climate database [1]. For the remaining services, the Transfer Value method is implemented employing the results of primary research studies in African areas with similar characteristics of the AWESOME case study accompanied by an appropriate weighting scheme (see Section 2.2.2) to better aggregate the available information by taking into account the study sites that concern areas which are as close as possible in characteristics with the policy site. This hybrid approach combining regularly recorded market data and VT methods variations, was the best approach given the inability to conduct primary research in the area due to the COVID-19 pandemics-related travelling restrictions. For these specific services, we avoided the scenarios analysis not to incur into results' inconsistencies.

Section 3 is dedicated to the presentation and illustration of the economic valuation results for the areas under study, both at a regional level and in total. In particular, the estimated economic values of the ES considered are aggregated (a) at a regional level, providing the Total Economic Value (TEV) of each type of ES and for all ES in total related to the NRB, and (b) at the river Nile basin level, providing the respective TEV per ES category and in total for this major part of the basin.

In Section 4, relevant international environmental policies are analysed or considerations are provided. In particular, international environmental policies and past or existing environmental multilateral agreements are listed and discussed under the light of the economic impact of the key ES on the socio-economic environment adjacent of the NRB and beyond.

[1]https://climateknowledgeportal.worldbank.org/download-data

2 ECOSYSTEM SERVICES PRIORITIZATION AND ASSESSMENT APPROACHES

2.1 IDENTIFICATION OF ECOSYSTEM SERVICES FOR THE AWESOME CASE STUDY

This part of the report is based on an initial literature review of the Ecosystem Services (ES) at the meso level conducted in the first half of 2021 for the preparation of the D6.1 [3] (specifically, Section 3.5) as well as the two first workshops (MAWGs) conducted in summer 2021 covering the micro and meso level (D6.2 [4], Section 2.3). The commonly accepted framework of the Common International Classification of Ecosystem Services (CICES) [14] developed by the European Environment Agency (EEA)[2] was used as a guidance for the classification and definition of the ES by AUEB team during this work in order to ensure that the resulting evaluated ES would be operational in the framework of AWESOME project. The multiplicity of benefits at the meso level, obtained from the rivers basin ecosystems, as well as the lost or gained ES, is an indicator of the ecosystems vulnerability for AWESOME. The resulting list of ES from the literature review are presented in Table 1.

Table 1 – List of Ecosystem Services based on literature review

Categories	Services Headline	Details
Provisioning	Crop production from irrigated agriculture	*Particularly cereals, crops, sugar and molasses (that have the highest production)*
	Livestock maintenance	*Essential for pastoralists and farming families using wetlands as watering point and pasture. It depends on the variability of livestock meat and milk as well as feed water productivity*
	Fish stock	*It depends on the proximity to fish production centres (inland production represented the 70% - 100% of total fisheries production in the basin)*
	Wild food	*(a) Fruits and vegetables: Balanities aegyptica (Lalop), Tamarindus indica fruits (Koat) and wild vegetables, (b) Hunting around wetlands*
	Fuelwood	*It exports out of Nile basin. Sudan's production is 88% sustainable*
Regulating	Water flow	*Important for hydropower generation and storing surplus water for use in arid periods*
	Flood control	*In high variability people are displaced, in low the rainfed agriculture is impacted*
	Carbon sequestration	*Terrestrial stock of carbon (C) and the organic carbon comprises the main pool of terrestrial C. Incomplete understanding of the long-term impacts of land use and management on soil in the Nile basin. Carbon sequestration from water stock.*
	Goods transportation	Carrier services (p.10 [14] (esp. in Lake Tana)
	Spiritual and religious services	Herbal medicines obtained from Nile's wetlands and high visitation of traditional healers. Still lack of official data
	Sediment retention	*Highly impacted in the Eastern Nile and in Ethiopia, Sudan and Egypt the water resources development is threatened by soil erosion and sedimentation*
	Water purification	*Especially wetlands regulate the quality and quantity of water coming from uplands and function as buffers against flooding as well as excess sediment loads related to runoff*
	Microclimate regulation	*As benefits from ecosystems*
Supporting	Habitats	*Gallery forests, herbaceous littoral vegetation, important species of vertebrates (Nile crocodile, hippopotamus etc), critical for migratory birds, amphibians and fish. Hosts of biodiversity (esp. food and fish). Among the 15 national parks of the basin Dinder Park, biosphere reserve, Omo National Park, Gabal Elba Part lay in the study area*
Cultural	Touring services	*In-situ* and *direct interaction* with the ecosystem (p.18-19 [14]) (esp. in Lake Tana and Luxor surroundings in river Nile in Egypt)

It should be observed that, that although studies on ES exist for the area, especially on the country level, very few exist for Sudan. The presented initial list was used as a basis for the parts of the MAWGs' discussions that were focused on ES and were further validated by the stakeholders, enriched with local specific information and prioritized according their perceptions. Results of that work is reported in D6.2 [4] (Section 4). The

[2] https://www.eea.europa.eu/

micro and meso level MAWGs bring together a number of domain experts, rural and river basin stakeholders (the meso level MAWGs) and a number of local actors and agri-business representatives. The list of ES were among the key outputs from the face-to-face MAWGs workshops that took place on the micro level on 5th July 2021 and the accompanying semi-structured interviews as well as the online MAWG that took place on the meso level on 22nd September 2021. That prioritization list of ES resulted both from direct question to the stakeholders on their perceptions and from the WEFE mental model that was produced by WP6 AUEB team (D6.2 [4], Section 4.4, page 48) including 130 parameters visualizing stakeholders' opinions, key words, opportunities, statistics or numbers as well as non-descriptive narratives.

Table 2 – List of prioritized Ecosystem Services based on AWESOME's stakeholders views

Categories	Services Headline	Details
Provisioning	Crop production from irrigated agriculture	*Examine it in relationship with a) rainfall variability, seasonality & b) climate change impacts*
	Livestock production	*Water needs are not met in Sudan, S.Sudan, and low land areas of Egypt.*
	Fish stock	*Especially from inland waters; Highly impacted in areas such as Delta Nile (70% reductions).*
	Fruits and vegetables	*The industry exports a lot across Nile, fruits and vegetables are high value commodities.*
	Fuelwood	*Exports out of Nile basin. Sudan's production is 88% sustainable*
Regulating	Water flow	*Wetlands are drying up*
	Flood control	*In high variability people are displaced, in low the rainfed agriculture is impacted*
	Carbon sequestration	*Especially from peatlands.*
	Goods transportation	Carrier services (p.10 [14] (esp. in Lake Tana)
	Microclimate regulation	*As benefits from ecosystems*
Supporting	Habitats	*Hosts of biodiversity (esp. food and fish).*
Cultural	Touring services	*In-situ* and *direct interaction* with the ecosystem (p.18-19 [14]) (esp. in Lake Tana and Luxor surroundings in river Nile in Egypt)

Due to COVID-pandemics related travelling restrictions, it was not possible to adopt on-site approached, but to analyse state-of-the-art methodologies in order to avalate the ES list shown in Table (2).

2.2 VALUATION METHODOLOGIES

In this section the methods and approaches that adopted for evaluating the ES illustrated in Table 2 are presented. The research group employed evaluation techniques that could combine available datasets in the web and previous studies results in areas of similar type. The assessment techniques employed for this task are (a) the Market Price Valuation approach (MPV), and (b) a hybrid version of the Value Transfer approach (VT) employing an appropriate weighting scheme. Both approaches are presented in the following subsections.

2.2.1 Market Price Valuation

The valuation of provisional services will be mainly performed using a market pricing approach. In particular, we will construct and estimate production functions for the sectors of the economy corresponding to the provisional services (see e.g. [25] for a detailed presentation of the modelling approaches) and then value them in terms of their contribution to the total Gross Domestic Product (GDP) of the country. This valuation will be based on reliable data provided by international organizations and is subject to rigorous statistical methodology. Moreover, the economic value will be based on explanatory variables for which scenarios for their future evolution is available (such as for example socio-economic or natural resources related variables) hence making it possible for providing future scenarios concerning the economic value of these provisional services; a task which may be quite useful for policy making considerations.

The economic valuation of the provisional services we focus on, requires an efficient modelling of the domestic production, Y_i, in the relevant sector of the economy i, along with an efficient modelling of the contribution of this sector to the total GDP, I, of the country. Socio-economic conditions, natural resources and environmental factors are expected to play a crucial role in production modelling. To better incorporate these features in our model, and based on relevant research findings we introduce as important environmental and natural resource factors in the production of the relevant sector the water stress , W, (which is defined as the freshwater withdrawal as a proportion of available freshwater resources according to SDG Indicator 6.4.2[3]), average temperature, T, average precipitation, Pr, and land area occupied for this particular task, A. The socio-economic factors, which affect the production of the relevant sector, are labor, L, (that depends on population). Finally, the contribution of the relevant sector in the GDP, from here onwards referred to as the gross product value of the country and denoted by V^i, is assumed to depend on two major factors: the production in the sector, Y^i, and the total GDP, I.

We decided not to include more variables for domestic production in the modelling framework as they are not always available for all countries of interest, and particularly for those in the developing world (non-OECD countries). It should be also mentioned that predicting future values of these data in various scenarios and in a form compatible with the probabilistic population projections, may be quite challenging or computationally intractable at least with the current state of the art of economic modelling and computational resources respectively. Hence, one of the main reasons for choosing the quantities mentioned above as explanatory variables, among other possibly relevant quantities, is that reliable historical data for them can be found in FAOSTAT database[4], in AQUASTAT[5] database, in World Bank database[6] and other public available data providers, over a reasonable time span, hence facilitating the statistical estimation of the proposed model. Moreover, for each of the explanatory variables that are used, there are scenarios concerning their future evolution, which can be used for producing scenarios for the valuation of the services. Finally, the statistical significance of the ex-

[3] https://www.sdg6monitoring.org/indicator-642/
[4] http://www.fao.org/
[5] https://www.fao.org/aquastat/en/
[6] https://data.worldbank.org/indicator

planatory variables will be assessed using the relevant historical data, in order to check whether our modelling intuition turns out to be correct.

To summarize, for each country c, we opt for a simple (minimal) model, in the form of a hierarchical three level model, which connects the quantity of interest, which is V_i, to the explanatory variables, in terms of the two intermediate quantities Y_i and W. The hierarchy starts by modelling W, then moving one level up to modelling Y_i and then reaching the top level which is the modelling of V_i. Our model, starting from bottom up, reads

$$
\begin{aligned}
&(1a)\ \ W_c(t) = \alpha_0 e^{\alpha_1 t} A_c^{\alpha_2}(t) Pr_c^{\alpha_3}(t) T^{\alpha_4}(t), \ \ \text{(water stress)},\\
&(1b)\ \ Y_{i,c}(t) = \beta_0\, e^{\beta_1 t} A_c^{\beta_2}(t) L_c^{\beta_3}(t) W_c^{\beta_4}(t) T_c^{\beta_5}(t), \ \ \text{(production in sector i)}\\
&(1c)\ \ V_{i,c}(t) = \gamma_0 Y_{i,c}^{\gamma_1}(t) I_c^{\gamma_2}(t), \ \ \text{(value of sector i)}
\end{aligned}
\tag{1}
$$

where (now starting from the bottom down)

- $V_{i,c}(t)$ is the gross product value of sector i, for country c and time t,
- $Y_{i,c}(t)$ is the production of sector i, for country c and time t (in tonnes),
- $W_c(t)$ is the water stress of country c and time t,
  - $I_c(t)$ is the GDP of country c at time t defined as $I =$ GDP per capita $\times$ Population),
  - A_c is the area of cropland of country c at time t,
  - $L_c(t)$ is the labour force of country c at time t,
  - $T_c(t)$ is the (average) temperature in country c at time t,
  - $Pr_c(t)$ is the (average) precipitation in country c at time t,

and α_i, β_i and γ_i are constants to be determined from past data. We emphasize that these parameters are country-dependent but we omit the subscript c, so as not to clutter the notation. These unknown parameters were estimated using typical least squares estimation procedures, upon taking logarithms for the model (1). If needed, i.e. in cases of multicollinearity, regularization techniques such as ridge regression were used. The statistical significance of the explanatory variables included in the model, has been checked using standard statistical tests.

Concerning model (1), it is a three stage model, which models gross product value of each sector in terms of socio-economic quantities (e.g. income, labour etc), natural resources (e.g. water stress, cropland etc) and environmental variables (e.g. temperature, precipitation). Population enters model (1) through various routes; it clearly affects the labour force as well as the income. Natural resources as well as environmental resources affect the domestic food production given by model (1b). As already mentioned, the nature of the data available requires a minimal aggregate model, containing explanatory variables which include socio-economic, natural resources and environmental variables, and the proposed model seems to be well suited in this respect - as it will soon be verified in the next section. Moreover, it contains scenario-dependent quantities; hence, it will allow us to assess the effect of various scenarios on the quantities of interest which are related to food security. Finally, the estimation of the model will be done in 3 stages, we will begin with the estimation of water stress using (1a), then we proceed to the estimation of domestic production using (1b), and finally proceed to the estimation of gross product value of the sector using (1c).

2.2.2 Value Transfer Approaches

The valuation of the non-provisional ecosystem services will be performed by Value Transfer (VT) approaches. This will consist of a meta-analysis based on unit values from relevant services and sites were primary research was conducted, appropriately transfered to the site of interest by a weighting scheme relying on geographical and socio-economic feature dissimilarities [16].

Contrary to the provisional services where market prices and values are available through various sources and data providers, this is not the case for the non provisional services, hence, in this case values must be extracted by different type of approaches, e.g. primary research in the area of interest by collecting questionnaires, revealed preferences approaches, etc. This is required since these types of services values are not quantified directly in the market or there exist no sufficient data to perform market valuation.

The Value Transfer method offers a convenient way out when there is not the capability (e.g. low budget or impossibility to go on the field) to conduct primary research in the area under study. Therefore, we use primary research results for the ecosystem services of interest in areas of similar stature, i.e. similar socio-economic conditions, climate, terrain morphology, demography etc., and to properly combine them in order to estimate the service's values. In particular the evaluation guidelines described in [7] are followed where the locations of the available studies are referred to as the study sites and the site for which the ecosystem services needs to be assessed is referred to as the policy site. The typical approach when the available studies evaluations have been performed through functions that cannot be applied to the policy site, is to convert the derived value to a *unit value*, e.g. if the economic value of a certain service for of a wetland has been derived, to convert it to an economic value per land unit or per household, and then use these values to estimate the economic value in the policy site. In this study, we work with the induced services unit values, not in the spirit of the unit value in the globe (see e.g. [8, 9]), but in a more localized sense by selecting carefully the study sites that participate in the unit values estimations, taking into account areas with conditions very close to the policy sites. A devoted study to African wetlands had been conducted in [24] where four different wetlands are taken into account to assess the related ecosystem services. In this perspective, an extensive literature research was conducted by our team to collect the most relevant studies in the African region, constructing an appropriate database of studies that will lead to as precise as possible estimates of the identified services unit values.

Clearly, when transferring the value from the study site to the policy site, especially when this task concerns different countries and different years, one needs to adjust the values accordingly. Assume that u_t^s denotes the unit value derived from the study site s for a certain ecosystem service at the year t and u_τ^p denotes the unit value of the same service at the policy site p for a possibly different year τ. The critical issues that needs to be addressed when calculating the unit value u_τ^p are: (a) the nominal difference between the income per capita in case that the country of the policy and the study site is different, (b) the difference in purchasing power of the individuals across the different countries and (c) the year that the valuation has been conducted on the study site and (d) the difference in currency. In this perspective, the employed unit value convertion formula is

$$u_t^s = u_\tau^p \; R_{t\to\tau}^s \; R_{s\to p}^\tau \; C_{t\to\tau} \tag{2}$$

where

- $R_{t\to\tau}^s = Y_\tau^s / Y_t^s$ denotes the convertion ratio for the unit value at study site at year t to the unit value at the same site at year τ taking into account the difference in year prices and the changes in the individual's purchasing power using as Y_j^s for $j = t, \tau$ the GDP per capita corrected to Power Purchasing Parity (PPP) and expressed to some constant currency value (e.g. 2017 USD[7])

[7] https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD

- $R^{\tau}_{s\to p} = Y^p_\tau / Y^s_\tau$ denotes the convertion ratio for the unit value at study site at year τ to the unit value at the policy site at the same year taking into account the differences between the two countries GDP per capita using as Y^j_τ for $j = s, p$ the GDP per capita corrected to Power Purchasing Parity (PPP) of both countries at the year τ (this ratio is equal to 1 if the country in study site and policy site is the same)

- $C_{t\to\tau}$ denotes the currency convertion factor of the currency used at time t to the same currency at time τ.

A second issue that has to be resolved is when multiple study sites for the same service are available with different unit values, let us say $(u^{s_1}_\tau, u^{s_2}_\tau, ..., u^{s_N}_\tau)$ if N study sites are available . In this case, the approach in (2) is first applied to convert all available unit values to an appropriate scale resulting to the converted unit values vector $(u^p_{1,\tau}, u^p_{2,\tau}, ..., u^p_{N,\tau})$, and the aggregate scheme

$$u^p_\tau = \sum_{j=1}^{N} w_j u^p_{j,\tau}, \quad w_j \geq 0, \quad \sum_{j=1}^{N} w_j = 1 \tag{3}$$

is employed to combine the information by the N different sites. Note once again that the studies used in this report for the evaluation task concern only countries of the African region to avoid possible inconsistencies in socio-economic situation, habits, economy statures, etc. A significant role in the aggregate scheme described in (2) is played by the weights w. A naive rule to allocate weights among the studies is to take into account equally all of them, i.e. assigning the weights $w_j = 1/N$ for $j = 1, 2, ..., N$. However, attempting to provide as accurate as possible estimates for the unit values on the policy sites, we adopt the following rule for weights determination. First, Land Use, Land Cover and population data for the policy and study sites are collected from available web databases (e.g. FAO) and then are used to derive a geomorphological profile for all sites. In particular, the characteristics that are used are the proportions for cropland, forests, meadows, inland waters, grassland, herbaceous crops, tree covered areas, woody crops and rural population. Let us denote by x^p_τ, $x^{s_j}_{t_j}$ for $j = 1, 2, ..., N$ the vectors containing these measurements for the policy site and the N study sites at year τ and the years $t_1, t_2, ..., t_N$ concerning the years where the studies have been conducted. Then, the weight that the j-th site will affect the evaluation is determined through the rule

$$w_j := \frac{d(x^p_\tau, x^{s_j}_{t_j})^{-1}}{\sum_{k=1}^{N} \left(d(x^p_\tau, x^{s_k}_{t_k})\right)^{-1}} \tag{4}$$

where $d(\cdot,\cdot)$ denotes the distance sense that is used, e.g. $d(x, y) = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2}$. This rule will allocate greater weights to the study sites that have closer terrain conditions and closer population distribution to rural areas comparing to the policy site of interest.

2.2.3 Valuation Approaches for the Selected Ecosystem Services

In Sections 2.2.1 and 2.2.2, both valuation strategies that are followed are described. Mainly, the provisional ecosystem services are treated with the Market Price valuation approach since there are available records for the fitting and determination of the related production functions. This fact, leads to a modelling of the service values depending on population, economic drivers and climate conditions allowing to provide valuations for future times under scenarios related to the aforementioned quantities. In particular, future scenarios combining (a) demographic and socio-economic scenarios developed in a probabilistic framework in D2.1 [2] according to the lines of the Shared Socio-economic Pathways (SSPs) framework [22], and (b) aggregate climate scenarios at a country level (e.g. average temperature and precipitation per year), as obtained from WB climate database, following the Representative Concentration Pathways (RCPs) [19] are considered to provide an assessment of the related services in the period 2019-2050 under different conditions. The list with the scenarios considered and their description are illustrated in Table 3.

Table 3 – The list of the SSP-RCP scenarios considered in this work

Scenario Name	SSP scenario	RCP scenario	Scenarios Description
SSP1-1.9	SSP1	RCP 1.9	*Most optimistic scenario.* Societies switch to more sustainable practices. Extreme weather is more common.
SSP1-2.6	SSP1	RCP 2.6	*Next-best scenario.* Same socioeconomic shifts towards sustainability as SSP1-1.9. Temperatures stabilize around 1.8C higher by the end of the century.
SSP2-4.5	SSP2	RCP 4.5	*Middle of the road scenario.* CO2 emissions hover around current levels before starting to fall mid-century, but do not reach net-zero by 2100. Socioeconomic factors follow their historic trends, with no notable shifts. Progress toward sustainability is slow, with development and income growing unevenly. In this scenario, temperatures rise 2.7C by the end of the century.
SSP3-7.0	SSP3	RCP 7.0	*Baseline of worst-case scenarios.* Emissions and temperatures rise steadily and CO2 emissions roughly double from current levels by 2100. Countries become more competitive with one another, shifting toward national security and ensuring their own food supplies. By the end of the century, average temperatures have risen by 3.6C.
SSP4-6.0	SSP4	RCP 6.0	*Best-case of the worst-case scenarios.* More optimistic outcomes of global warming in a world that fails to enact any climate policies.
SSP5-8.5	SSP5	RCP 8.5	*Worst-case scenario.* CO2 emissions levels roughly double by 2050. The global economy grows quickly, but this growth is fueled by exploiting fossil fuels and energy-intensive lifestyles. By 2100, the average global temperature grows 4.4C.

Ecosystem services for which systematic prices records are not available or refer to indirect values are evaluated by the Value Transfer approach. This covers some provisioning services like fish production and fuelwood production and all other categories considered here. For Sudan, there are not available records for all data required to perform a Market Price valuation for its provisioning services. Therefore, the Value Transfer method is applied using as study sites the valuations provided for Egypt and Ethiopia accordinig to the guidelines described in Section 2.2.2. For all services in which production functions are not estimated, the valuation is not conducted on the future scenarios framework to avoid major inconsistencies. A summary of the ecosystem services that are evaluated and the methodology followed is illustrated in Table 4.

Table 4 – List of Ecosystem Services to be evaluated

Category	Service headline	Valuation Method	Future Scenarios
Provisioning	Crop production	Market Price	SSPs-RCPs
	Fruits and vegetables production	Market Price	SSPs-RCPs
	Fish stock	Value Transfer	-
	Fuelwood	Value Transfer	-
	Livestock production	Market Price	SSPs-RCPs
Regulating	Carbon sequestration	Value Transfer	-
	Flood control	Value Transfer	-
	Microclimate regulation	Value Transfer	-
	Water regulation	Value Transfer	-
Supporting	Biodiversity on the wetlands	Value Transfer	-
Cultural	Touring services & open water transportation	Value Transfer	-

3 ECOSYSTEM SERVICES ASSESSMENT

3.1 DATA COLLECTION

Provisioning services for the main river Nile basin, and in particular for Egypt and Ethiopia, related to crop production, fruits and vegetables production and livestock products are evaluated under the Market Price approach, since exact and detailed data concerning these services are officially recorded and are available through the FAO database. Therefore, employing the modeling approach presented in Section 2.2.1, the relevant Cobb-Douglas type production functions are estimated using past data and then using the available projections for population, economic drivers and climate conditions under the SSP-RCP framework are performed evaluations for these grouped provisioning services on the time interval 2019-2050. Unfortunately, for the case of Sudan (which is considered as one region including Sudan and South Sudan) there are not consinstently recorded data to perform this approach. However, since estimations for Egypt and Ethiopia are possible, we combine these estimations by weighting the resulting functions adopting the approach discussed in 2.2.2 in order to derive estimates for the related provisioning services of Sudan. However, we must be aware of possible inconsistencies on these estimations due to lack of data to perform cross validation on the results.

For the remaining ecosystem services illustrated in Table 4, the Value Transfer approach is employed using properly estimated unit values for each service according to the hybrid-VT approach described in Section 2.2.2. The resulting unit values employed for the evaluation of the ES in each region are illustrated in Table 5 (in USD of 2017 converted with respect to the GDP corrected by the purchase power in each country) and have been calculated by combining the deduced unit values from relevant studies in countries with similar characteristics in Africa using the weighting approach discussed in Section 2.2.2.

Table 5 – Estimated unit values per Ecosystem Service for Egypt, Ethiopia and Sudan (USD 2017 per hectare yearly)

Ecosystem Service	Egypt	Ethiopia	Sudan	Related Studies
biodiversity	3493.77	646.69	1187.42	[20, 21]
carbon sequestration	4760.73	886.18	1594.08	[10, 11]
fish production	598.43	112.50	205.81	[15, 20, 24]
flood control	2506.42	463.84	836.44	[20]
fuelwood	68.29	12.64	22.79	[5, 13, 20, 24]
microclimate regulation	1980.74	360.77	625.50	[15, 20]
touring services & open water transportation	14.75	3.65	6.44	[20, 23, 24, 27]
water regulation	224.22	40.84	70.81	[15, 20]

For the calculations of the Total Economic Value for each Ecosystem Service land cover and land use data where used from FAOSTAT database and from the GIS project websites related to the studies [17, 18] where exact data for the wetlands total area, water bodies, lakes, etc in the basin are available. In total, from the NRB area, 29860.54 thousand hectares lie in the Egyptian domain, 36247.35 thousand hectares lie in the Ethiopian domain and 197741.26 thousand hectares lie in the Sudanian domain.

3.2 ECOSYSTEM SERVICES VALUATION FOR EGYPT

3.2.1 Provisioning ecosystem services

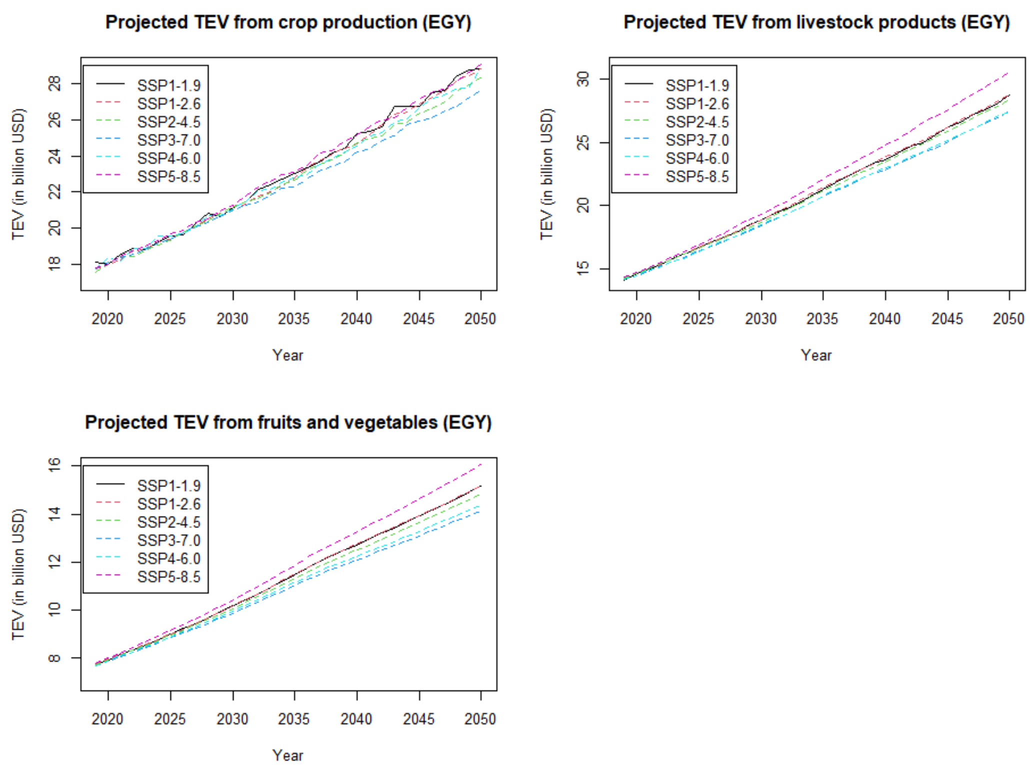
Crop production, livestock products and fruits and vegetables services are evaluated under the SSP-RCP framework. The projected medians of the economic value for these services under each scenario are illustrated in Table 6 and in Figure 1.

Table 6 – Median projections for the economic value (in billion USD 2017 constant) of major crop, livestock and vegetable products for Egypt under the SSP-RCP scenarios up to year 2050

	Scenario					
Year	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP4-6.0	SSP5-8.5
			Crops production			
2025	19.55	19.35	19.32	19.36	19.59	19.70
2030	21.15	21.21	21.12	20.98	21.08	21.27
2035	23.02	22.81	22.65	22.25	22.79	23.09
2040	25.22	24.67	24.75	24.20	24.54	25.18
2045	26.78	26.87	26.36	25.94	26.72	27.17
2050	28.86	28.85	28.34	27.64	28.85	29.09
			Livestock products			
2025	16.69	16.74	16.67	16.44	16.42	16.92
2030	18.92	18.90	18.75	18.40	18.51	19.37
2035	21.32	21.39	21.17	20.72	20.75	22.08
2040	23.65	23.86	23.41	22.85	22.99	24.76
2045	26.25	26.22	25.87	25.05	25.10	27.54
2050	28.68	28.74	28.33	27.42	27.35	30.52
			Fruits and vegetables production			
2025	9.00	9.01	8.96	8.85	8.89	9.14
2030	10.19	10.19	10.08	9.89	9.97	10.44
2035	11.48	11.49	11.32	11.03	11.14	11.87
2040	12.72	12.74	12.50	12.10	12.25	13.27
2045	13.94	13.94	13.65	13.11	13.30	14.64
2050	15.18	15.18	14.82	14.14	14.37	16.05

In general, the evolution of the economic value for these services does not seem to diversify significantly among the various scenarios for the time period 2022-2050. The economic value for crop products is estimated about to 19 billion USD in 2022 and is expected to evolve to a range between 26.8 and 28.3 billions up to year 2050 presenting a quite homogeneous pattern across scenarios. The economic value of livestock products is estimated about to 16 billion USD in 2022 and presents three, but not so diversified, distinct patterns. Scenario SSP5-8.5 (worst-case) indicates the high value path resulting on a median economic value of about 30.5 billions in 2050, SSP3-7.0 and SSP4-6.0 indicate the lowest value path resulting on an economic value of 27.4 billions and the rest scenarios form the middle path resulting on a median economic value of the service ranging from 28.3 to 28.7 billions in 2050. Concerning the fruits and vegetables production, three patterns are also observed with the same clustering result concerning the various SSP-RCP pathways. The economic values of the service is estimated at about 9 billions USD in 2022, while the highest median pathway leads to a value of 16.05 billions in 2050, the lowest to 14.14 billions and the middle ones to a range between 14.8 and 15.2 billions. As a rough figure, it seems that the economic value of crop production service is expected to present a yearly mean rate of return of about 1.53%, livestock products about 2.21% and fruits and vegetables production about 2.06%

Figure 1 – Estimated TEV for provisioning ES for Egypt under the SSP-RCP scenarios



on the next 30 years. In total, a rough estimate for the median increase for these three services is estimated to 27 billion USD, which is a quite substantial value to be added to the Egyptian economy.

Two more provisioning services, fuelwood production and fish stock produced from inland waters in the river Nile basin, are evaluated following the Transfer Value approach due to lack of sufficient data. In particular, fuelwood production service value is estimated at 4 million USD and fishing service at 35 million USD concerning the expected output from the basin. The estimated total economic value for Egypt's provisioning services is estimated to 42.303 billion USD which is more than the 50% of TEV related to provisioning services for the major river Nile region (see Table 10).

3.2.2 Non provisioning ecosystem services

From the identified regulating ecosystem services in Egypt, microclimate regulation is the most appreciated evaluated at 64.605 billion USD. Clearly, high levels of water stress in Egypt in the later years place the services concerning water regulation issues and flood control, which is crucial for the extension of irrigated farming activities, to high stakes with estimated values 7.313 and 2.755 billion USD, respectively. Carbon sequestration service is evaluated quite lower comparing to the other countries in the main basin, and specifically at 267 million USD. The reason for this difference in evaluation with Ethiopia and Sudan (please see Table 10), is the major differences in the terrain morphology between these countries and the total area covered by wetlands. The total figures stand on the amount of 231.21 billion USD for the regulating services in Egypt. Wetlands biodiversity is highly appreciated in Egypt with estimated value at 113.955 billion USD. This figure highly characterizes the total economic value of supporting services in Egypt. Tourism services and open water transportation in Egypt has an estimated economic value of 12 million USD on a yearly basis. The latter constitutes the estimation for the cultural services total economic value related to NRB in Egypt.

3.3 ECOSYSTEM SERVICES VALUATION FOR ETHIOPIA

3.3.1 Provisioning ecosystem services

Similarly with Egypt, crops production, livestock production and vegetables and fruits production for Ethiopia in the river Nile basin are evaluated under the SSP-RCP framework. Projected medians for these services values in the time period 2025-2050 are illustrated in Table 7 and in Figure 2.

Table 7 – Median projections for the economic value (in billion USD 2017 constant) of major crop, livestock and vegetable products for Ethiopia under the SSP-RCP scenarios up to year 2050

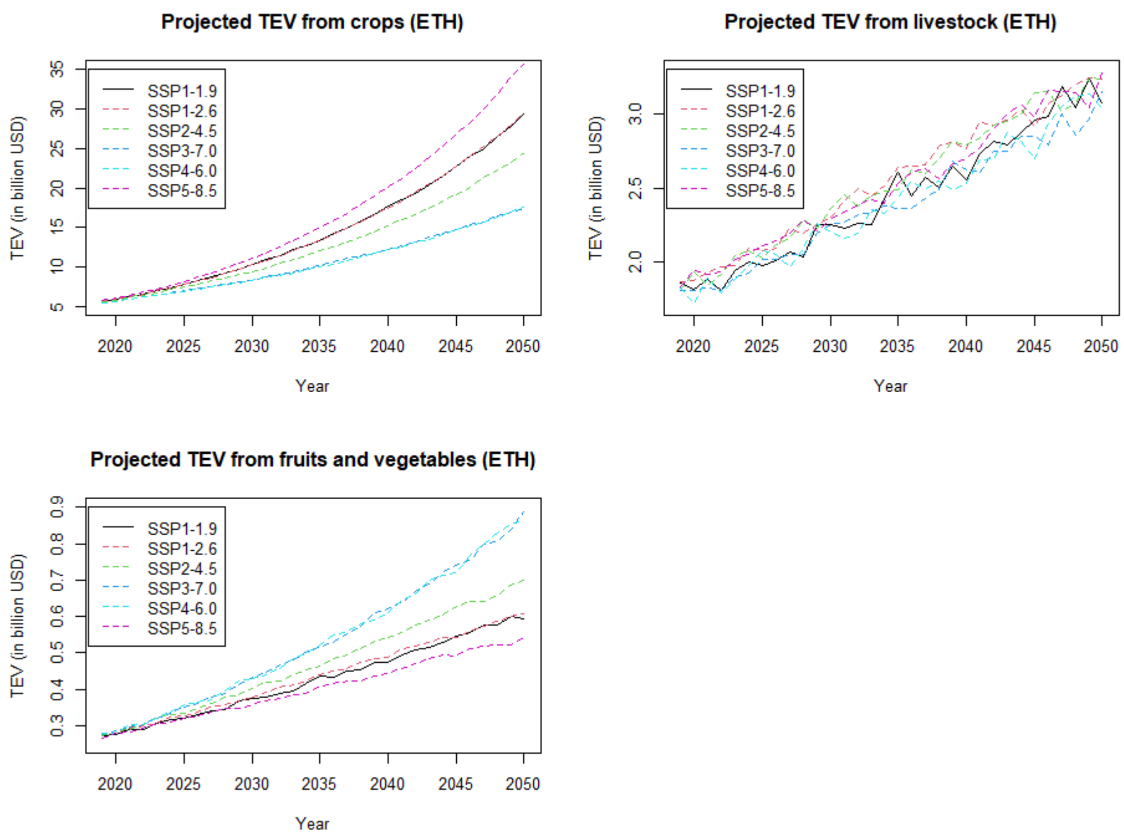
	Scenario					
Year	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP4-6.0	SSP5-8.5
Crops production						
2025	7.81	7.75	7.45	6.95	6.85	8.14
2030	10.33	10.23	9.43	8.33	8.29	11.10
2035	13.38	13.33	12.01	10.13	10.00	14.84
2040	17.65	17.46	15.19	12.25	12.13	20.09
2045	22.79	22.81	19.18	14.67	14.75	26.88
2050	29.35	29.61	24.30	17.46	17.62	35.66
Livestock products						
2025	1.98	2.07	2.03	2.02	2.08	2.11
2030	2.25	2.30	2.36	2.25	2.20	2.28
2035	2.60	2.64	2.48	2.36	2.44	2.53
2040	2.55	2.76	2.79	2.62	2.53	2.70
2045	2.96	2.92	3.15	2.85	2.70	2.97
2050	3.08	3.24	3.24	3.15	3.04	3.28
Fruits and vegetables production						
2025	0.32	0.33	0.33	0.35	0.36	0.32
2030	0.37	0.38	0.40	0.43	0.43	0.36
2035	0.44	0.44	0.46	0.51	0.52	0.40
2040	0.47	0.49	0.54	0.62	0.61	0.44
2045	0.54	0.54	0.63	0.74	0.72	0.49
2050	0.60	0.61	0.70	0.89	0.86	0.54

Crops and vegetable and fruit production services values seems to provide four distinct evolution patterns in the period under study for the given SSP-RCP scenarios. In particular for crops production, the highest pathway is provided by SSP5-8.5 where the services value is expected to increase from about 5 billion USD in 2020 to 35 billion, indicating an extremely significant yearly mean rate of return of about 6.7%. The lowest pathway cluster is constituted by SSP3-7.0 and SSP4-6.0 scenarios, which indicate a median level of the service's price in 2050 of about 17.5 billion USD indicating a yearly mean rate of return of about 3.75%. The medium-high pathway is constituted by SSP1-1.9 and SSP1-2.6 which indicates a yearly mean return rate of about 5.45% in the service's value, while the medium-low pathway includes only scenario SSP2-4.5 (baseline) indicating a mean return rate of about 4.84%. It is evident that in all scenarios, the crop production service's value is expected to significantly increase at the next 30 years.

A similar but not so rapidly increasing trend is also estimated for the vegetables and fruit production service. However, the derived clusters are oppositely constructed comparing to the crops production service groupings. The highest pathway is expected to be displayed by the SSP3-7.0 and SSP4-6.0 scenarios, where from an initial value of the service of about 250 million USD in 2020, is expected to reach at 900 million USD in

2050 indicating a yearly mean return of 3.73%. The lowest pathway includes only SSP5-8.5 scenario, indicating a mean return of 2.11%. The medium-low pathway is constituted by SSP1-1.9 and SSP1-2.6 scenarios indicating an increasing trend where the service's value is expected to reach the 600 million USD in 2050, while the medium-high scenario includes only SSP2-4.5 scenario indicating a yearly mean return of 3.05% up to 2050. As a result, in all scenarios a significantly increasing trend in the service's value is displayed, less rapid than the crops production service and with the exact opposite characterization on the various SSP-RCP scenarios with respect to the levels of the values that are expected to be reached.

Figure 2 – Estimated TEV for provisional ES for Ethiopia under the SSP-RCP scenarios



The livestock production service seems to be the provisioning service, among the three considered, that is less affected by the SSP-RCP scenario realization. The differences among the different socio-economic and climate scenarios are quite small and not much distinct evolution patterns are displayed. In general, the service's value is expected to increase from about 1.8 billion USD in 2020 to 3.1 billion USD in 2050, displaying a yearly mean return of about 1.83%. Clearly, the increase in the value of the service is not expected to be that rapid as in the aforementioned provisioning services, but still under all scenarios an increase is expected.

The services of fishing from inland waters in the basin and fuelwood production are evaluated under the Transfer Value approach due to the lack of sufficient data. After properly weighting the available unit values for these services in relevant wetland areas in the Africa region, the economic value for fishing is estimated at about 75.434 million USD while the fuelwood production service has an estimated value of about 327.063 million USD. The total economic value of the provisioning services for Ethiopia (in terms of Ethiopian individuals' purchasing power) is estimated at 9.057 billion USD.

3.3.2 Non provisioning ecosystem services

Total economic value for regulating services in the Ethiopian territory of the NRB is estimated at 38.049 billion USD using the Value Transfer approach. In particular, the carbon sequestration service is evaluated at 22.931 billion USD making the highest impact in the total value of regulating services, microclimate regulation service is accounted at 13.463 billion USD being the second higher, water regulation services are evaluated at 1.524 billion USD, while flood control service value is estimated at 134.628 million USD. Supporting ecosystem services economic value, and in particular wetlands biodiversity in the Ethiopian part of the NRB, is estimated at 24.133 billion USD. Lastly, touring services and open water transportation services value, is estimated at 2.936 million USD having a very limited impact on the TEV of the services deduced by the Nile river basin in Ethiopia. The total figure for Ethiopia's ecosystem services in the basin stands at 71.242 billion USD, with the major part of this economic value coming from wetlands biodiversity, carbon sequestration, microclimate regulation and crops production services.

3.4 ECOSYSTEM SERVICES VALUATION FOR SUDAN

3.4.1 Provisioning ecosystem services

Unlike Egypt and Ethiopia, for Sudan it is not possible to apply directly the Market Price valuation approach since several parts of data required are not recorded regularly (e.g. Gross Product value per crop product, livestock product, water use, etc) and as a result the estimation of the models in (1) is not feasible. However, since this approach has been applied for two very close countries, Egypt and Sudan, we apply the Value Transfer approach with appropriate selected weights to provide valuations for Sudan. In Table 8 and Figure 3 the results are illustrated.

Table 8 – Median projections for the economic value (in billion USD 2017 constant) of major crop, livestock and vegetable products for Sudan under the SSP-RCP scenarios up to year 2050

	Scenario					
Year	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP4-6.0	SSP5-8.5
Crops production						
2025	26.76	26.54	25.57	24.09	24.19	27.80
2030	35.20	34.87	32.35	28.87	29.52	37.77
2035	46.54	46.36	41.99	35.72	36.30	51.94
2040	62.38	61.69	53.85	43.63	44.49	72.20
2045	81.90	82.00	69.00	52.75	54.65	99.37
2050	107.50	108.46	88.95	63.57	66.20	135.87
Livestock products						
2025	6.77	7.10	6.96	7.00	7.33	7.21
2030	7.67	7.84	8.08	7.81	7.84	7.77
2035	9.06	9.18	8.69	8.32	8.86	8.87
2040	9.03	9.77	9.88	9.33	9.29	9.71
2045	10.64	10.49	11.32	10.25	10.00	10.99
2050	11.27	11.85	11.85	11.47	11.42	12.51
Fruits and vegetables production						
2025	1.10	1.13	1.15	1.22	1.26	1.09
2030	1.28	1.29	1.38	1.50	1.53	1.22
2035	1.52	1.53	1.62	1.81	1.90	1.41
2040	1.67	1.73	1.92	2.21	2.25	1.60
2045	1.96	1.95	2.26	2.66	2.67	1.82
2050	2.18	2.23	2.56	3.23	3.25	2.07

The economic value of crop production seems to be separated into four distinct evolution patterns. The highest pathway corresponds to SSP5-8.5 scenario, indicating a median increase from about 20 billion USD in 2020 to about 135 billion USD in 2050, a very high yearly mean return rate of about 6.57%. The lowest pathway corresponds to the group of SSP3-7.0 and SSP4-6.0 scenarios, indicating a yearly mean return rate of about 4%. The median pathways are distinguished to: (a) the medium-low pathway (SSP2-4.5) leading to a value of about 89 billion USD in 2050, and (b) the medium-high pathway (SSP1-1.9 ans SSP1-2.6), indicating a mean return rate of about 5.78% per year. This is a similar pattern to what happens for Ethiopia in the relevant scenarios and can be accounted to the large increase in GDP and population as well as the large agricultural potential for these countries. In contrast, for Egypt (that has already achieved a high level of agricultural productivity) the increase of TEV for crop production in these scenarios is more moderate, with a mean return rate of about 1.6%.

The value of vegetables and fruits production service presents three major evolution patterns. The highest pathway which is constituted by SSP3-7.0 and SSP4-6.0, leading to a yearly mean increase of about 4% in the service's value till 2050 from its initial value of 1 billion USD in 2020, the median pathway (SSP2-4.5) indicating a yearly mean increase of about 3.2%, and the lowest pathway (SSP1-1.9, SSP1-2.6 and SSP5-8.5) leading to a yearly mean increase of about 2.4 - 2.7% to the service's value. Similarly to the crops production services, the tendency is increasing to all scenarios but they differ on which scenarios lead to higher stakes (almost opposite characterization).

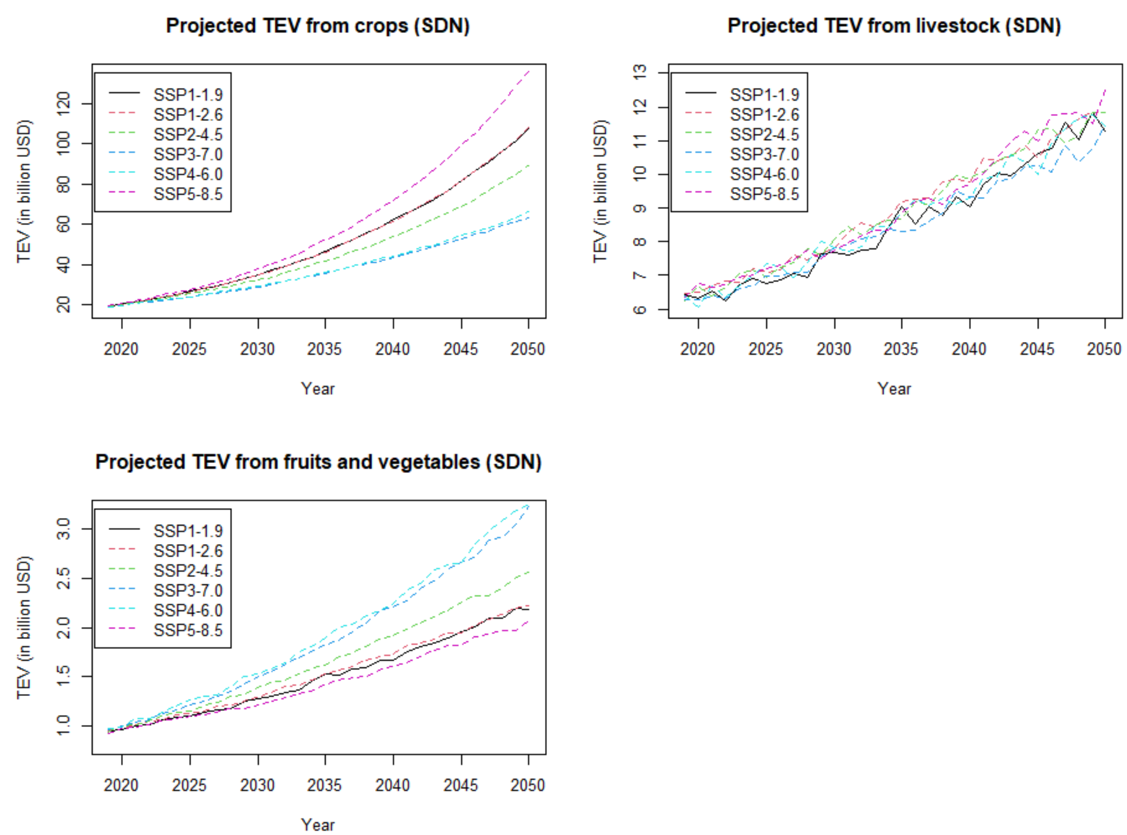


Figure 3 – Estimated TEV for provisional ES for Sudan under the SSP-RCP scenarios

Livestock products related services economic values for Sudan seems to be quite insensitive to the various socio-economic and climate scenarios considered. The tendency to the economic value of the service is clearly increasing, no much different patterns are observed and in median sense the service's value is expected to evolve from about 6.5 billion USD in 2020 to about 11.5 - 12 billion USD in 2050, a yearly mean increase of about 1.9 - 2.1%.

The services from inland fishing and fuelwood production are also evaluated by the Value Transfer method employing unit values from quite similar wetland regions in Africa. Weigthing properly the available data and estimations, the fishing in inland waters service's value is estimated at 14.196 million USD while the fuelwood production service's value is estimated at 796.225 million USD. In general, the total economic value for the provisioning ecosystem services of Sudan related to the river Nile basin is estimated to 30.723 billion USD.

3.4.2 Non provisioning ecosystem services

The total economic value for regulating services in the Sudanian territory of the NRB is estimated at 155.933 billion USD using the Value Transfer approach. In particular, the microclimate regulation service is evaluated at 86.973 billion USD making the highest impact in the total value of regulating services, carbon sequestration service is accounted at 55.69 billion USD being the second higher, water regulation services are evaluated at 9.845 billion USD while flood control service value is estimated at 4.424 million USD. Supporting ecosystem services economic value, and in particular wetlands biodiversity in the Sudanian part of the river Nile basin, is estimated at 165.105 billion USD. Lastly, touring and open water transportation services' value is estimated at 4.593 million USD having a very limited impact on the TEV of the services deduced by the Nile river basin in Sudan. The total figure for Sudan's ecosystem services in the basin stands at 351.879 billion USD, with the major part of this economic value coming from wetlands biodiversity, microclimate regulation, carbon sequestration and crops production services.

3.5 TOTAL ECONOMIC VALUE FOR THE MAJOR ECOSYSTEM SERVICES WITHIN THE RIVER NILE BASIN

3.5.1 Provisioning ecosystem services

The provisioning services for the main river Nile basin (Egypt, Ethiopia and Sudan), and in particular, crop production, livestock production and vegetables and fruits production, are evaluated by aggregating the per country regional evaluations for the part corresponding to the basin presented in Sections 3.2, 3.3 and 3.4. In order to provide a valid estimate, before performing the aggregation task for the ecosystem services estimated values, we first convert the regional evaluations to the Egyptian's economy reality (by converting the estimated economic values to represent the price that it would cost each service if it was offered in Egypt). So, keeping this convention in mind, the estimated economic values and projections in the time period 2020-2050 for the aforementioned provisioning services, are illustrated in Table 9 and Figure 4.

Table 9 – Median projections for the economic value (in billion USD 2017 constant) of major crop, livestock and vegetable products for the main Nile basin under the SSP-RCP scenarios up to year 2050

	Scenario					
Year	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP4-6.0	SSP5-8.5
			Crops production			
2025	126.19	125.14	121.14	114.92	114.82	130.61
2030	161.74	160.49	149.99	135.50	136.96	172.23
2035	207.39	206.47	188.65	162.99	164.20	228.36
2040	270.79	267.53	236.51	195.45	197.17	307.59
2045	347.10	347.56	296.12	232.21	237.96	411.62
2050	446.26	449.96	373.77	275.02	283.42	548.81
			Livestock products			
2025	43.66	45.05	44.39	44.19	45.30	45.68
2030	49.57	50.22	50.95	49.39	49.28	50.41
2035	57.20	57.76	55.52	53.50	55.27	57.12
2040	59.20	62.31	62.27	59.46	59.04	62.73
2045	67.86	67.23	70.13	65.15	63.77	70.06
2050	72.45	74.76	74.34	72.04	71.26	78.37
			Fruits and vegetables production			
2025	13.40	13.50	13.53	13.68	13.85	13.51
2030	15.28	15.33	15.59	15.83	15.98	15.31
2035	17.52	17.56	17.73	18.17	18.54	17.47
2040	19.31	19.54	20.05	20.77	20.96	19.52
2045	21.59	21.54	22.50	23.52	23.61	21.68
2050	23.65	23.82	24.76	26.70	26.86	23.97

The economic value of crop production service evolution in the region, along the socio-economic and climate scenarios considered, seems to be distinguished in four distinct patterns. The highest pathway (SSP5-8.5) predicts an increase from about 100 billion USD in 2020 to about 549 billion USD in 2050. The lowest pathway (SSP3-7.0 and SSP4-6.0) indicates a more conservative increase to about 275-283 billion USD in 2050. The two median patterns are categorized as: (a) the medium-low pathway (SSP2-4.5), where a yearly mean increase of about 4.6% to the economic value of the service is predicted and (b) the medium-high pathway (SSP1-1.9 and SSP1-2.6), where a yearly mean increase of about 5.18 - 5.25% to the service's value is predicted.

The total economic value of the services related to livestock in the basin seems to be quite indiffirent among all scenarios considered. An increasing trend is expected under all scenarios with minor differences between making difficult to separate to distinguished evolution patterns. In general, the service's value is expected to increase from about 40 billion USD in 2020 to 72-78 billion USD in 2050.

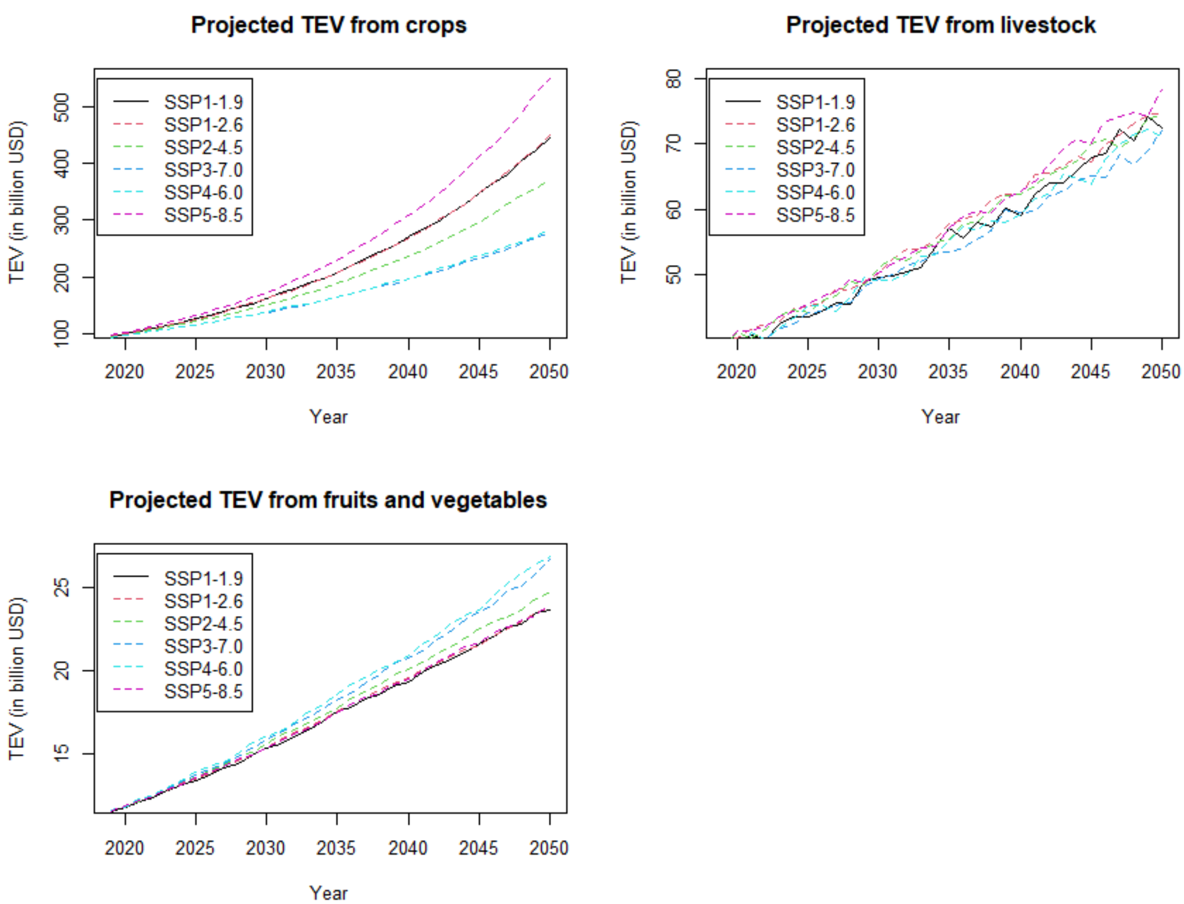


Figure 4 – Estimated TEV for crops production, livestock production and vegetables and fruits production services in the main river Nile basin under the SSP-RCP scenarios (converted to USD 2017 for Egypt)

Vegetables and fruit production service's value seems to appear two major increasing trends in the region for the time period 2020-2050. The cluster leading to higher economic values for the service, includes SSP3-7.0 and SSP4-6.0 scenarios, predicting an increase from about 10 billion USD in 2020 to about 26.7 billion USD in 2050. The set of scenarios leading to lower economic values for the service, consisting from SSP1-1.9, SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios, indicates an increase to about 23.5-24.5 billion USD in 2050.

Fishing in inland waters related to the river basin of the region is evaluated at about 481 million USD for the main basin, where the major contribution is expected to come from Ethiopian region at 411 million USD. Fuelwood production service's value is estimated at 3.692 billion USD, where Egypt contributes the smaller amount (about 4 million USD) and Ethiopia and Sudan contribute 1.782 and 1.907 billion USD, respectivelly. The total economic value for the provisioning services in the basin is estimated at 165.507 billion USD, where the services that contribute mostly to this value are crop production (107.026 billion USD) and livestock products (41.818 billion USD).

3.5.2 Non provisioning ecosystem services

The total economic value for regulating services in the main Nile river basin is estimated at 657.971 billion USD by aggregating the estimates for Egypt, Ethiopia and Sudan obtained by the Value Transfer method. From this total value, about 11.7% is contributed by Egypt, 31.6% is the contribution of Ethiopia and 56.7% comes from Sudan. The microclimate regulation service in the basin is evaluated at 348.2 billion USD[8] having the major impact in the TEV of regulating services, carbon sequestration service is evaluated at 258.599 billion USD being the second most contributable service while water regulation service and flood control are evaluated at 39.417 and 11.755 billion USD, respectively. Supporting ecosystem services economic value, and in particular wetlands biodiversity in the river Nile basin, is estimated at 644.296 billion USD from which value 18.17% comes from Egypt, 20.34% comes from Ethiopia and 61.33% comes from Sudan. In general, regulating services and supporting services in the basin are estimated to have a contribution of about 88.7% of the total economic value of all services in the basin. Cultural services are estimated to have the less impact, evaluated at 39 billion USD, however this could be significantly underestimated.

Table 10 – Total Economic Values per Ecosystem Service and for each region in the major Nile river basin in billion USD (constant 2017 values)

Ecosystem Service	Egypt	Ethiopia	Sudan	Major Nile Basin
PROVISIONING (total)	*42.306*	*49.346*	*73.854*	*165.507*
crop production	18.447	35.079	53.499	107.026
fish production	0.036	0.411	0.034	0.481
fuelwood	0.004	1.782	1.907	3.692
livestock production	15.485	10.429	15.904	41.818
vegetables production	8.332	1.646	2.510	12.489
REGULATING (total)	*77.190*	*207.313*	*373.469*	*657.971*
carbon sequestration	0.275	124.942	133.381	258.599
flood control	2.838	0.714	8.202	11.755
microclimate regulation	[8]66.543	[8]73.352	[8]208.305	[8]348.200
water regulation	7.533	8.303	23.580	39.417
SUPPORTING (total)	*117.374*	*131.487*	*395.435*	*644.296*
wetlands biodiversity	[8]117.374	[8]131.487	[8]395.435	[8]644.296
CULTURAL (total)	*0.012*	*0.016*	*0.011*	*0.039*
touring services & open water transportation	[8]0.012	[8]0.016	[8]0.011	[8]0.039
Total Economic Value (TEV)	**236.882**	**388.162**	**842.769**	**1467.813**

[8] The estimates for microclimate regulation, wetlands biodiversity and touring and open water transportation services should be treated as upper bounds since they might be affected by the double counting effect.

4 RELATED POLICY SELECTION CONSIDERATIONS

This part of the report is based on an extension of the matrix analysis presented in MS9 - Catalogue of international policies related to environmental protection of the AWESOME project that provided a catalogue of the International Environmental Agreements (IEAs), whether Multilateral Environmental Agreements (MEAs) or Bilateral Environmental Agreements (BEA) among Egypt, Sudan and Ethiopia (meso level), regarding environmental protection with particular focus on the Water, Energy, Food, and Ecosystem (WEFE) Nexus issues as well as Ecosystem Services (ES). International environmental agreements (IEA) are efforts to regulate human interactions with the environment that involve legally binding commitments (”agreements”) among governments (”international”) that have environmental protection as a primary objective (”environmental”) (International Environmental Agreement (IEA) Database project)[9]. For the IEAs listed an extensive review of databases, collections[10], archives[11] of international environmental treaties, conventions, and protocols was realized.

For the development of the catalogue, it was necessary to set criteria for selecting environmental policies from the above sources that align with the AWESOME Grant Agreement (GA) description of the MS9 and the needs of the D2.5. The policies needed to be:

(a) Relevant to the meso-level model of AWESOME that WP4 is developing and signed by at least one of the meso-level countries (i.e., Egypt, Sudan and Ethiopia),

(b) Relevant to environmental protection, that can be divided into the following categories based on the European standard statistical classification of environmental protection activities (CEPA)[12]:
I) Protection of ambient air and climate
II) Wastewater management
III) Waste management
IV) Protection and remediation of soil, groundwater and surface water
V) Noise and vibration abatement
VI) Protection of biodiversity and landscapes
VII) Protection against radiation
VIII) Environmental research and development
IX) Management of waters
X) Management of forest resources
XI) Management of wild flora and fauna
XII) Management of energy resources
XIII) Management of minerals
XIV) Research and development activities for resource management
XV) Other resource management activities

(c) Relevant to the ES, divided into the categories listed in the Section 2.1.

Based on the above selection criteria and the initial matrix of MS9 Annex 10 Multilateral agreements and 3 Bilateral among Egypt and Sudan were identified, which are listed in Table 11. No Bilateral agreements signed among Egypt and Ethiopia or Sudan and Ethiopia were identified. Two among the agreements in the table

[9] International Environmental Agreement (IEA) Database project, https://iea.uoregon.edu/
[10] United Nations Treaty Collection, https://treaties.un.org/
[11] African Union https://au.int/en
[12] Eurostat Classification of Environmental Protection Activities (CEPA) https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Classification_of_environmental_protection_activities_(CEPA)

are directly related to the management of the Nile River or lakes within its river basin. An issue to consider is that there is no clear reference to ES in any of the reviewed policies and no agreement, formal or informal on the collective use of dams. The cross-reference of the initial matrix with the ES categories was implied by the agreements' text.

Table 11 – Extension of listed International Environmental Agreements regarding their relevance with Ecosystem Services

International Environmental Agreement level	
Multilateral	**Bilateral Egypt-Sudan**
Khartoum Declaration (2018): Shared ecosystem management	Agreement for the Hydrometeorological Survey of Lake Victoria, Kyoga, and Albert (Mobuto Sese Seko) (1967): Water regulation (provisioning)
Intergovernmental Oceanographic Commission: Promotion of coastal and marine ecosystem services	Regional Convention For The Conservation Of The Red Sea And Gulf Of Aden Environment (1982): enabled the conservation of biodiversity and establishment of protected areas (supporting services)
African Convention On The Conservation Of Nature And Natural Resources (Chapter 2.1 and 2.2.), 2013: Habitat protection (supporting services), regulating and provisioning services related to land, soil and water	Agreement Between The Republic Of The Sudan And The United Arab Republic For The Full Utilization Of The Nile Waters (1959): Water flow and flood control (regulating services), irrigated agriculture production (provisioning services)
Convention on Wetlands of International Importance especially as Waterfowl Habitat (1971): Migratory birds stock, wetland flora and fauna (supporting services) Water purification, flow regulation (regulating services)	
Convention For The Protection Of The World Cultural And Natural Heritage (1972): Supporting services	
Convention On International Trade In Endangered Species Of Wild Fauna And Flora (1975): Wild animals and plants protection (supporting services)	
United Nations Convention On The Law Of The Sea (1982): conservation and management of straddling fish stocks and highly migratory fish stocks (supporting and provisioning services)	
Convention On The Control Of Transboundary Movements Of Hazardous Wastes And Their Disposal (1989): control of hazardous pollutants with indirect benefit for supporting, provisioning and regulating services	
Convention On The Ban Of The Import Into Africa And The Control Of Transboundary Movement And Management Of Hazardous Wastes Within Africa: control of hazardous pollutants with indirect benefit for supporting, provisioning and regulating services	
United Nations Framework Convention On Climate Change (1992): carbon sequestration (regulating services)	

Implications in terms of the Water sector are found in establishment of the Intergovernmental Oceanographic Commission in which Sudan, Egypt and Ethiopia participate and the most important ones in terms of direct applicability in AWESOME are found in the Agreement for the Hydrometeorological Survey of Lake Victoria, Kyoga, and Albert (1967), in the Agreement Between The Republic Of The Sudan And The United Arab Republic For The Full Utilization Of The Nile Waters (1959) and the Convention on Wetlands of International Importance especially as Waterfowl Habitat (1971). However, in all three agreements there is minor or no consideration of intersectoral implications. Two further international conventions are relevant with the water sector, the United Nations Convention On The Law Of The Sea (1982) and the Convention On The Control Of Transboundary Movements Of Hazardous Wastes And Their Disposal (1989).

Implications in terms of the Energy sector can be found only in the Convention of the African Energy Commission (AFREC) functions as a specialized agency in the African Union towards harmonizing, protecting and conservation the energy resources of the continent. Although in the treaty's document there is no reference in the other WEFE sectors apart from land (combating desertification), in its Agenda 2063 and its program there is a clear alignment with the SDGs and the promotion of agro-business development.

Implications in terms of the Food sector are found in the Agreement Between The Republic Of The Sudan And The United Arab Republic For The Full Utilization Of The Nile Waters (1959) which is among the factors that have influenced the regular supplies of irrigation water from dams along the River Nile and its tributaries. While on the international level some implications in terms of the fish stock are related with the United Nations Convention On The Law Of The Sea (1982).

Implications in terms of the Ecosystems sector are mostly coming from the African Convention On The Conservation Of Nature And Natural Resources (2013 and revised in 2016) which refers to the interrelations of the nature conservations with the water sector as well as with the soil and land and considers inter-sectoral processes affecting the environment and the resources. While implications are also coming from international declarations and conventions beyond the Nile River Basin such as the Khartoum Declaration (2018), Regional Convention For The Conservation Of The Red Sea And Gulf Of Aden Environment (1982), Convention For The Protection Of The World Cultural And Natural Heritage (1972) and the Convention On International Trade In Endangered Species Of Wild Fauna And Flora (1975).

Although the above connections and implications between water, energy, food and ecosystems are obvious, one can notice that there is no clear reference to Ecosystem Services and there is still no relative "Nexus" of capacities to address and manage the resulting challenges at the international political level. The institutional framework is quite fragmented and leads to sectoral approaches to policy planning. Despite a near decade of research on solutions and management approaches that tackle WEFE sustainability there is still a focus on economic and security performance and a lack of interlinkages that can support the development of socially and politically-relevant policies [1]. Embedding the political dimension and minimizing the science-policy barrier is crucial in order to have a complete picture of the WEFE Nexus complexity and deliver effective solutions [26]. There is still a lot of work to be done in terms of translating technological innovation of WEFE into effective policies, especially when it comes to transboundary resources.

A recommendation, especially under the view of the global commitments of the SDGs 2030, would be the need for revision of the current institutional framework in the main countries of NRB, as development strategies as well as national and international policies should no longer be formulated for individual sectors. Multi-stakeholder approaches that work across the different sectors, such as the one adopted in the framework of AWESOME, can add towards that direction by addressing challenges, trade-offs and synergies that arise in the Nexus. While clear roles in the national institutions aligned with the Nexus mandate could result in more determinated polices.

5 CONCLUSIONS

This report provides an assessment of ES relevant for the AWESOME case study along with an analysis for international policies for environmental protection. This research is an addition to the current literature on economic valuation of ES in the NRB. Its methodology concerning the valuation of non-provisioning services is in line with the standard practice employed in the literature, that of Value Transfer based on unit values obtained from survey studies in regions with similar characteristics combined with meta-analysis. It must be noted that the available studies concerning wetlands in river basins in Africa are rather limited and heavily used as primary data for secondary meta-analysis. There is therefore the need for more primary research based on survey analysis for ES valuation in the Africa region. Such a task however would require considerable funds and very careful central planning. On the other hand, our valuation of provisioning services is data-driven, relying on economic values as recorded from the market prices. The nature of the data impose the need for aggregate pricing at a country level, eventhough the methodology is in principle valid for finer scales given the necessary data. Moreover, the introduction of socio-economic and environmental variables in the economic models allow for scenario-based evaluations.

The list of ES considered of major importance for the NRB are prioritized and identified in collaboration with the MAWGs constituted by the associated regional stakeholders in cross-reference with the activities of WP6. The valuation of the final list of ES is performed by two methodologies (a) the MPV approach and (b) the VT method and appropriate variations of it, depending on data availability issues. The ES valuations at a regional level were subsequently aggregated to obtain the TEV for the NRB. Our findings indicate that the major contribution to the TEV comes from regulating services (and in particular carbon sequestration and climate regulation), followed by supporting services (biodiversity on wetlands) and provisioning services (and in particular crop production).

For those ES that were evaluated by the MPV approach (mainly provisioning services), we additionally provide probabilistic projections for the values of the services for the time period 2019-2050 under the combined framework of the SSPs and RCPs (socio-economic scenarios considered in WP2 D2.1 and aggregate climate scenarios as provided by the WB climate online database). Concerning crop production services, future scenario results can be distinguished into four different evolution patterns, as far as the rate of increase of the economic value of the service is concerned. On the other hand, for livestock products, fruits and vegetables production, the trend in the rate of increase of the economic value does not display increased variability under the various socio-economic and climate scenarios.

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