Land Use Policy 92 (2020) 104431

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Bioeconomic modelling – An application of environmentally adjusted economic accounts and the computable general equilibrium model

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ARTICLE INFO

Keywords:
Natural resources
Land use management
Computable general equilibrium model
CGE
SEEA
System of environmental economic accounting
Supply and use tables
System of national accounts

ABSTRACT

Building on the current international discourse and United Nation's System of Environmental-Economic Accounting (SEEA) this study provides further empirical evidences on how failure to include natural capital resources in national accounting leads to erroneous calculation of macroeconomic estimates. The SEEA methodological framework for integrating natural capital into the System of National Accounts amplifies analytical power of computable general equilibrium (CGE) models and allows to investigate relationship between the economy and the environment. This paper integrates values of natural capital into Supply and Use Tables (SUTs) to illustrate depletion of forest due to natural disaster. It further applies CGE model to demonstrate economy-wide effects of a real event in which hurricane felled almost 80 thousands hectares of trees in Polish forests in 2017. The model results corresponds with the statistical data published after the mentioned event. Furthermore they align with findings of previous studies, which applied different methodical approach and show that without natural capital accounting the macroeconomic estimates provide misleading information about economic performance.

1. Introduction

Nature in highly developed countries has become almost entirely anthropogenic which, in the long run, has led to the change in priorities in order to ensure the renewability of natural resources and follows pro-social/pro-environmental criteria for allocating production factors (Czyżewski and Matuszczak, 2016). Europe is changing its course towards a resource-efficient and sustainable economy. The European Bioeconomy Strategy aims at creating an innovative and low-carbon economy, which reconciles "demands for sustainable agriculture and fisheries, food security, and the sustainable use of renewable biological resources for industrial purposes while ensuring biodiversity and environmental protection" (European Commission, 2018). Many economies rely on natural capital as a significant influencer of their gross domestic product (GDP). An abundance of natural resources has positive effects on economic growth in economies which are able to develop a relatively large manufacturing sector, which enables them to avoid the effects of the Dutch disease (Gerelmaa and Kotani, 2016). GDP is calculated according to the methodology of the System of National Accounts (SNA) (United Nations et al., 2008). SNA determinates the GDP by measuring the production of all resident producers from the monetary markets' perspective. GDP, based on the Keynesian macroeconomic model, relates only to the phenomena in the economic system but ignores social or environmental systems. The comparability of a nation's wealth would be reoriented if, for example, carbon emissions, pollution, consumption and the state of natural resources or ecosystem services were considered in addition to economic performance. At present "a country could exhaust its mineral resources, cut down its forests, erode its soils, pollute its aquifers, and hunt its wildlife and fisheries to extinction, but measured income would not be affected as these assets disappeared" (Repetto et al., 1989, p. 2). If the stocks of natural capital are excessively depleted, nature may not be able to replenish them. Poor and unsustainable management of natural capital stock may cause degradation or even collapse of ecosystems at the local, national or global level (KPMG and Flora International, 2014). As a consequence, economies that depend on natural capital products face increased costs or are even unable to function. A need for extending or adjusting traditional GDP calculation model to include the environmental impact on economic growth has been fairly well described in the literature (Alfsen and Greaker, 2007; Boyd, 2007; Garcia and You, 2017; Nahman et al., 2016; Talberth and Bohara, 2006; Yu et al., 2019), however, there is an insufficient number of empirical studies that can be used for policy analysis. This study harnesses a theory from the literature and previous studies to provide a practical example of natural capital integration into the SNA (specifically into Supply and Use Tables - SUTs) for policy analysis in Poland.

The economic concept of natural capital is not isolated from other sciences but, on the contrary, there is a significant conceptual trade

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https://doi.org/10.1016/j.landusepol.2019.104431
Received 11 March 2019; Received in revised form 14 August 2019; Accepted 13 December 2019

between economics and the biophysical sciences (Desroches, 2015). Natural capital in economics has been, and always will be, a product of interaction between those two sciences. To include natural capital stock and flows in the SNA, the UN System of Environmental-Economic Accounting Central Framework (SEEA-CF) has been created. This system contains internationally accepted standards, definitions, classification and rules for developing internationally comparable environmental and economic statistics (United Nations, 2012). It outlines the integration of natural capital to link environmental resources and all sectors of the economy in one comprehensive framework.

The purpose of this paper is to: (i) apply the methodological framework for integrating natural capital from the SEEA-CF structure into the SUTs for Poland, (ii) demonstrate how natural capital data from the SEEA-CF can be used for policy analysis in a computable general equilibrium (CGE) model, (iii) illustrate the difference in economic impacts of policy shocks resulting from the integration of natural capital into the SNA, and (iv) compare the results with the previous study by Ochuodho and Alavalapati (2016).

This paper is organised as follows: Section 2 presents the current international discourse and recent findings on extending economic analysis over the environmental aspects. Section 3 demonstrates how values of natural capital resources can be integrated into SUTs; Section 4 presents an example of how to use environmentally adjusted SUTs in a CGE framework to assess economic impacts of policy decisions in regard to natural resources. Section 4 also presents differences between simulations with and without natural capital integration in application to real life example for Poland, i.e. the hurricane in 2017 resulting in significant damage in state-owned forest. The last section summarizes the paper.

2. Literature review

The development of natural capital accounts described in the SEEA was conducted mainly by the official international statistical bodies (Obst, 2015). Within the first 20 years since the presentation of the first edition of SEEA in 1993, the scientific discourse devoted relatively little attention to issues related to natural capital accounting from a standpoint of national accounts (Obst, 2015). Before going into the methodological sections of this paper, it is important to present the current scientific discourse relating to the application of SEEA for CGE modelling. The main international papers that have undertaken this niche area are studies by Obst (2016), Banerjee, Cicowiez, Horridge, and Vargas (2016), and Ochuodho and Alavalapati (2016).

Obst (2016), in his paper, used the SEEA Experimental Ecosystem Accounts for integration ecosystem services with the input-output tables (IOTs) for the purposes of CGE modelling. The author developed a nomenclature of integration, such as 'Input Output Tables incorporating Ecosystem Services (IOTES)'. Tables are extended within the production boundaries of SNA and in accordance with the methodology of the SEEA. Ecosystem services are considered as additional production and ecosystem assets as additional sectors. Tables have been extended by extra rows and columns. Obst (2016) pointed out that due to the lack of comprehensive information and data on ecosystem services and the lack of a unified framework for the integration of ecosystem services with IOTs, there are few scientific papers which address this issue. Three interrelated concepts are the basis for the construction of IOTES: (i) ecosystem services as traditional production (output) of goods and services, (ii) additional production must be the source of this production, and (iii) the concept of ecosystem services is an exact analogy of the concept of capital services. The author draws attention to the key challenges related to the measurement criteria.

- Measurement of ecosystem service flows: A particular challenge in the context of accounting and IOTs is the need to clearly distinguish between: (i) final ecosystem services, (ii) intermediate ecosystem services, and (iii) the combination of final ecosystem services with labour or other components.
- Valuation of ecosystem services: In order to integrate ecosystem services with IOTs, it is essential to estimate flows in monetary units and include the various ecosystem services provided by different ecosystems.
- Accounting for degradation and disservice of ecosystems: The degradation of ecosystems creates challenges with the measurement and valuation of changes in ecosystems.

Banerjee et al. (2016) demonstrated a conceptual framework for the integration of natural capital into SNA for CGE modelling, the so-called "Integrated Economic-Environmental Modelling" (IEEM). According to the authors, this platform fulfils the gap in the literature and macroeconomic models, allowing for the complex analysis of the two-way relationship between the economy and environment. The concept of IEEM allows presenting and using environmental inputs to the economy, both in monetary and physical units. It also allows accounting for emissions that are returned to the environment. IEEM provides a platform to account for the changes in resource stocks based on extended social accounting matrix (SAM) tables. In a CGE model, environmental resources are considered as non-produced assets. Services which are provided by environmental resources are considered to be rent payments or a flow of economic resources. For example, standing wood is treated as a factor of production and is used for a given economic activity. The authors summarize that the integration of SEEA to frames of CGE modelling will expand analytic capabilities, allowing not only for simulating relations between branches of the economy, but also for accounting for changes in environmental stocks.

Ochuodho and Alavalapati (2016) integrated a stock of standing timber with national accounts by adjusting IOTs according to the SEEA: Central Framework. The authors increased the stumpage price by 10 % using their own CGE model (static, one region, 23 sectors, 3 factors of production — labour, capital and stumpage). Afterwards, they compared results of the simulations using a database with integrated standing timber resources and without them. The analysis of the results illustrated the difference between basic macroeconomic variables in the two cases. In a variant, without taking into account the standing timber resources, the effect of the shock is higher (positive) than when the resources were included. It indicates a strong notion that economic analyses that do not properly account for environmental aspects are biased and provide overestimated results. The magnitude of the bias may differ between the models and databases used for their calibration. One of the main motivations for this study is to test if those differences exist in case of Poland and what their magnitude is when different data are applied to the same CGE model for verification.

3. Integrating natural capital into The System of National Accounts (SNA)

3.1. The supply and use tables - structure and treatment of natural resources

As suggested by the methodology of SEEA-CF, natural capital values may be integrated into the SNAs both to IOTs and to supply and use tables (SUTs). SEEA provides a few approaches for accounting and integrating natural resources into SNA (United Nations, European Union, Food and Agriculture Organization of the United Nations, International Monetary Fund, Organisation for Economic Co-operation and Development, The World Bank, 2012). This study integrates an exemplary natural resource — standing wood in state-owned forests — into SUTs, based on the asset value accounts and combined accounts approach. SUTs are the main data source for constructing a database to the applied CGE model (details in Section 4). This section outlines the elements of SUTs and presents how stocks of standing timber are considered in current accounts.

SUTs are matrices representations of the "relationship between components of value added, industry inputs and outputs, and product

Table 1
General structure of Supply Table.
Source: (United Nations, 2017).

Products \ Industries	Industries: Agriculture, etc.	Industries: Mining and quarrying; etc.	Industries: …	Industries: Services	Imports	Total
Agriculture etc. Ores and minerals; etc. … Services	Output by product by industry				Imports by product	Total supply by product
Total	Total output by industry				Total imports	Total supply

supply and demand" (Office for National Statistics, 2019). The SUTs describe the whole economy by industries (e.g., construction industry) and products (e.g., cars). The SUTs provide a comprehensive framework for estimating the GDP for both the production and expenditure sides. SUTs are based on a principle that the number of products available for use in a given economy must have been supplied either by domestic production or by imports. All supply must be used in the same accounting period, for either or both intermediate consumption and final use, which covers: (i) final consumption by household, non-profit institutions serving households, and general government; (ii) gross capital formation; and (iii) and exports (Asian Development Bank, 2012).

SUTs consist of two interlinked tables: the Supply Table and the Use Table — see Tables 1 and 2. The Supply Table (Table 1) illustrates the supply of goods and services by type of products and by type of industry. The supply distinguishes between the domestic industries and imports of goods and services. Real aggregated values for the forestry sector in Poland are presented in a later part of this section. The mere structure of the adjusted SUTs created in this paper is the same as presented below, but the values differ — it is explained and presented in Section 3.2.

The Use Table (Table 2) illustrates the use of different goods and services by type of product and by type of use (i.e., intermediate consumption, final consumption, gross capital formation, exports; Eurostat, 2018). The Use Table (Table 2) also illustrates the components of gross value added by industry (i.e., pay to employees, other taxes less subsidies on production, consumption of fixed capital and net operating

Table 2
General structure of Use Table.
Source: (United Nations, 2017).

Products \ Industries	Industries: Agriculture etc.	Industries: Mining and quarrying; etc.	Industries: …	Industries: Services	Final use: Final consumption	Final use: Gross capital formation	Final use: Exports	Total
Agriculture etc. Ores and minerals; etc. … Services	Intermediate consumption by product and by industry				Final use by product and by category			Total use by product
Value added	Value added by component and by industry							Value added = Gross Domestic Product
Total	Total output by industry				Total final use by category			

■ Empty cells by definition

surplus; Eurostat, 2018). The 'Total' column represents total uses by products and the 'Total' row stands for the total output by economic activity, total final consumption, total gross fixed capital formation and total exports.

Supply and Use tables (SUTs) as well as input-output tables (IOTs) constitute the primary database for CGE models and can also be used for the creation of Social Accounting Matrices. Both types of tables are equally good for CGE analysis — both have their strengths and weaknesses — and the choice between them depends only on a structure of a given model. There is also the matter of availability due to the fact that SUTS are published more regularly than IOTs. The main differences between SUTs and IOTs are the following aspects. First, the total uses presented in IOTs are different from those in SUTs due to the valuation of intermediate and final uses at basic prices — not the purchasers' prices. The difference results from the necessity to use the same valuation mode between supplies and uses (CIRCABC, 2012; Czyżewski and Grzelak, 2012; The French National Institute of Statistics and Economic Studies (INSEE), 2016; United Nations et al., 2008). In order to balance supplies and uses, the supply table has an additional column with trade and transport margins and taxes less subsidies on products, which constitute the difference between the supply at the purchasers' prices and output and imports at basic prices. Second, regarding the intermediate and final use, in IOTs there is a distinction between the part of the product supplied by domestic production and the part that is imported (CIRCABC, 2012; Czyżewski and Grzelak, 2012; The French National Institute of Statistics and Economic Studies (INSEE), 2016; United Nations et al., 2008). Third, the most important difference is a production matrix that details production of each branch by product, which replaces the production column of SUTs (CIRCABC, 2012; Czyżewski and Grzelak, 2012; The French National Institute of Statistics and Economic Studies (INSEE), 2016; United Nations et al., 2008). Both tables have pros and cons; however, both are compiled to measure and represent the economic activity of a nation in the form of comprehensive national accounts following the logic of Wassily Leontief, who received the Nobel prize in economics in 1973 for his work.

The Polish Statistical Office prepares national accounts in accordance with European System of National and Regional Accounts "ESA 2010" (Eurostat, 2013; Statistics Poland (Główny Urząd Statystyczny), 2014a, p. 5). ESA 2010 is consistent with guidelines on national accounting set out in the System of National Accounts 2008 (SNA 2008; United Nations et al., 2008). According to the SNA 2008, wild forests do not count as production, however "deliberate felling of trees in wild forests, and the gathering of wild fruit or berries, and also firewood, counts as production" (United Nations et al., 2008, p. 7). Most Polish forests are public forests (approximately 80 %). A vast majority are managed by the State Forests Holding management (Państwowe Gospodarstwo Leśne Lasy Państwowe), but they are treated as wild growing forests and their stocks of standing timber are not included within the boundaries of the SNA. In other words, in the case of the Polish forestry sector, national accounts do not account for the accumulation or decline in asset values of standing timber, both in public and private wild forests. However, asset values of cultivated forests (e.g., plantations) are recorded as increases or consumption of fixed capital — similar to the annual growth of crops (United Nations et al., 2008, p. 112).

The forestry sector, similar to agriculture, supplies products for intermediate consumption as well as for final demand. The intermediate consumption of forestry products exceeds final demand almost 3.5 times (Table 3). The biggest users of forestry products in Poland in 2010 are the following industries: (i) the manufacture of products of wood, cork, straw and wicker (3 754.58 M pln); (ii) forestry and logging (2 488.19 M pln); and (iii) the manufacture of paper and paper products (982.25 M pln).

The forestry sector uses a wide range of products from its own production and the production of other sectors (Table 4). The most used products include: (i) forestry products (2488.19 M pln); (ii) coke, refined petroleum products (207.63 M pln); (iii) construction and construction works (196.38 M pln); and (iv) wood and products of wood (174.23 M PLN). The value added of the forestry sector disaggregates as follows: (i) compensation of employees (2580.91 M pln), (ii) other net taxes on production (210.74 M pln), (iii) consumption of fixed capital (447.86 M pln), and (iv) net operating surplus (854.80 M pln).

At this point it is important to mention that the methodology, presented in the following subsection, for integrating natural capital monetary values into the SUTs do not affect the general structure of the SUTs. Adjustments apply only to specific values in SUTs according to the methodology of SEEA, which is discussed in the next section.

Table 3
Supply and use of forestry products in Poland in 2010 (current prices in M PLN). Source: Author's elaboration based on Polish Supply And Use Tables in 2010 (Statistics Poland (Główny Urząd Statystyczny), 2014b).

			2010 (M PLN)
Supply		Output of forestry	8 114.08
		Import	486.04
		Trade and transport margins	2 527.59
		Taxes less subsidies on products	244.96
		Forestry Products at purchasers' prices	**11 372.67**
Use	Intermediate consumption	Agriculture and hunting	58.89
		Forestry	2 488.19
		Wood	3 754.58
		Paper	982.25
		Furniture	289.94
		Construction	200.33
		Other sectors	1 049.78
		Total intermediate consumption	**8 823.97**
	Final demand	Final consumption	1 928.80
		Export	622.36
		Changes in inventories and changes in valuables	-46.75
		Gross fixed capital formation	44.30
		Total final demand at purchasers' prices	**2 548.71**

Table 4
Intermediate consumption by forestry sector in Poland in 2010 (basic prices in M PLN).
Source: Author's elaboration based on Polish Supply And Use Tables in 2010 (Statistics Poland (Główny Urząd Statystyczny), 2014b).

Forestry products	2488.19
Coke, refined petroleum products	207.63
Construction and construction works	196.38
Wood and products of wood	174.23
Land and pipeline transport services	166.04
Motor vehicles	138.93
Food products	103.73
Chemicals and chemical products	101.86
Fabricated metal products	71.11
Financial services	70.04
Products of agriculture and hunting	68.93
Other	1009.62
Total intermediate consum./final demand	**4796.70**
Compensation of employees	2580.91
Other net taxes on production	210.74
Consumption of fixed capital	447.86
Operating surplus, net	854.80
Operating surplus, gross	1302.66
Value added at basic prices	**4094.30**
Output at basic prices	**8891.00**

3.2. Methodology for integrating natural capital monetary values into the supply and use tables

The SEEA-CF is constructed as a set of tables and accounts that provide information about stocks and flows within the economy and environment. It includes SUTs in physical and monetary units illustrating flows of natural inputs, products, residuals and "a series of economic accounts highlighting depletion-adjusted economic aggregates" (Ochuodho and Alavalapati, 2016, p. 3). The integration of natural capital into the SNA involves augmenting national accounting tables with the monetary value of natural capital according to the SEEA framework (United Nations et al., 2017, 2012). The study by Ochuodho and Alavalapati (2016) accounted for forest depletion in the forest sector of British Columbia (Canada) using the 2006 Input-Output table as a baseline dataset. This study tested its methodological assumptions with different datasets and different CGE model. The main dataset is the national 2010 SUTs for Poland. For the purpose of comparability, the reason behind the main assumption is similar to the previous study and accounts for forest depletion in the forestry sector. It is grounded on the supposition that natural resources are being overexploited or were subject to some catastrophic losses (i.e., there are more removals than replenishments); this should be reflected in the national accounts as it may impact the wellbeing of future generations (Dieren, 1995). In this study, depletion reflects the total accumulation of standing timber stock — plus or minus changes due to economic activities (Gundimeda, 2014; Ochuodho and Alavalapati, 2016). The total value of standing trees in Poland (both private and public) at the end of 2008 was estimated to be 160 bln PLN (Gołos, 2013), whereas the total value of gross fixed capital formation of "products of forestry" in 2010 SUTs equals only 44.3 M PLN (Statistics Poland (Główny Urząd Statystyczny), 2014b). It can be seen that current national accounts do not provide full values of the sector that depend on natural capital.

The study follows the methodology of Ochuodho and Alavalapati (2016) and assumes that monetary valuation of the forestry sector has been done as in Table 5 presented below or in Table 3 by Gundimeda, Sukhdev, Sinha, & Sanyal (2007). This reflects net value changes of timber value that have been determined based on opening stock, revaluations, additions due to natural growth and reclassifications, reductions in stock due to economic activities, removals, felling residues, natural losses, catastrophic losses, reclassifications, and closing stock (United Nations et al., 2012). In the illustrative example of value asset account in Table 5 net value changes of timber would have been equal 1 M PLN as the difference between opening stock and closing stock are equal (minus) -1 M PLN (depletion due to catastrophic losses).

Compared to the values chosen by Gundimeda et al. (2007) and Ochuodho and Alavalapati (2016) based on value asset account from SEEA, this study considers net changes of timber value equal to 0.2 % (depletion) of total GDP, which is equal to approximately 10.09 M PLN. As Polish forests are not a subject of overexploitation, this value represent a depletion as a result of catastrophic losses (e.g., due to wildfire or hurricane). At first glance, this number may look enormous, but in relation to values of natural resources it is rather tiny. In 2017, a catastrophic hurricane damaged 79.7 thousands ha of Polish forests (Trębski, 2017). The volume of fallen and broken trees was estimated to reach 9.8 M m^3 (Trębski, 2017). The average price of wood in 2017 equalled 197.06 PLN/m^3 (Statistics Poland (Główny Urząd Statystyczny), 2017) which means that there was over 1 931 M PLN of unexpected timber supply.

Table 5
Basic form of a value asset account from SEEA.
Source: Author's elaboration based on System of Environmental-Economic Accounting 2012— Central Framework (United Nations et al., 2012, p. 19)

	Value account (M pln)
Opening stock of environmental assets	100
Additions to stock	
Growth in stock	12
Discoveries of new stock	0
Upward reappraisals	0
Reclassifications	1
Total additions of stock	*12*
Reductions of stock	
Extractions	10
Normal loss of stock	1
Catastrophic losses	2
Downward reappraisals	0
Reclassifications	0
Total reductions in stock	*13*
Revaluation of the stock[a]	0
Closing stock of environmental assets	99

a - Only applicable for asset accounts in monetary terms.

According to the methodology of the SEEA Central Framework (United Nations et al., 2012) and the framework applied by Ochuodho and Alavalapati (2016) to account for the depletion of timber value in the forestry sector, the following aggregates of SUTs have been adjusted: a) capital formation (investment) and b) capital consumption (value added) (United Nations, 2017b; United Nations et al., 2012). Adjustments made in the forestry sector accounts resulted in imbalances in the SUTs. In order to correct those imbalances, the GRAS (Generalized Rapid and Simple) method has been applied (also known as the matrix balancing/updating, biproportional method; Temurshoev et al., 2013).

It should be stressed out that the base-level GDP in SUTs is affected by those adjustments, that is, the GDP is larger by the amount of net changes of timber value (which is 0.2 % more compared to the original value of GDP). That is in line with this approach because the goal of this study was to use the environmentally adjusted SUTs as a database for the CGE model so the GDP is also environmentally adjusted in our case. Outputs of the model are presented in percentage change not absolute values (with some exceptions such as real price index) and in relation to the baseline.

4. Application of environmentally adjusted accounts into computable general equilibrium (CGE) model

Agreeing with Ochuodho and Alavalapati (2016, p. 4), the mere integration of natural capital values into SNA has limited value to natural resource based policy analysis because: "(i) it does not establish any relation and intersectoral linkages between natural capital and other industry sectors, and (ii) it does not illustrate economy-wide impacts resulting from potential natural capital policy shock or other disturbances". Therefore, a valuable extension of the analysis is the application of the integrated accounts into the CGE model, provided here for Poland.

4.1. CGE model specification and simulation

CGE models are economic models that combine data from national accounts with microeconomic theory through the system of mathematical equations and model calibration. What distinguishes them from input-output models is, among the other,: (i) the consideration of both input and output sides, (ii) endogenization of the price and demand system, (iii) substitution of goods and services in production and demand, (iv) realistic treatment of factor scarcity, institution and the macroeconomic environment, and (v) allowing for the optimization of agent behaviour through non-linear relationships (Horridge et al., 2017; Ochuodho and Alavalapati, 2016; Pan and Richardson, 2015; West, 1995). The Enormous Regional Model (TERM) applied in this study is based on the equations of the ORANI model (Fig. 1) (Dixon et al., 1982). TERM uses the bottom-up approach where solutions for the national economy are derivative (sums) of solutions for given regions. It means that TERM includes series of independent CGE models which affect each other by trade and basic factors of production (Horridge et al., 2017). An important feature of TERM is the possibility to include a significant number of regions and sectors (Horridge et al., 2005). The database for TERM is based on national supply and use tables and not on IOTs. When developing the TERM database, it is important to disaggregate the national tables. It is assumed that a given

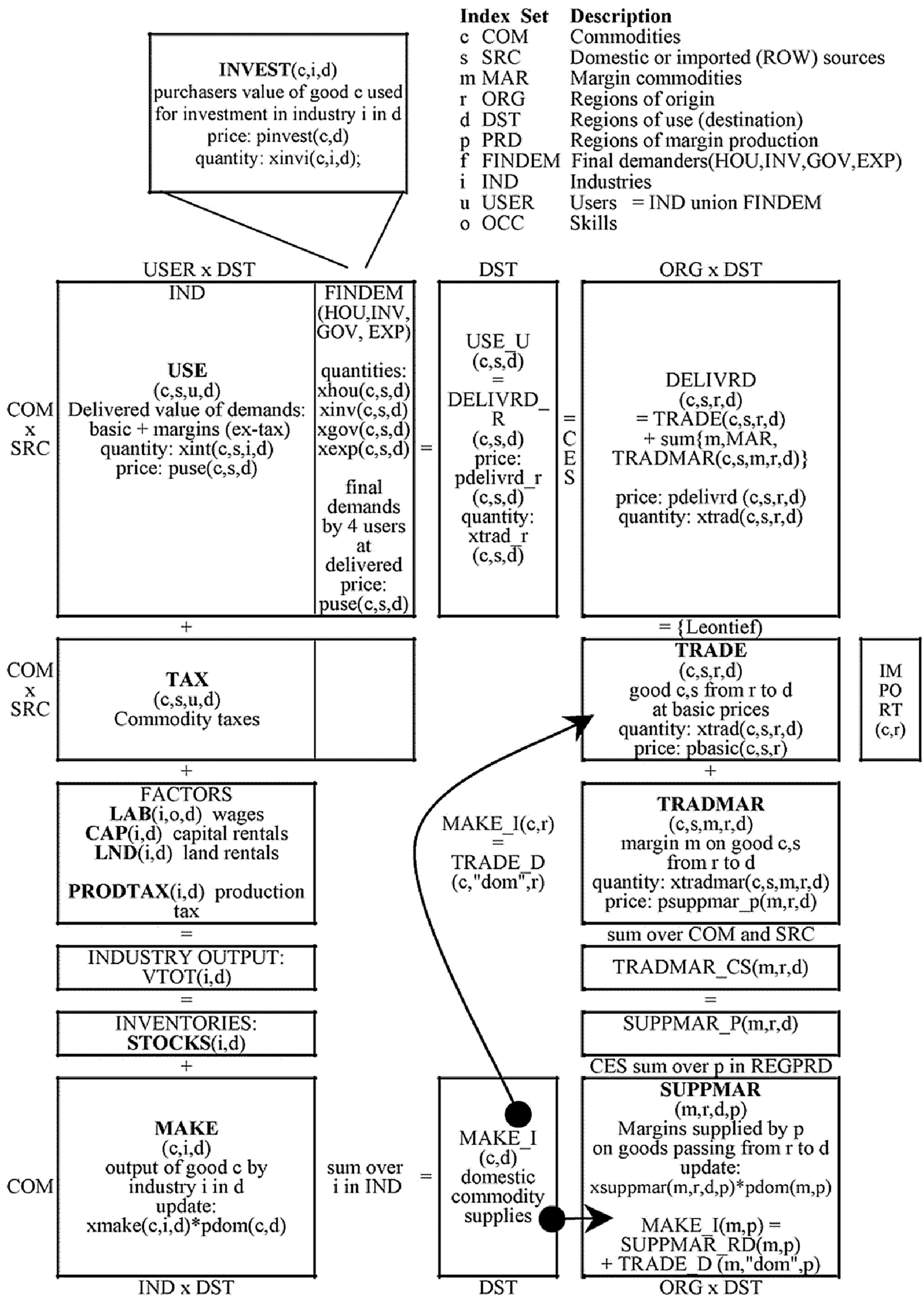

Fig. 1. TERM flows database.
Source: Horridge et al., 2005.

industry in each region uses the same technology (Wittwer, 2017). Regional differences in technologies are, however, captured via regional differences in the composition of outputs (Wittwer, 2017). Some sectors in the model, such as housing, are treated as non-traded, meaning that supply equals demand in each region. Trade volumes in interregional operations are inversely proportional to the distance between the place of origin and destination. Disaggregation of sectors depends on given policy issues. For this study, the sectors were aggregated into 10 sectors, 9 the most important from the perspective of the forestry sector and one aggregating other sectors.

4.2. Simulation design: model closure and shock

To demonstrate how natural capital integration can be used for CGE analysis and how it affects economic estimates a real natural disaster case (trees felled by the hurricane in Poland in 2017) was examined. The shock was designed to depict the immediate effects of the accident on the Polish economy (more facts on this natural disaster given in subsection 3.2). It represents the destroyed capital stock and 10 % inventory loss in the forestry sector.

A model closure for this shock is a short-run closure, where (i) regional consumption follows wage income, (ii) national propensity to consume and (iii) national real wage for all occupations are fixed. In addition, the Dixon–Parmenter–Sutton–Vincent (DPSV) investment rule is in force (Dixon et al., 1982, p. 19).

The next section presents economy-wide impacts of the shock introduced in the CGE model with and without natural capital values integration and hence illustrates the magnitude of the over/under estimation of economic analysis without environmental accounts.

4.3. Simulation results

Simulation results of a 10 % drop of inventory in the forestry sector are illustrated in Table 6. Numbers in the table represent percentage changes from base values. One of the goals of this study was to test and present, in a simplified way, the differences of shock results between simulations with and without natural capital integration into SNA. The results obtained show similar logic of the findings as those presented in the paper by Ochuodho and Alavalapati (2016) - that the evaluation of the forest damage is underestimated in case without taking into account natural capital. That is represented by smaller GDP decline in case without natural capital than with it included. As indicated in Table 6, the key differences between the two scenarios are in the case of the impact on the total real investment and real GDP (−0,0021 percentage points). Other noteworthy differences are observed in macro estimates, such as export (−0,0020 p.p.), household consumption (−0,0013 p.p.), aggregated employment (-0,0008 p.p), or import (−0,0005 p.p). Industry output prices in the forestry sector increased and had a direct impact on the prices in sectors directly depending on the wood supply, such as: (i) wood and products of wood sector; (ii) paper and paper products sector; (iii) and sector of furniture. Results generated by the model correspond with the official statistical data published after the case of damage caused by the hurricane in 2017 – the wood prices in Poland increased significantly from their long term trend after the accident (Statistics Poland (Główny Urząd Statystyczny), 2018, 2017, 2016, 2015). The investment rise in the forestry sector was observed in the empirical data and in the model output. Some investments were incurred due to efforts to recover timber, cleaning of the damaged areas and replanting them with new trees.

The general impact of the simulated shock is, as expected, negative for the economy in both cases (with and without natural capital integration); however, the scenario run without integrated natural capital demonstrates more positive results as compared to the one that includes values of natural capital. The analysis of the results from the simulation that does not include natural capital could lead to the implementation of considered investments, strategies or policies in anticipation of more positive outcomes. As economic decisions can bring direct and indirect implications, not considering values of natural capital while conducting economy-wide analyses could result in some serious unexpected costs to certain actors.

5. Summary and conclusions

This study applied methodological framework for integrating natural capital values into SUTs based on United Nation's System of Environmental-Economic Accounting (SEEA; 2012) following the approach developed by Ochuodho and Alavalapati (2016). Furthermore, it has been demonstrated how the methodological framework can be used as a tool for evaluating the economy-wide consequences of a natural disaster (case of the hurricane-felled trees) with use of a CGE model for Poland. The results correspond with the statistical data published after the catastrophic event and are align with the previous studies which applied different CGE models and databases. Despite the differences in analysed case studies, the results seem to be unanimous and indicate that without the integration of natural capital values, the outcomes of economic analysis are far more optimistic in comparison to integrative approach. The results without taking into account of natural capital are overestimated and hence might cause a misleading interpretation of analysed cases/policies as they do not take into account losses of natural account (since GDP is not environmentally adjusted in such cases). In other words, the absence of natural capital accounting in the SNA can lead to incorrect and biased economic estimates, where economic development could occur at the expense of natural resources and general sustainability. This study also provides an idea about the effects of economic activities and policies on stock of natural resource and how changes of the latter influence economic processes. The results are consistent with the previous research by Ochuodho and Alavalapati (2016) who came to similar conclusions by applying a different dataset and CGE model. The different methodological setting of this study acknowledges and supports the methodology and results of the study conducted by Ochuodho and Alavalapati (2016).

Despite the results obtained, some limitations of natural capital values integration into SNA should also be highlighted. As concluded by Ochuodho and Alavalapati (2016), those challenges, among others, relate to the compatibility between economic and environmental accounts, the problem of double counting and sources of data (e.g., directly observed or computed). Moreover, there are challenges related solely to the natural capital accounting, which include greenwashed figures, nature valuation, data gaps or inconsistent methodologies.

This study uses the approach of asset value accounts and combined accounts where the data represent consolidated monetary/physical information (depletion adjusted aggregates). In case of integrating more than one natural resource at a time it would be very difficult to

Table 6
Total economy-wide impact of a 10 % decrease of inventories stock in the forestry sector (% change).

	Without Natural Capital Accounting	With Natural Capital Accounting	Difference (Column 3 – Column 2)
Real GDP	−0.0676	−0.0696	−0.0021
Total real household consumption	−0.0839	−0.0852	−0.0013
Total real investment	−0.1060	−0.1081	−0.0021
Total real government consumption	0.0000	0.0000	0.0000
Volume of exports	−0.0029	−0.0049	−0.0020
Volume of imports used in destination	−0.0153	−0.0158	−0.0005
Volume of imports landed in destination	−0.0153	−0.0158	−0.0005
Aggregated employment	−0.0408	−0.0416	−0.0008
Gross Domestic Product Price Index*	−0.0209	−0.0198	0.0012
Consumer Price Index*	−0.0046	−0.0042	0.0004

* Real price index – not percentage change.

interpret results of simulation due to problematic distinction between impacts of different natural capitals. However, the SEEA provides more complex approaches to integrate natural capital into SNA (United Nations et al., 2012). Thus, further research should focus on the development of methodologies to integrate more than one natural resource at a time into the comprehensive framework for bioeconomic CGE modelling (e.g., soil resources, timber resources, aquatic resources, biological resources, water resources, land, mineral and energy resources). More comprehensive integrations of natural resources with the CGE modelling environment could enable the achievement of more reliable results of economic and policy analysis. An even more demanding and advanced step would be to integrate ecosystem services and their respective values to achieve a full insight into a two-way relationship between nature and bioeconomy-based systems.

Funding

Funded by "National Science Centre, Poland". Project number: 2018/29/N/HS4/01394.

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