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Gross Ecosystem Product in macroeconomic modelling

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Contents

Abstract

The benefits provided by ecosystem services, such as crop pollination and water purification, are of great importance to any economy, both directly and indirectly. Therefore, nature-inclusive decision-making requires that such benefits are taken into account in the economic decision-making process. However, in most assessments, the Gross Domestic Product (GDP), which shows the total value of output/income generated in a country, is used as the main economic development indicator, not capturing fully the contributions of nature to economic activity and human well-being. The concept of Gross Ecosystem Product (GEP) (see Ouyang et al. 2013 and 2020), which summarizes the value that ecosystem services provide to the economy in monetary terms is a way to overcome these shortcomings in policy assessments.

This technical report introduces and showcases the new *GEP module* in the macroeconomic model MAGNET. MAGNET is a GTAP-based global CGE model used to assess policy impacts on the economy. MAGNET's endogenous land supply and forestry representation makes this model particularly suitable for this task. Built upon the Integrated Natural Capital Accounting (INCA) database on monetary value of ecosystem services, the new GEP module allows for comparison of the impact of different policies on both GDP and GEP in the European Union. The report provides an example of a practical application of the *GEP module.* In particular, we apply a forward-looking policy scenario that assumes a significant change in consumption patterns. The results of preliminary simulations show that such an impact can significantly differ both between GDP and GEP and across particular ecosystem services.

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1 Introduction

The benefits provided by ecosystem services, such as crop pollination, carbon sequestration, or water purification, are of great importance to any economy, both directly and indirectly. Nature-inclusive policy requires such benefits to be taken into account in the economic decision-making process. As a result, there is a need to move beyond current indicators of economic development, such as Gross Domestic Product (GDP), that fail to fully capture nature's contribution to the economy and well-being and do not factor in environmental impacts (e.g., Sen et al., 2010; Dasgupta, 2021). The latter is particularly important nowadays, given that the global stock of ecosystems, for example wetlands, grasslands, and forests, is under increasing pressure from an expanding world population with rapidly changing consumption patterns (EEA, 2023). In reference to the above considerations, Ouyang et al. (2013) proposed and further developed (e.g. Ouyang et al. 2020) the concept of Gross Ecosystem Product (GEP), which summarizes the value that ecosystem services provide to the economy in monetary terms.

The concept of GEP is receiving increasing attention worldwide. In March 2021, the United Nations (UN) Statistical Committee approved a global standard on Ecosystem Accounting (EA) under the System of Environmental Economic Accounting (SEEA) EA, which reflects the contribution of nature in measuring economic prosperity and human well-being (UN, 2021b). Since then, several countries have started developments related to its adoption and policy implementation (Comte et al., 2022). For instance, the Netherlands and Iceland have decided to reflect the value of ecosystem services in national accounts (de Jongh et al., 2021, Cook et al., 2022). China is the first country to implement GEP and integrate the value of ecosystem services into decision-making processes alongside conventional macroeconomic indicators such as GDP (Ouyang et al. 2020; Zheng et al. 2023).

The strength of GEP lies largely in the fact that it can serve as a complement to GDP measures. By using the national accounts approach, it provides policymakers with a clear and intuitive indicator of the value of nature. The use of GEP alongside other macroeconomic indicators provides a more accurate picture of the impact of policies on the economy and on nature, to be included in the decision-making process. Analogous to GDP, GEP can be assessed not only as a single metric; an evaluation of the different components and related indicators is also useful. Trade-offs (and synergies) among different categories of ecosystem services, such as provisioning services, regulating services, and cultural services, are seen as one of the most important current sustainability issues and should be considered in decision-making (Bennett et al., 2023; Le et al., 2023).

This report introduces the GEP module, an application of GEP that links ecosystem flows and their values to known macroeconomic indicators for nature inclusive decision-making. The GEP module is a new extension to the computable general equilibrium (CGE) model MAGNET developed by Wageningen Economic Research in collaboration with the units D3 and D4 of the Joint Research Centre (JRC). It enables forward-looking macroeconomic scenario studies on the relationship between macroeconomic indicators and GEP. MAGNET is a global CGE model used to assess the policy impacts on the economy. MAGNET's endogenous land supply and forestry representation make this model particularly suitable for this task, as does its international dimension.

Built upon the INCA database on monetary value of ecosystem services, the new module allows for comparison of the impact of different policies on both GDP and GEP in the European Union. The report provides an example of the practical application of the GEP module. In particular, we apply a forward-looking policy scenario that assumes a significant change in consumption patterns. The results of preliminary simulations show that such an impact can significantly differ both between GDP and GEP and across particular ecosystem services.

2 Methodological background

2.1 GDP, green GDP and GEP

The Gross Domestic Product (GDP) summarizes the total output and income of the economy. It is focused on the monetary value of the economy only, and fails to fully capture the contributions of nature to economic activity and human well-being.

In 1993, the United Nations published the Handbook of National Accounting: Integrated Environmental and Economic Accounting (SEEA) as an interim report. The SEEA 1993 handbook focused on the monetary valuation of natural resources, allowing the cost of natural resource depletion and environmental degradation to be subtracted from gross domestic product. In particular, the handbook advocated compilation of an 'environmentally adjusted domestic product' — also known as 'green GDP'." Although developed in 1993, research on green GDP has expanded only after 2000. One of the reasons may be the existence of barriers in its implementation related to political processes - see Hoff et al. (2021) who investigate the reasons for the slow adoption of green accounting, using Denmark as an example. They distinguish three types of barriers: analytical barriers, processual barriers and actor barriers. They find that the aforementioned barriers "make a transition towards green national accounting very difficult".

There is no uniformly accepted way to calculate green GDP. The most common approach to measure the Green GDP is to deduct social and environmental costs (for example natural resources depletion and pollution damage) from the standard GDP measure:

Green GDP = GDP − Environmental pollution cost - Resource depletion cost - Environmental improvement cost

Equation 1. Green GDP formula

Several authors have applied the above methodology. For instance, Wang et al. (2020) have constructed green GDP for China. As a proxy for environmental pollution, the authors incorporate three sources of pollution – CO2 and SO2 emissions for air pollution, wastewater discharge for water pollution, and solid waste discharge and storage for solid pollution. Fossil energy consumption and water resources consumption were used as a proxy for resource depletion costs. However, environmental improvement costs were excluded due to data limitations.

An alternative approach for constructing green GDP was proposed by Stjepanović et al (2019):

$$GreenGDP = GDP - (KtCO_2 * PCDM) - Twaste * 74kWh * P_{elect}) - (\frac{GNI}{100} * \%NRD)$$

Equation 2. Alternative green GDP formula

In their paper, Green GDP was calculated by adjusting standard GDP with the cost of climate change, the cost of waste generation, and the cost of nature degradation. The cost of climate change was calculated as *Kt* of CO2 emissions (ktCO2) times the price of CO2 (PCDM). The cost of waste generation was calculated as total waste produced times the energy content of waste (74kWh) times the price of energy (P_{elect}). Finally, the cost of nature degradation was calculated as a percentage decline of natural resource depletion (%NRD) in gross national income (GNI), where NRD is a sum of net forest depletion, energy depletion, and mineral depletion.

The problem with the above definitions of green GDP is that while they account for the cost of environmental pollution and resource depletion, they ignore the value of ecosystem services. In other words, green GDP accounts for the cost of using nature but does not account for the benefits that nature provides to the economy. A reference to green growth accounting and green GDP is also made in the context of sustainable productivity growth. The concept of "environmentally-adjusted" TFP or Total Resource Productivity (TRP) was proposed by Fuglie et al. (2016). It represents a complete metric of sustainable intensification that takes into account agriculture's effect on natural resources and environmental services. Also, the OECD (2022) proposes an analytical model of environmentally adjusted agricultural productivity using by-products. Their approach is based on an adjustment of standard TFP measures for changes in in non-commodity outputs that may include desirable by-products (public goods), undesirable by-products (pollution) and depletion of natural capital. In the case of agricultural TFP, the main focus is on mobilising data on water, soil, forests, fishery resources and biodiversity, and sector-specific pollution such as ammonia and nitrogen leakages (see Bureau and Antón, 2022).

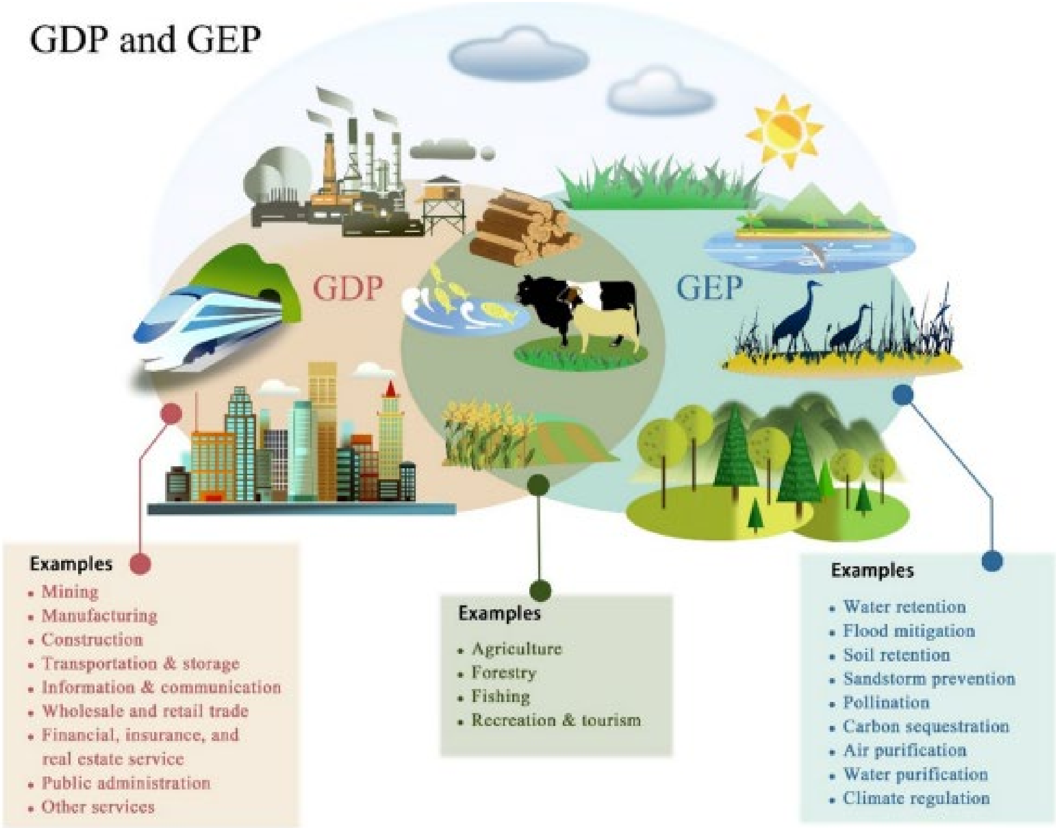
Ouyang et al. (2013) and Ouyang et al. (2020) provide an alternative to the green GDP measure. Instead of adjusting the GDP estimates, the authors suggest calculating a new indicator: the Gross Ecosystem Product (GEP). This indicator can be used alongside the GDP indicator. The GEP indicator summarizes the value ecosystem services provide to the economy in a single monetary metric (also explained in the Dasgupta Report, 2021). Analogous to GDP, GEP uses market prices and surrogates for market prices to calculate the accounting value of ecosystem services and aggregate them into a measure of the contribution of ecosystems to the economy. The power of GEP is enhanced by using similar methods for its construction as those underpinning GDP. A recent example of GEP estimation can be found for China (NBS China, 2021).

The calculus of GEP follows guidance provided by SEEA EA, which complements the previously introduced SEEA Central Framework (SEEA CF). Adopted by the United Nations Statistical Commission in 2012, the SEEA CF advanced the framework of the 2003 SEEA handbook (which, in turn, replaced the earlier SEEA 1993 handbook) to become an international statistical standard, on par with the SNA. Featuring stock and flow accounts in both physical and monetary terms, it enables a comprehensive view of the sustainability of our use of the environment and natural resources. The SEEA combines economic and environmental data to offer a more comprehensive and versatile understanding of the connections between the economy and the environment, including the stocks and changes in stocks of environmental assets that provide benefits to humanity.

SEEA EA is "a spatially-based, integrated statistical framework for organizing biophysical information about ecosystems, measuring ecosystem services, tracking changes in ecosystem extent and condition, valuing ecosystem services and assets and linking this information to measures of economic and human activity" (United Nations et al., 2021). SEEA EA adopts an ecosystem perspective and examines the interactions among individual environmental assets within a specific spatial area as part of natural processes. Ecosystem accounts allow for the representation of indicators that measure the extent and worth of "ecosystem services" within a defined spatial area.

A significant aspect of GEP is its ability to be compiled concurrently with GDP using national accounts, allowing for these indicators to be compared and analysed together. It is important to note that the GEP indicator encompasses nature's contributions to the economy, including marketable ecosystem services such as crop and wood provisioning. As this is also included in the GDP calculation, there is an overlap between the two indicators (Polasky et al., 2023; Zhang et al., 2023). This is illustrated in Figure 1 Therefore, both indicators should be used alongside each other. It is not possible, for example, to subtract the GEP indicator from the GDP indicator to arrive at a version of the green GDP indicator.

Figure 1. Illustration of GEP and GDP partly overlapping



Source: Zheng et al (2023)

The Gross ecosystem value is equal to the total economic value of ecosystem provisioning services (EPV), ecosystem regulating and maintenance services (ERV), and cultural services (ECV) in the given country/region annually:

$$GEP = EPV + ERV + ECV$$

Equation 3. General GEP formula

Following Zheng et al. (2023) four steps are needed to understand and properly assess GEP. This includes:

- accounting of the asset stock of ecosystems providing services supporting human well-being (this includes both natural ecosystem assets such as forests or rivers as well as modified ecosystem assets such as farmland and reservoirs);
- estimating the ecosystem service supply, where supply is determined by the structure and function of a given ecosystem;
- determining the value of each ecosystem service;
- aggregating the total value of particular ecosystem services.

In accordance with the above, a comprehensive assessment of GEP should include both the value of ecosystem assets and the value related to the flow of ecosystem services. Nevertheless, there are many problems related to the proper valuation of ecosystem assets (e.g., Zheng et al., 2023). This is due to the fact that such an evaluation must account for the extent (e.g., area of particular ecosystem type), condition (e.g., quality of water, vegetation coverage, biomass) and the integration of the afore-mentioned factors. This in turn, requires a lot of data that in many cases turn to be very difficult to gather. Hence, the simplified GEP version, applied in the majority of studies, is based on the value of ecosystem services only.

Following the definition of GEP, all ecosystem services are simply additive. As a result, the monetary value of GEP for different kinds of ecosystem services can be calculated as follows:

$$GEP = \sum_i Y_i * Q_i * P_i + \sum_j Y_j * Q_j * P_j + \sum_k Y_k * Q_k * P_k$$

Equation 4. Detailed GEP formula

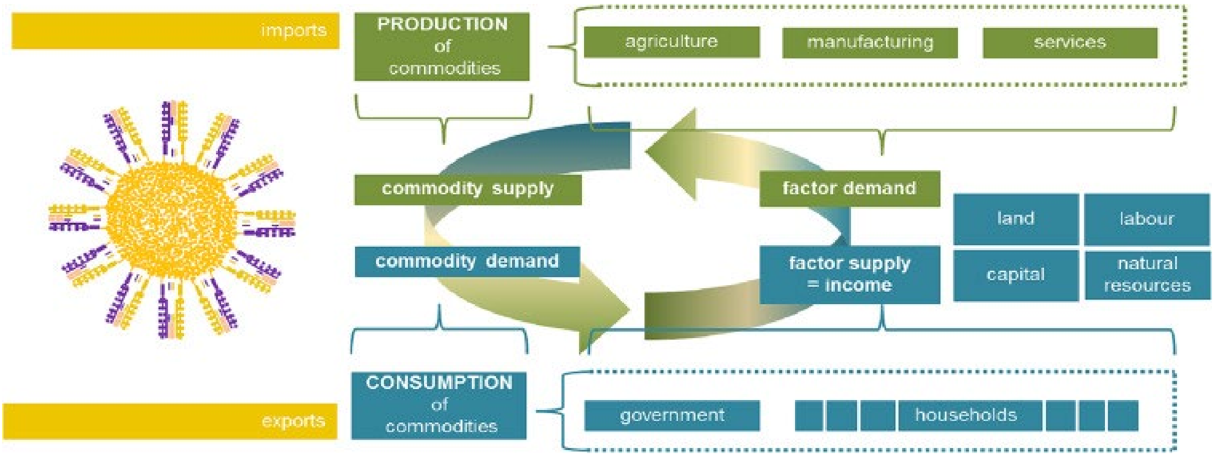
where i, j and k are sets of provisioning, regulating and maintenance, and cultural ecosystem services, respectively, Y is the proportion of accounting value attributable to nature, P is the accounting price of ecosystem service i, and Q is the quantity provided of ecosystem service i. For regulating and cultural ecosystem services, the entire value of the services is attributable to nature (Y_i = 1). For provisioning there is a contribution from human labour and human-made inputs, so that Y < 1.

2.2 MAGNET model

The *GEP module* is implemented as an extension to the global CGE model MAGNET. The Modular Applied GeNeral Equilibrium Tool (MAGNET) is a recursive dynamic, multi-regional, multi-commodity CGE model, covering the entire global economy (Woltjer and Kuiper, 2014). As with other CGE models, MAGNET explicitly represents the economic linkages across the sectors of each regional economy. This is particularly important when analysing policy effects in sectors that are vertically linked with each other, such as bioeconomy sectors. It is built upon the GTAP (Global Trade Analysis Project) model (Hertel, 1997) and has been widely used for policy analysis (Philippidis et al., 2018; Doelman et al., 2019; Kuiper and Cui, 2021; Latka et al., 2021; Philippidis et al., 2023).

The core of the global MAGNET model is the standard GTAP model (Corong et al., 2017), graphically illustrated in Figure 2. There are four basic production factors (land, labour, capital, and natural re-sources) supplied by households to three production sectors (agriculture, manufacturing, and ser-vices). Specific commodities are produced by combining basic production factors with intermediate products and sold either on domestic or foreign markets (exports). The model is based on behavioural equations that capture agents' rational behaviour consistent with neoclassical theory. A series of further market clearing and accounting equations enforce the closed circularity conditions (supply equals demand, zero economic profits, value of macroeconomic output, expenditure, and income are equal).

Figure 2. *MAGNET model structure*



Source: Philippidis et al (2023)

For every region in the model there is a single representative household demanding consumption goods (including savings) on the behalf of the private household and the government. Total demand is determined by income earned by land, labour and capital as well as income from taxes. The demand for goods can be met by national producers or by imports. Each commodity is produced by one sector, while each sector produces only one commodity. For each sector there is a single producer, i.e. there is one producer of wheat, one for gas, one for wood products, etc.

The model includes trade between all regions in the model and accounts for trade barriers between regions via tariffs. These tariffs may drive a wedge between prices in regions, i.e. the same product may be more expensive in one region than in another because of tariffs. Whereas international trade is modelled by tracing all bilateral flows, international capital flows are governed by a global bank. This bank collects savings and uses them for international investments. Since savings are pooled by the global bank before being used for investments, it is not possible to trace bilateral capital flows.

Prices of goods and of land, labour and capital in each region adjust to assure that both national and international demand and supply are equal, hence the term general equilibrium model. Thus, when a policy simulation is run, for example to analyse the impacts of lowering tariffs between regions, the model computes by sector the production, consumption and trade (both imports and exports) as well as price levels that result in equilibrium in national and international markets.

MAGNET currently uses the GTAP 11 database with a coverage of 141 countries and 19 aggregated regions, 65 sectors and 8 production factors including natural resources, oil and gas. In MAGNET, the original GTAP database, was further disaggregated to include additional agricultural and bioeconomy sectors. As a result, the complete MAGNET database contains the total of 122 sectors and 143 commodities. The database includes detailed information on production, gross bilateral trade flows, transport costs and trade protection data for a 2017 benchmark year.

The MAGNET model is modular in nature and extends the GTAP model through the addition of a number of policy-relevant modules. Some modules are compulsory while the others are optional. The examples of such modular extensions include:

- Flexible production structure that allows to choose the number of nests or intermediate inputs that enter given nest;

- Dynamic segmented factor markets divided into agricultural and non-agricultural labour and capital;
- Land supply curve which specifies the relationship between land rent and a the area of land destined to agricultural activities;
- Different substitutability amongst groups of land use types, with the degree of substitutability varying across but not within the groups and considers three hierarchical land use type groups;
- Livestock sectors are linked in various ways to the crop sectors;
- A flexible constant elasticity of substitution (CES) tree production structure;
- A dynamic constant difference of elasticities (CDE) expenditure function;
- Common Agricultural Policy (CAP) module that allows to include changes to the CAP budget;
- Sustainable Development Goals (SDG) module that introduces different indicators to assess multiple dimensions for each one of 12 included SDGs;
- Nutrition module that allows to calculate food security indicators defined by FAO;
- Emissions module that calculates GHG emissions (both combustion and non-combustion related emissions)

In total, over 20 modules are available for modellers. Beyond the standard GTAP specification, MAGNET (Woltjer and Kuiper, 2014) provides additional sophistication. As a recursive-dynamic treatment, the model rolls-over single time period 'comparative-static' solutions across chosen discrete time frames to capture gradual capital accumulation and structural economic change. MAGNET also offers parsimonious flexibility by allowing multiple structures of input combinations or 'nests' to capture an array of representative technologies.

2.3 Ecosystem services accounting and INCA database

The ecosystem services are categorized under the Common International Classification of Ecosystem Services (CICES) V5.2 (see e.g., www.cices.eu) and include provisioning services (e.g. food, timber, water), regulating and maintenance services (e.g. water purification, carbon sequestration) and cultural services (e.g. ecotourism, nature experience for mental health) (Haines-Young, 2023).

Table 1. Definition and examples on the three major Sections in CICES V5.2

Section in CICES	Definition	Examples
Provisioning services	This section covers all nutritional, non-nutritional material and energetic outputs from living systems as well as abiotic outputs (including water)	Crop provisioning, Timber provisioning
Regulating and maintenance services	All the ways in which living organisms can mediate or moderate the ambient environment that affects human health, safety or comfort, together with abiotic equivalents	Water purification, carbon sequestration, flood control, crop pollination, natural pest control

Cultural services	All the non-material, and normally non-rival and non-consumptive, outputs of ecosystems (biotic and abiotic) that affect physical and mental states of people	Nature based recreation

Source: *cices.eu*

The economic valuation of some ecosystem services is relatively straightforward. For instance, services such as the production of timber, or crops have market prices that reflect their value. However, for many other services, such as cultural and regulating and maintenance services, there is no market structure to indicate their monetary value. These public goods are non-excludable and non-rivalrous, meaning that there is no market to reflect their demand and therefore their value (e.g., UN, 2021). A detailed description of available valuation methods is provided by NCAVES and MAIA (2022).

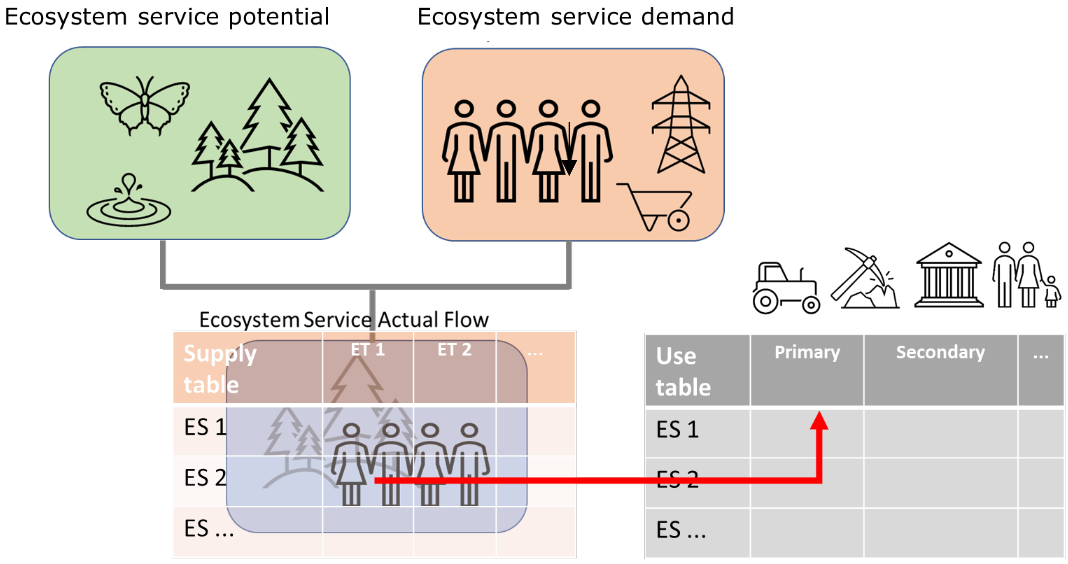
As already mentioned, to calculate GEP, it is necessary to have data on the monetary value of specific ecosystem services. For the European Union member states, such data is accessible through the Integrated Natural Capital Accounting (INCA) project in the INCA database (e.g., La Notte et al., 2022). . The INCA project is a collaborative endeavour involving Eurostat, the Joint Research Centre, DG Environment, DG Research and Innovation, and the European Environment Agency. Since its commencement in 2015, the project has progressed through three implementation phases, and is currently in its third phase as of 2021. Over this period, the primary aim of INCA has been to develop pilot applications for accounts at the EU level, focusing on ecosystem extent, condition, and services in line with the SEEA framework.

The INCA database offers a range of accounting modules, such as ecosystem service extent, potential supply, demand, and actual flow or use. The actual flow or use is presented in both physical and monetary terms. With the economic value of ecosystem services available from the INCA database, it is possible to calculate the GEP indicators. The approach to ecosystem services accounting in INCA considers the extent and condition of ecosystems. Ecosystem extent accounts offer insights into the characteristics, distribution, proportion, and land use changes of various ecosystem types at the national level (or more spatial granularity). The spatial data on ecosystem type distribution, compiled in extent accounts, provides critical input for calculating other ecosystem accounts, such as those related to ecosystem condition or ecosystem service flows. INCA's ecosystem extent accounts are based on Corine Land Cover (CLC) data, which aids in identifying different ecosystem types. The project has created ecosystem extent accounts at three levels of increasing detail (referred to as tiers), which are interconnected. Tier I ecosystem types are subdivided into Tier II categories, which are further divided into Tier III sub-categories. Tier I, relevant for this report, provides the most general ecological detail and distinguishes nine broad ecosystem types, for example, cropland, grassland, woodland and forests.

The INCA approach offers a practical method for evaluating and assigning value to ecosystem services. The assessment begins by examining the potential of ecosystem services, which quantifies what ecosystems can provide regardless of actual use. This is followed by an assessment of the socio-economic aspect of ecosystem services, encompassing the demand from economic sectors, households, and global society (relevant for overarching environmental targets like climate change and biodiversity loss). When the potential of an ecosystem service matches its demand, it leads to its use. However, if there is a mismatch, it indicates either a shortage of ecosystem services or their overuse, the latter occurring when regeneration or absorption rates are exceeded.

The main components of the accounting process are illustrated in Figure 3 below.

Figure 3. Elements of ecosystems services accounting



Source: https://publications.jrc.ec.europa.eu/repository/handle/JRC126566

Once the supply and demand for ecosystem services are mapped and aggregated across a specific area (e.g., region or country), the actual flow or use is then calculated as that part of the Ecosystem Service Demand covered by the Ecosystem Service Potential The actual flow is therefore computed as the interaction between the Ecosystem Service Potential and the Ecosystem Service Demand and eventually reported in the supply and use tables. Specifically, the supply table reports the flow of each ecosystem service provided by each ecosystem type within the accounting area for a given accounting period. Meanwhile, the use tables reports the same flow by economic units, which can be economic sectors and/or households. INCA offers supply and use tables (SUTs) for nine ecosystem services measured in physical and monetary terms (in euros) for four accounting periods (i.e. 2000, 2006, 2012 and 2018). These services encompass:

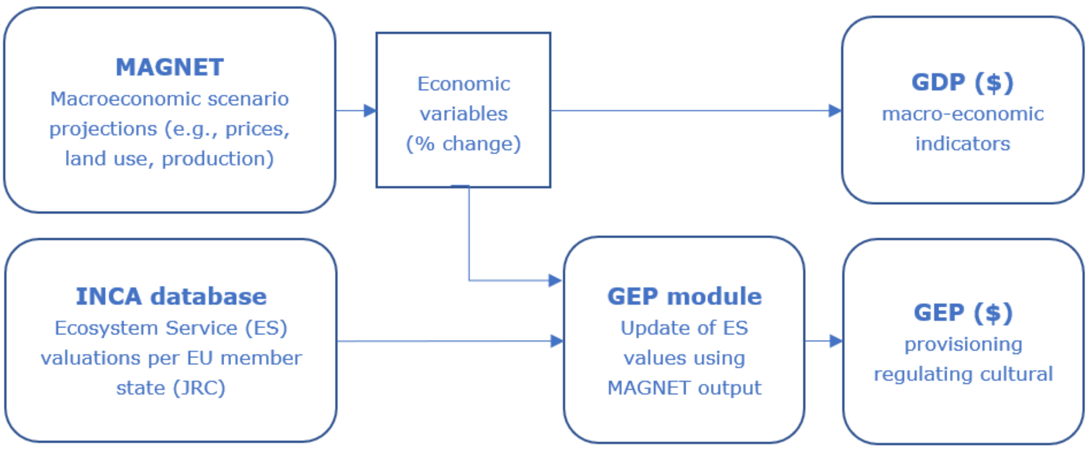
- Crop provision
- Timber provision
- Crop pollination
- Carbon sequestration
- Flood control
- Soil retention
- Water purification
- Nature-based recreation
- Habitat and species maintenance

2.4 Linking INCA data to MAGNET variables

The new GEP module utilizes the INCA dataset to establish the initial quantities and prices of ecosystem services (Vysna et al., 2021). Within the GEP module, GEP indicators are integrated and revised with economic change variables (such as land use and production) in MAGNET through a process called post-processing of the quantitative forward-looking scenario results of the model. Currently, the GEP module encompasses only a subset of ecosystems and their associated services. Three ecosystem types—cropland (€61,441 million), grassland (€29,071 million), and woodland/forests (€81,414 million)—were selected due to their strong connection to economic sectors and land use variables accessible in MAGNET. This approach enabled the inclusion of over 90 percent of the monetary value of all ecosystem services available in the INCA database, as shown in Table 2.

The GEP module updates the input variables for GEP computation by associating them with changes in related MAGNET economic variables. For instance, the estimation of water purification ecosystem services value is contingent upon the volume of fertilizers introduced into the environment when applied to cropland. In the context of cropland water purification, we commence with the initial INCA value for that ecosystem service (refer to Table 2) and adjust this value based on the percentage changes in fertilizer inputs within the crop production sector. A beneficial aspect of the MAGNET model in relation to GEP, beyond its global scope, is its ability to internally compute land use changes, given that various aspects of the GEP module rely on those outcomes. For instance, the flood control ecosystem service currently hinges solely on alterations in land demand, wherein, for example, a specific expansion of forest area directly updates the value of the flood control ecosystem service as a percentage change.

Figure 4. Model setup GEP module in MAGNET



Source: own preparation

Table 2. Aggregated supply of the ecosystem services provided by the INCA database (2012, million EUR).

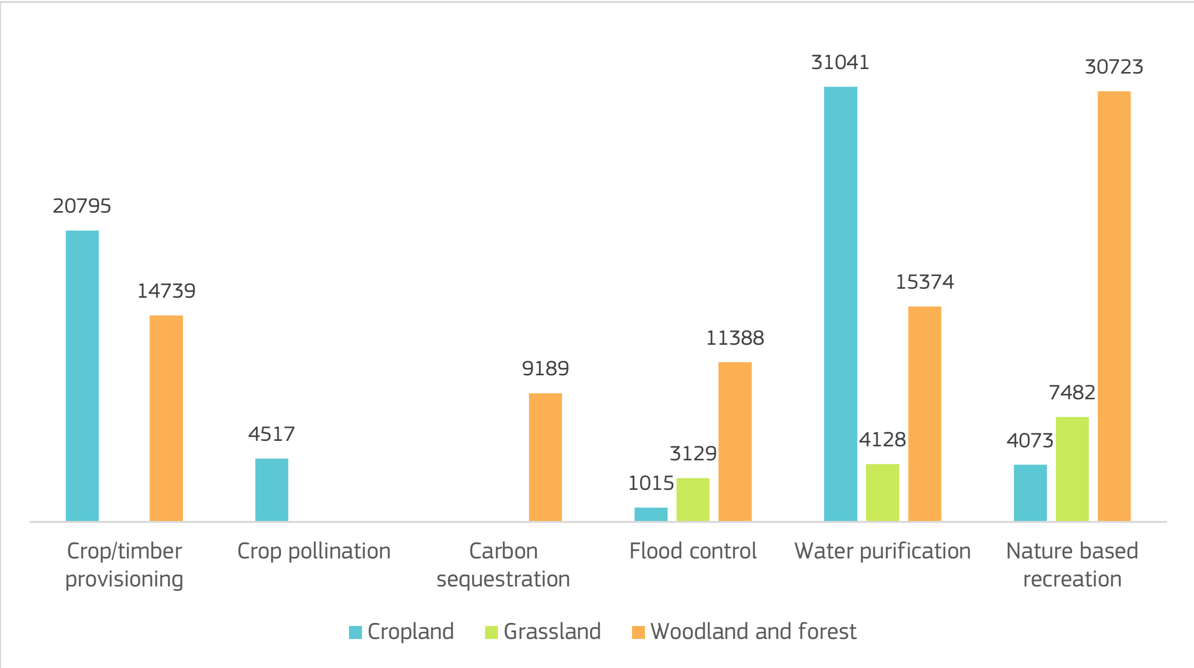
	Cropland	Grassland	Woodland and forest	Wetland	Heartland and shrub	Sparsely vegetated land	Rivers and lakes	Marine inlets and transitional waters	Urban
Crop provisioning	20 795	0	0	0	0	0	0	0	0
Timber provisioning	0	0	14 739	0	0	0	0	0	0
Crop pollination	4 517	-	-	0	-	0	0	0	-
Carbon sequestration	0	0	9 189	0	0	0	-	-	0
Flood control	1 015	3 129	11 388	333	357	1	-	-	89
Water purification	31 041	4 128	15 374	330	312	170	3114	-	1105
Nature based recreation	4 073	7 482	30 723	2296	3097	1351	1015	279	77

Source: own preparation based on the INCA database (https://ecosystem-accounts.jrc.ec.europa.eu/).

As mentioned earlier, we have opted to incorporate three ecosystem types: cropland, grassland, and woodland and forests, based on their strong connection to the land types available in MAGNET. In MAGNET, the crop sectors utilize cropland, livestock sectors utilize grassland, and the forestry sector utilizes woodland and forests. Therefore, the initial association between ecosystem services and MAGNET variables is the utilization of land within the respective crop, livestock, and forestry sectors. However, this is just the beginning.

Each of these diverse ecosystems yields a variety of ecosystem services. Figure 5 presents an outline of the ecosystem services associated with each ecosystem in the EU for the three selected ecosystems.

Figure 5. Value of Ecosystem Services per ecosystem type in 2012 (in millions of euros)



Source: adapted from Vysna et al (2021)

The various ecosystem services need to be associated with different MAGNET variables, and this association can be either positive or negative. Utilizing the provisioning services of crop and forests may have a detrimental impact on most of the other ecosystem services. A straightforward way to link MAGNET and the INCA database is to update the provisioning service with the percentage change of output in the sector. However, this assumes that the human input to provisioning services remains constant.

A more comprehensive linkage between MAGNET and the INCA database could be achieved by connecting the MAGNET variables to the equation that determines the ecosystem contribution. In the INCA dataset, the timber provision service is defined as the ecological contribution to the production of timber that can be harvested and used as a raw material. In terms of the ecological process, we need to refer to natural growth of a biotic resource; this in turn implies that the service flow for accounting purposes is the net annual increment (NAI) of standing timber in forests that is available for wood supply with no human input disentangled from the NAI (see La Notte et al., 2021). This is approximated simply by:

$$EcoCon_{timber}(NAI) = timber\ provision * unit\ roundwood\ value$$

Equation 5. Ecosystem contribution for forestry

However, at the same time, ecosystem contribution for crop provisioning can be approximated using the following equation:

$$EcoCon_{crops} = 1 - \frac{energy + fertilizers\,\&\,pesticides + services + transport}{ValueOutput}$$

Equation 6. Ecosystem contribution for crop provisioning

By establishing connections between various human inputs and the intermediate demand for MAGNET commodities within particular sectors, we can update the ecosystem contribution and simulate the value of provisioning in future periods, without making assumptions about a constant human contribution. Table 3 outlines the connections between particular human inputs required for forestry and crop sectors and MAGNET commodities.

Table 3. Links between INCA cost items and MAGNET commodities

Provisioning sector	Human inputs	MAGNET commodity (GTAP codes)
Forestry	Planting material	nuts, ocr
	Machines	Ome, p_c
	Chemicals	chm
Crops	Energy	p_c, ely
	Fertilizers and pesticides	fert_n, fert_p, fert_k, chem
	Services	ofi, ins, obs
	Transport	atp, otp, wtp

Source: own preparation.

To maintain alignment with the INCA data, we cannot directly use the absolute production and intermediate cost values from MAGNET to compute the revised ecosystem contribution. Hence, we initially compute the economic production value and costs based on the INCA data. For crop sectors, we distribute the total value across individual crop sectors in MAGNET (e.g., paddy rice, wheat, grains, vegetables, fruits, nuts, roots, pulses, oilseeds, sugar beets, other agriculture, other crops) using an intermediate demand share. Similarly, the intermediate costs are calculated by multiplying the total value of the ecosystem provisioning service by (1- ecosystem contribution)/ecosystem contribution.

Subsequently, the computed intermediate costs and economic production value are adjusted based on quantity changes calculated by MAGNET. The production value is updated using changes in output by activity, while the cost value is updated using changes in intermediate demand. An aggregated change variable, is then computed as the weighted change in intermediate demand of economic cost variables considered in the INCA dataset.

3 A showcase example of GEP module in MAGNET

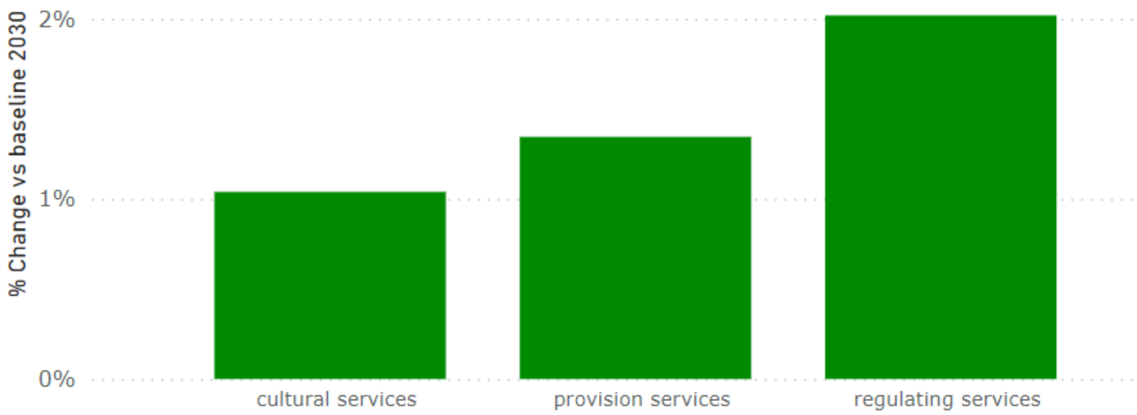
3.1. Empirical analysis

The following demonstrates an application of the GEP module in macroeconomic simulations, aiming to showcase the new module and demonstrate its potential usefulness in decision-making. It is important to note that the presented data is preliminary and only offers insights into the interpretation of GEP results. Therefore, no policy conclusions can be drawn from this illustration.

The module is still in development and has several limitations, such as data completeness. The scenario discussed here is the plant protein scenario, where global consumption gradually shifts towards plant protein in steps of 10 years (2030, 2040, and 2050). This scenario is simplified and focuses only on one aspect of the multifaceted relationship between the economy and land use. In particular, an increased demand for plant proteins leads to an increase demand for cropland. The scenario assumes a gradual change in consumer preferences over several decades and reflects a macroeconomic shift that could result from policy intervention. The scenario analysis is compared against the unchanged policy scenario, which follows a path where social, economic, and technological trends do not significantly deviate from historical patterns.

According to the simulation results, the altered consumption pattern has a very slight (yet positive) impact on **GDP (+0.01%)** in the EU in 2030 compared to the reference scenario. In contrast, the **GEP index increases by 1.5%, or 2.3 billion euros** compared to the reference scenario, with the components of GEP increasing by 1 to 2 percent depending on the type of ecosystem service: cultural services, provisioning services, and regulating services, as shown in Figure 6 below.

Figure 6. Policy scenario result EU 2030, GEP % change vs. baseline



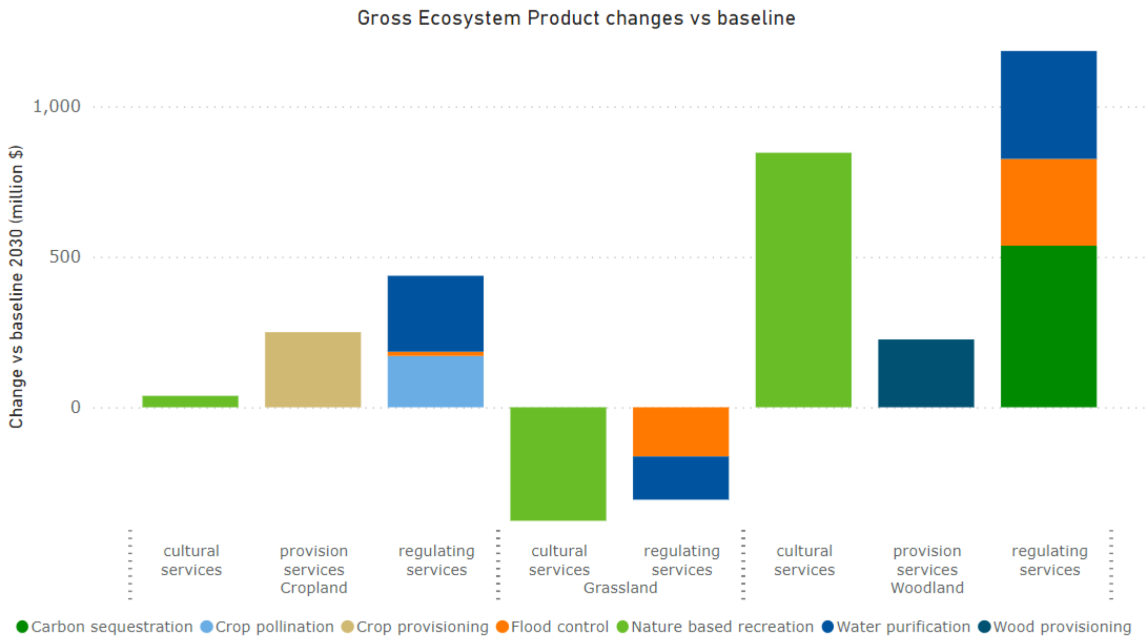
Source: own preparation

In the European Union, this scenario leads to a slight decrease in grassland area (-36 kha, -5%) and associated services, but an increase in forest area (1.3 kha, 3%) by 2030. Additionally, there is an increase in cropland production (17.5 kha, 4%). As a result, ecosystem services related to cropland and forest generally increase, including nature-based recreation, crop provisioning, water purification, crop pollination, flood control, wood provisioning, and carbon sequestration. Conversely, ecosystem services related to grassland, such as nature-based recreation, water purification, and flood control, decrease. It is important to note that the currently available INCA data used in this illustration does not include provisioning services (e.g., fodder provisioning) related to grassland. In terms of ecosystem service trade-offs, the decrease in grassland negatively affects nature-based recreation, which is offset by the increase in forest ecosystem services, resulting in a net increase in nature-based recreation due to this policy scenario.

Please note that water purification, being a sink service, needs careful interpretation. The actual flow, in fact measure the nitrogen input that is absorbed by ecosystems. However the pollution removal that takes place in freshwater ecosystems may be higher than what could be sustainably absorbed (La Notte et al., 2017). Therefore, for all sink services in general and for water purification in particular, it may be useful not only to assess the actual flow but also the sustainable flow.

Moreover, as a result of this policy scenario, carbon sequestration increases due to the expanded forest area. Other ecosystem services also contribute to carbon sequestration, particularly wetlands, which can act as carbon sinks. In this scenario, the net increase in carbon sequestration resulting from changing consumption patterns is attributed solely to forests, as the INCA data, following land use, land-use change, and forestry (LULUCF) reporting guidelines in the EU, considers only forests as net sinks of atmospheric carbon, as shown in Figure 7 below.

Figure 7. Policy scenario result EU 2030, GEP absolute change in million Euro versus baseline



Source: own preparation

3.2. Discussion

Note, that the above simulation results are based on the preliminary version of the GEP module applied on the former GTAP 10 database. Further development of the module is ongoing. On the one hand it will allow to apply the GTAP 11 database together with the latest INCA data. On the other hand, it will lead to an improvement of the ESS modelling. In particular, it is planned to thoroughly specify both supply and demand functions for each ecosystem service. This in turn should lead to more precise estimates of GEP and its comparison to other macroeconomic indicators such as GDP.

The GEP indicator and its components offer valuable insights by quantifying the contribution of ecosystem services to the economy and emphasizing their importance. This allows for the assessment of ecosystem services performance and their reflection in statistics, thus providing information for the ex-ante evaluation of policy scenarios. The application of the GEP is not restricted to environmental oriented policies, instead it is meant to ensure that policy impacts associated with nature are considered in any policy option. Additionally, it can demonstrate that policies to care for natural capital are in a country's economic self-interest (UN, 2021a). While GEP provides valuable insights into sustainability issues through the impact on and trade-offs between ecosystems flows, additional measures are required to track natural capital stocks. Here, GDP and GEP are similar in that they are not characterized as wealth measures but as measures of "income" (Polasky et al., 2023). For assessing sustainable development, it makes sense to have a specific measure of "wealth," one that fits within a broad perspective on welfare. Monitoring the extent and condition of ecosystems as an indication of sustainable development requires parallel and separate measures (UN, 2021a).

The implementation of GEP in policy, particularly in forward-looking policy analysis, is still in the early stages. Although the concept has potential and possible applications in policy, recent research has identified two main challenges to making GEP an established complementary measure to GDP (Hao et al., 2022). Firstly, there is a need to improve the accuracy of GEP accounting, as no ecosystem services valuation technique is perfect, and uncertainty is always a critical issue. There are several areas for improvement to achieve better valuation measures globally (Brander et al., 2023, Hao et al., 2022). The optimal valuation method for different ecosystem services requires a unique approach for each service, presenting a challenge when aggregating different ecosystem services. Secondly, consideration should be given to how GEP results can be applied in policy decision-making (Hao et al., 2022). In addressing this challenge, this study takes a step by connecting GEP with macroeconomic models and policy scenario analyses.

We acknowledge that there are certain discrepancies and simplifications in how anticipated ecosystem service flows are computed in the present GEP module relative to real-world scenarios. For instance, the calculation of crop pollination ecosystem services is initially established solely based on the increase in crop production output (i.e., the demand side), as there are currently no additional explanatory variables in the MAGNET model that would impact the supply of the pollination service. Another area for potential future enhancement is the calculation of carbon sequestration, which presently utilizes a fixed price of 30 euros per ton of CO2, but could potentially be linked to exogenous or endogenous CO2 prices in a MAGNET model simulation.

4 Conclusions

The present report explains and showcases how the Gross Ecosystem Product (GEP) indicator and its components offer valuable insights by quantifying the contribution of ecosystem services to the economy and emphasizing their importance. In order to achieve comprehensive decision-making, it is essential to go beyond the standard indicators and utilize GEP insights to assist policymakers in designing optimal policies. The GEP module outlined here facilitates the analysis of potential impacts of various policies on both GDP and GEP, providing analysts with the opportunity to incorporate natural capital into broader economic strategies in a consistent manner and therefore offering to the policymaking process a more comprehensive picture. The GEP's structure and alignment with SEEA EA ensure that the accounts are directly relevant to these macroeconomic decision contexts (UN, 2021a).

Macroeconomic models, such as input-output models and general equilibrium models, form the foundation of government economic analyses (UN, 2021a). Alongside other capital forms, such as produced and human capital, the GEP index can be integrated as an additional dimension in existing macroeconomic models. This approach allows natural capital to be included in ongoing analyses and integrated into all economic decision-making, similar to other capital forms.

The application of the GEP module in the forward-looking approach in the MAGNET model differs from other GEP applications, which often involve more isolated and retrospective policy evaluations, rather than future assessments of the effects of various policies on the contribution of ecosystem services (see Ouyang et al., 2020 and de Jongh et al., 2021). For instance, the Chinese government uses the GEP to assess policy effectiveness, evaluate policy implementation, and as a reference for Ecological Fiscal Transfers (EFT) and Payments for Ecosystem Services (PES) (Hao et al., 2022), with a focus on promoting and evaluating environmental policies.

One policy application of the GEP module involves modelling policy scenarios with a medium to long-term time horizon. This can support policymakers in selecting the best policy option through ex-ante policy evaluation, considering the GEP indicator alongside other macroeconomic indicators. By integrating GEP into a macroeconomic model, the GEP module also provides insights into indirect effects and spillovers. Utilizing a multi-country model such as MAGNET enables a better understanding of international trade-offs and the systemic impact of policies across national borders. This approach can demonstrate the influence of different trade-induced shocks on GEP, such as reduced meat consumption in Europe leading to lower meat imports, less deforestation, and consequently a higher GEP value in Brazil (however, in combination with a slight reduction of GDP).

Moreover, the GEP module offers insights into trade-offs and synergies among ecosystem services. Economic development that benefits from ecosystem services often involves trade-offs, and it is essential for sustainable development to balance this in a way that preserves natural capital for future generations. The GEP module aids in evaluating co-benefits and minimizing conflicts between various ecosystem service flows, as well as their relationship with GDP and other indicators (Le et al., 2023).

Accurate measurements play a crucial role in incorporating nature into policy decision-making. The application of GEP to assess the value of ecosystem services in the decision-making process has the potential to enhance the quality of new policies and stewardship, leading to improved management of natural capital and the continued provision of essential goods and services. While this innovative metric has gained global attention, there is ongoing development and adoption of SEEA EA-consistent ecosystem accounting on a broader scale, encompassing multiple ecosystems. However, real-world policy implementations of GEP as a metric alongside GDP, are still pending due to various reasons, including technical limitations related to data availability and the complexity of ecosystem service valuation in the context of aggregation.

There is potential for further development of the GEP module in the context of policy decision-making. When enhancing the GEP module and integrating it into the decision-making process, it is important to consider the spatial distributional effects of GEP. For example, in the application of GEP in China, it is observed that a region within China, acting as a net exporter of ecosystem services, contributes to the provision of these services without fully benefiting from them (Ouyang et al., 2020). These regional disparities should be taken into consideration when evaluating policy decisions. Also, implementing the concept of Total Resource Productivity (Fuglie et al., 2016) in MAGNET by adjusting Total Factor Productivity for ecosystem services could be an interesting further extension in the future.

We recommend that the development of the GEP module should be an ongoing process with both, short-term and long-term improvement objectives. The former refers to improved specification of the ecosystem services supply functions as well as the application of the latest available data. The latter could lead to an improvement in calculation consistency or an extension of the list of ecosystem services that are included in the GEP indicator. Potential improvements may also involve the establishment of principles for screening indicators. Enriching GEP accounting with perspectives on the link between biological and human production, or considering harm to the ecosystem carrying capacity, may be other valuable enhancements (Zhang et al., 2022).

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List of abbreviations and definitions

Abbreviations	Definitions
CGE	Computable General Equilibrium
CLC	Corine Land Cover
EU	European Union
GDP	Gross Domestic Product
GEP	Gross Ecosystem Product
GTAP	Global Trade Analysis Project
INCA	Integrated Natural Capital Accounting
LULUCF	Land Use, Land-Use Change and Forestry
MAGNET	Modular Applied General Equilibrium Tool
SEEA	System of Environmental Economic Accounting
UN	United Nations

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