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# Sustainability Assessment and Reporting

*Edited by Soner Gokten and Pinar Okan Gokten*

# SUSTAINABILITY ASSESSMENT AND REPORTING

Edited by **Soner Gokten**
and **Pinar Okan Gokten**

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# Meet the editors

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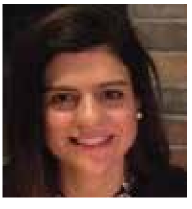

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# Contents

# Preface

"We need to achieve more sustainable consumption and production patterns, to increasingly decouple environmental pressure from economic growth, to ensure sustainable management of natural resources, and to work together in partnership to reduce poverty. Within societies, the luxuries of one generation are often the needs of the next."

Berglind Ásgeirsdóttir
Former Deputy Secretary-General of the OECD

We are more aware of the need to achieve sustainable development than ever before. One of the main factors to achieve the goal of sustainable development is sustainability assessment and reporting because it is not possible to take precautions without understanding the current situation. And also, undoubtedly, future generations have a right to know what kind of world we will leave them.

This book brings together different perspectives on sustainability assessment and reporting. When you look at the chapters, you will understand that sustainability assessment and reporting are addressing interdisciplinary and vast areas. It should be because sustainability assessment and reporting cover all aspects of social, economic and environmental factors. In this five-chapter book, you will see how sustainability assessment and reporting are addressed in different areas.

In the first chapter, Susana Santos presents a methodology that allows a better knowledge of the different aspects of the activity of a country, as well as carrying out experiments on its functioning. In this sense, the data of the flows associated with market transactions and transfers, measured by the national accounts of Portugal, are organized in a matrix form by applying the social accounting matrix (SAM)-based approach. The author concludes that the effects of increases in the households' income depend on its origin and the corresponding multiplier effects, which are in turn influenced by the structure of the use of this income.

Lassaad Ben Mahjoub emphasizes the importance of sustainability accounting by focusing on the effect of sustainability reporting in earnings quality in Chapter 2. The author tries to explain the link between earnings quality and sustainability communication using the data of Saudi listed companies. Empirical results show that sustainability reporting has significant effects on income smoothing.

Jaime Fabián Cruz, Yolanda Mena and Vicente Rodríguez-Estévez review the methodologies and difficulties for assessing the sustainability in farming systems in Chapter 3. They touch on the need to integrate a comprehensive assessment of ecological, economic and social dimensions to achieve sustainable agriculture by comparing the first-, the second- and the third-generation sustainability indexes.

Antonio Valero and Alicia Valero propose an approach—Global System of Environmental-Thermo-Economic Accounts (SETEA)—for accounting for abiotic resource depletion through the second law of thermodynamics in Chapter 4. They suggest 'replacement' as the keyword for reproducing the planetary global accounts, from households to the whole planet in a comprehensive way.

In the last chapter, Gogoberidze George and Rumiantceva Ekaterina deal with the method of comprehensive assessment of the sustainability of coastal infrastructure systems of the Arctic zone of the Russian Federation, which allows for analysing the socioeconomic development of the Arctic regions of Russia in order to ensure national security, as well as forecasting the environmental and socioeconomic situation in the coastal zone of the Russian Arctic using simulation prediction methods. Using a comprehensive indicator system, they create a dynamic model of strategic spatial planning of the Russian Arctic regions and the integrated geographic information system of coastal systems and coastal infrastructure of the Russian Arctic 'AZRF Coastal Systems'.

We would like to express our sincere gratitude to all the authors for their high-quality contributions. The successful completion of this book has been the result of the cooperation of many people. In the end, we would like to thank the Publishing Process Manager, Mr. Julian Virag for his support during the publishing process, as well as the Commissioning Editor, Ms. Ana Pantar for inviting us to be the editors of this book.

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# Using a Social Accounting Matrix for Analysing Institutions' Income: A Case from Portugal

Susana Santos

Additional information is available at the end of the chapter

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**Abstract**

A social acccounting matrix (SAM) is a tool that has specific features for conducting studies in several different areas, as well as for supporting the policy decision process. Following an application for Portugal, a SAM-based approach is adopted for studying (measuring and modelling) the impact of the introduction of a social policy measure of the increase in households' income on the socio-economic activity of a country, and the associated institutions' income. Numerical and algebraic versions of a SAM enable the identification of the networks of the linkages of the monetary or nominal flows measured by the national accounts and the corresponding structural features, as well as the associated multiplier effects, which are used to measure the impact on the socio-economic activity. This measurement is at a macroeconomic level, using macroeconomic aggregates and balances.

**Keywords:** social accounting matrix, national accounts, SAM-based approach, social policy, multiplier effects

## 1. Introduction

The increasing importance of markets has involved an increasing volume of transactions and a consequent and progressive (re)organisation of the activity of society, which has focused its attention and needs on this process. This activity is known as being economic.

Associated to each market transaction are two or more flows with opposite directions, which are often denominated 'inflows' and 'outflows', which balance when the transaction is concluded. The nature of these flows can be the same or not; however, the balance means that when the transaction is concluded, both inflows and outflows have the same value. We can thus think about the existence of a transaction of economic value, whose measurement is 'a premise for understanding economic activity' ([1], p. 12).

The abovementioned (re)organisation of the activity of society also involves transfers, which are also flows, but with different characteristics from those associated with market transactions. Taxes, remittances, property income, social security system, and so on, are all the examples of these flows, which are nonreturn flows in a strict sense, but which balance at a macroeconomic level. When this facet is also considered, from the author's point of view, the term "socioeconomic" is more appropriate to designate this activity.

Interest in the measurement of these flows has been increasing, especially among researchers of the activity of society and by those involved in the policy decision process. Several types of statistics have focused on and registered different types of transactions; however, the national accounts have progressively made an effort to fully cover them. To this end, and also to allow comparability among countries, since 1953 an international system has been implemented to define rules and nomenclatures that can be adopted by countries or groups of countries and, in principle, better data. This system is now in its fourth version of 2008 in the case of the base system, which is known as the System of National Accounts (SNA) [2], and of 2010, in the case of the European system, which is known as European System of National and Regional Accounts (ESA) in the European Community [3].

Monetary or nominal flows and the so-called income are associated with at least one of the abovementioned directions of market transactions. Therefore, those who have income can intervene in the market, and the level to which this is possible is associated with well-being, power, and prestige, which justifies the importance of income and the attraction for it.

In this chapter, a social accounting matrix (SAM), adapted for the SNA, is used for studying the income of institutions, or institutional sectors–defined by that system as being groups of those "engaged in the full range of transactions… on the basis of their principal functions, behaviour, and objectives" ([2], Paragraphs 2.16 and 2.17). An application for Portugal in 2015 will illustrate the various sections. The purpose is to study (measuring and modelling) the impact of the introduction of a social policy measure on the increase in households' income, on the socioeconomic activity of a country, and also on the associated institutions' income[1].

Section 2 presents the SAM framework, showing how society's activity is organised, using a top-down method, and also the underlying network of flows which can work together.

Covering the households' institutional sector of "all physical persons in the economy", and attributing to the (general) government institutional sector the political responsibility of, among others, "to redistribute income" ([2], Paragraph 2.17), Sections 3 and 4 focus on these two sectors. Thus, Section 3 identifies the structural features of the origin and use of the so called institutions' aggregate income. In turn, Section 4 simulates multiplier effects of a social policy measure of the increase in households' income, whereby the percentage changes regarding the original situation are compared with those that result from an identical increase, but with a different origin (compensation of labour).

A summary and some remarks conclude the chapter in Section 5.

[1]Social issues using SAMs were previously addressed by the Author, for instance, in [12–14].

## 2. The SAM framework

The SAM represents the monetary or nominal flows occurring in a particular geographical space, during a given time period. As mentioned earlier, the version presented here is consistent with the rules and nomenclatures of the latest version of the SNA [2]. This is a version of the author, which was a result of research supported mainly by Stone [namely, 4–6], Pyatt [namely, [7–9], and Pyatt and Round [namely, 10].

### 2.1. The macro SAM

A SAM is a square matrix, with equal row and column sums. By convention, inflows are entries in rows, and outflows are entries in columns. Its adaptation to the SNA also allows one to state that the former describe resources, incomes, receipts or changes in liabilities, and net worth; whereas the latter describe uses, expenditures, or changes in assets.

**Table 1** represents a so-called "macro SAM", representing the highest aggregated level allowed by the national accounts, following a top-down method. From that level, the accounts (rows-columns) can be broken down into categories without losing the initial consistency. Numbers between brackets correspond to the application to Portugal in 2015, and it can be used to illustrate how the activity of a country in a specific year is portrayed with this SAM macro.

Therefore, with production and institutions' accounts representing the (domestic) economy and the underlying transactions, the so-called "circular flow of income" can be identified and specified. On the other hand, by means of the rest of the world account, the transactions between the (domestic) economy and that of abroad can be identified. Let us first take a snapshot of the activity of Portugal in 2015, as described later.

At the level of production accounts, the factors of production account show the aggregate or primary income generated in 2015, which is also designated as compensation of the factors of production, namely of labour and capital, which was in the sum of 162,306 million Euros. Reading in rows, this amount was respectively composed of 155,958 and 6347 million Euros, received from domestic activities[2] and from the rest of the world[3]. Reading in columns, this amount was composed of 149,923 and 12,382 million Euros, paid to domestic institutions[4] and to the rest of the world, respectively.

In turn, continuing at the level of the production accounts, the activities account shows, respectively, the production value and the total costs associated with the process of production, which totalled 318,313 million Euros. In rows, this amount represents the output of goods and services. In columns, it comprises 155,958 million Euros of compensation of factors of production, 161,475 million Euros of intermediate consumption, 1867 million Euros of net

[2]Received by residents and non-residents working in the Portuguese economic territory. This amount is the gross added value, and it does not include taxes and subsidies on production and imports.

[3]Received by residents in the Portuguese economic territory working in the rest of the world.

[4]Paid to residents in the Portuguese economic territory working in the Portuguese economic territory and in the rest of the world. This amount is the gross national income, and it does not include taxes and subsidies on production and imports.

| | | **Outflows (expenditures, …)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Production | | | Institutions | | | Rest of the World (RW) | Total |
| **Inflows (incomes, ..)** | | **Factors of production** | **Activities (Industries)** | **Products** | **Current account** | **Capital account** | **Financial account** | | |
| Production | Factors of production | 0 | Gross added value (155,958) | 0 | 0 | 0 | 0 | Compensation of factors from the RW (6347) | Aggregate factors income (162,306) |
| | Activities (Industries) | 0 | 0 | Production (318,313) | 0 | 0 | 0 | 0 | Production value (318,313) |
| | Products | 0 | Intermediate consumption (161,475) | Trade and transport margins (0) | Final consumption (150,311) | Gross capital formation (28,452) | 0 | Exports (72,648) | Aggregate demand (412,884) |
| Institutions | Current account | Gross national income (149,923) | Net taxes on production (1867) | Net taxes on products (23,078) | Current transfers (90,027) | 0 | 0 | Current transfers from the RW (6716) | Aggregate income (271,610) |
| | Capital account | 0 | 0 | 0 | Gross saving (26,858) | Capital transfers (2131) | 0 | Capital transfers from the RW (2436) | Investment funds (31,425) |
| | Financial account | 0 | 0 | 0 | 0 | Net lending (567) | Financial transactions (878) | Financial transactions from the RW (6577) | Total financial transactions (8022) |
| Rest of the World (RW) | | Compensation of factors to the RW (12,382) | Net taxes on production (−986) | Imports + net taxes on products (71,601 + 108) | Current transfers to the RW (4415) | Capital transfers to the RW (276) | Financial transactions to the RW (7144) | | Transactions value to the RW (94,724) |
| TOTAL | | Aggregate factors income (162,306) | Total costs (318,313) | Aggregate supply (412,884) | Aggregate income (271,610) | Aggregate investment (31,425) | Total financial transactions (8022) | Transactions value from the RW (94,724) | |

Sources: Statistics Portugal (*INE*); Portuguese Central Bank (*Banco de Portugal*).

**Table 1.** A macro SAM of Portugal in 2015 (in millions of Euros).

taxes on production received by the Portuguese Government, and – 986 million Euros of net taxes on production received by European Union institutions[5].

Finally, still at the level of the production accounts, the products account shows the main components of the aggregate demand and supply of the goods and services in the Portuguese economy in 2015, which amounted to 412,884 million Euros. Reading in rows, the aggregate demand was composed of 161,475 million Euros of intermediate consumption, 150,311 million Euros of final consumption, 28,452 million Euros of gross capital formation, and 72,648 million Euros of exports. Reading in columns, the aggregate supply was composed of 318,313 million Euros of the output of goods and services, 23,078 million Euros of net taxes on products received by the Portuguese Government, − 108 million Euros of net taxes on products received by the institutions of the European Union (see footnote 5), and 71,601 million Euros of imports—the last two being added in the same cell. The trade and transport margins also feature as a component in the products account, which amounts to zero at this level of disaggregation.

At the level of the domestic institutions accounts, in the current account, the aggregate income of the Portuguese institutions in 2015 is shown, which amounted to 271,610 million Euros. The origin of this income is shown in rows, with the following composition: 149,923 million Euros of compensation of the factors of production received by domestic institutions; 1867 and 23,078 million Euros of net taxes on production and net taxes on products, respectively— both received by the Portuguese government, and 90,027 and 6716 million Euros of current transfers within domestic institutions and from the rest of the world, respectively. In turn, the destination or use of that same income is shown in columns, with the following composition: 150,311 million Euros of final consumption; 90,027 and 4415 million Euros of current transfers within domestic institutions and to the rest of the world, respectively, and 26,858 million Euros of gross savings.

The capital account, apart from showing the net lending (or borrowing) of institutions, also shows information regarding acquisitions less disposals of non-financial assets (or the various types of investment in non-financial assets) and capital transfers, which amounted to 31,425 million Euros. Reading in rows, this amount represents investment funds, and it was composed of 26,858 million Euros of gross savings, and 2131 and 2436 million Euros of capital transfers within domestic institutions and from the rest of the world, respectively. Reading in columns, this amount represents aggregate investment and was composed of 28,452 million Euros of gross capital formation, 2131 and 276 million Euros of capital transfers within domestic institutions and to the rest of the world, respectively, and 567 million Euros of net lending.

The financial account represents the net flows associated with the acquisition of financial assets and the incurrence of liabilities, underlying which is the abovementioned net lending. These flows amounted to 8022 million Euros. Reading in rows, this amount is composed of 567 million Euros of net lending, 878 million Euros of net financial transactions within domestic institutions, and 6577 million Euros of net financial transactions from the rest of

[5]Due to the conventions underlying the SAM structure, this negative (net) amount represents a receipt and not an expenditure, that is to say, the amount received as subsidies was greater than the amount expended on taxes.

the world. Reading in columns, besides the net financial transactions between domestic institutions (878 million Euros), this amount also includes 7144 million Euros of net financial transactions to the rest of the world.

The rest of the world account shows all the transactions between resident and non-resident actors in the accounts described earlier (production and domestic institutions), or between the Portuguese economy and the rest of the world in 2015, which amounted to 94,724 million Euros. Thus, the row represents the flows to the rest of the world, with the following composition: 12,382 million Euros of compensation of factors of production, − 986 million Euros of net taxes on production (taxes received minus subsidies paid by European Union institutions), 71,493 million Euros of imports (71,691 million Euros), to which is added net taxes on products (− 108 million Euros, of taxes received, minus subsidies paid by European Union institutions), 4415 million Euros of current transfers, 276 million Euros of capital transfers, and 7144 million Euros of financial transactions. In turn, the columns show the decomposition of the flows from the rest of the world as follows: 6347 million Euros of compensation of factors of production; 72,648 million Euros of exports; 6716 million Euros of current transfers; 2436 million Euros of capital transfers, and 6577 million Euros of net financial transactions.

Therefore, as can be checked in the structure of an integrated economic accounts table of the national accounts, practically all the flows measured by the latter are covered by the SAM—the grand totals in the above-presented macro SAM; other levels of disaggregation in SAMs constructed for specific studies, always respecting those grand totals.

### 2.2. The macroeconomic aggregates and balances

As practically all the flows observed and measured by the national accounts are included in the above-presented SAM, it is possible to calculate and/or extract from it the main macroeconomic aggregates that are usually considered.

The following description is based on **Table 1**.

Gross domestic product (GDP) can be calculated using the three known approaches: the production approach - in which intermediate consumption (161,475) is subtracted from production, or from the output of goods and services (318,313), adding the net taxes on products (23,078–108); the expenditure approach—in which final consumption (150,311), gross capital formation (28,452), and net exports (72,648–71,601) are added; and the income approach - in which net taxes on production and imports (23,078–108 + 1867–986) are added to the gross added value (155,958). The Portuguese GDP in 2015 was 179,809 million Euros.

GDP is the income generated in the domestic economy by residents and non-residents, added to the total net taxes on production and imports, to be valued at market prices.

Gross domestic product can be converted into gross national product or income (GNI) by adding the compensation of factors of production (labour and capital) received from the rest of the world (6347) and by deducting the compensation of factors of production (labour and capital) and net taxes on production and imports sent to the rest of the world (12,382–986 - 108). GNI can also be calculated directly from the SAM by adding the compensation of factors received by domestic institutions to the net taxes on production and on products received by domestic institutions (149,923 + 1867 + 23,078). The corresponding amount for Portugal in 2015 was 174,868 million Euros.

GNI is the income generated in the domestic economy and in the rest of the world by residents, added to the part received by the general government of net taxes on production and imports, to be valued at market prices.

Disposable income (DI) can be calculated by adding the net current transfers received by domestic institutions (6716–4415) to GNI. In our application for Portugal, this was 177,168 million Euros.

Gross saving and net lending or net borrowing are usually presented with the above macroeconomic aggregates, which are items that are provided directly by the SAM and, in the case of Portugal in 2015, were 26,858 and 567 million Euros, respectively, with the last being net lending.

Representing the capital and financial accounts the investment in nonfinancial and financial assets, respectively, which is the so-called accumulated income of institutions, the study that follows is going to be on the current or aggregate income of institutions. Thus, let us focus our attention on the current account of institutional sectors, highlighted with thicker borders in **Table 1**.

## 3. The origin and the use of institutions' aggregate income

From the reading of the macro SAM presented in Subsection 2.1, it is possible to see that the study of the institutions' income, in general, and of the effects of a social policy measure of the increase in households' income, in particular, involves the current or aggregate institutions' income, which supposes the disaggregation of the institutions' current account. On the other hand, as illustrated in **Table 1**, because the main source of that income is GNI, that is to say, the compensation of factors of production received by residents, or the income generated by them in the (domestic) economy and abroad, the factors of production account should also have some disaggregation.

According to the SNA nomenclatures and the available information provided by the national accounts, the disaggregation of the factors of production account are going to be made in 'labour' and 'others' (factors of production), with the former (labour) including the compensation of employees, and the later (others) including the compensation of employers and own-account (or self-employed) workers, and also the compensation of capital, namely property income. In turn, although five institutional sectors can be identified in the institutions' current account, considering that the abovementioned purpose of this study, this disaggregation is going to be in: 'households'—"all physical person in the economy"; '(general) government'—with the political responsibility of redistributing income, and 'others'—the non-financial and financial corporations and non-profit institutions serving households.

Following the previous application, **Tables 2** and **3** represent the result of this disaggregation regarding, respectively, the origin (rows) and use (columns) of the aggregate income can be found in the totals of these tables – the amounts between brackets in the cells of the row and the column with the thicker border in **Table 1** (the institutions' current account).

Even when continuing at a high level of aggregation, much information regarding institutions' aggregate income can be taken from the following two tables. Our focus will be directed mainly on the households. Government, as an intervenient in the households' income through (re)distribution policies, also deserves special attention. Households hold 60.8% of the total aggregate income, the Government holds 24.6%, and the other institutions (non-financial and financial corporations and non-profit institutions serving households) hold the remaining 14.6%.

As shown in **Table 2**, households' income source is mainly compensation of factors of production (73.8%), in which labour represents the main part (47.7%). The other source of households' income is current transfers from domestic institutions (23.3%) and from the rest of the world (2.9%). Within these transfers, the largest share comes from the Government (19.1%).

| | **Current account of institutions** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Households** | | **Government** | | **Others** | | **Total** | |
| **Inflows (incomes,..)** | **Millions of Euros** | **%** | **Millions of Euros** | **%** | **Millions of Euros** | **%** | **Millions of Euros** | **%** |
| Compensation of factors of production (gross national income) | | | | | | | | |
| Labour | 78,724 | 47.7 | 0 | 0.0 | 0 | 0.0 | 78,724 | 29.0 |
| Others (factors..) | 42,984 | 26.0 | −1330 | −2.0 | 29,545 | 74.4 | 71,199 | 26.2 |
| (sub)Total | 121,708 | 73.8 | −1330 | −2.0 | 29,545 | 74.4 | 149,923 | 55.2 |
| Net taxes on production and imports | | | | | | | | |
| from industries and products | 0 | 0.0 | 24,945 | 37.3 | 0 | 0.0 | 24,945 | 9.2 |
| Current transfers from domestic institutions | | | | | | | | |
| Households | 2098 | 1.3 | 35,736 | 53.4 | 5078 | 12.8 | 42,912 | 15.8 |
| Government | 31,507 | 19.1 | 22 | 0.0 | 2169 | 5.5 | 33,698 | 12.4 |
| Others (institutions) | 4842 | 2.9 | 6225 | 9.3 | 2350 | 5.9 | 13,417 | 4.9 |
| (sub)total | 38,446 | 23.3 | 41,983 | 62.8 | 9597 | 24.2 | 90,027 | 33.1 |
| Current transfers from… | | | | | | | | |
| Rest of the world | 4860 | 2.9 | 1,273 | 1.9 | 582 | 1.5 | 6716 | 2.5 |
| Total (received) | 165,014 | 100.0 | 66,871 | 100.0 | 39,724 | 100.0 | 27, 610 | 100.0 |

Source: Statistics Portugal (*INE*).

**Table 2.** The origin of aggregate income of institutions in Portugal in 2015.

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| | Current account of institutions | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Households | | Government | | Others | | Total | |
| Outflows (expenditures) | Millions of Euros | % | Millions of Euros | % | Millions of Euros | % | Millions of Euros | % |
| Final consumption | | | | | | | | |
| .. of products | 114,058 | 69.1 | 32,584 | 48.7 | 3669 | 9.2 | 150,311 | 55.3 |
| Current transfers to domestic institutions | | | | | | | | |
| Households | 2098 | 1.3 | 31,507 | 47.1 | 4842 | 12.2 | 38,446 | 14.2 |
| Government | 35,736 | 21.7 | 22 | 0.0 | 6225 | 15.7 | 41,983 | 15.5 |
| Others (institutions) | 5078 | 3.1 | 2169 | 3.2 | 2350 | 5.9 | 9597 | 3.5 |
| (sub)total | 42,912 | 26.0 | 33,698 | 50.4 | 13,417 | 33.8 | 90,027 | 33.1 |
| Current transfers to the .. | | | | | | | | |
| Rest of the world | 1219 | 0.7 | 2241 | 3.4 | 956 | 2.4 | 4415 | 1.6 |
| Gross savings | | | | | | | | |
| Households | 6826 | 4.1 | 0 | 0.0 | 0 | 0.0 | 6826 | 2.5 |
| Government | 0 | 0.0 | −1652 | −2.5 | 0 | 0.0 | −1652 | −0.6 |
| Others (institutions) | 0 | 0.0 | 0 | 0.0 | 21,683 | 54.6 | 21,683 | 8.0 |
| (sub)total | 6826 | 4.1 | −1652 | −2.5 | 21,683 | 54.6 | 26,858 | 9.9 |
| Total (expended) | 165,014 | 100.0 | 66,871 | 100.0 | 39,724 | 100.0 | 271,610 | 100.0 |

Source: Statistics Portugal (*INE*).

**Table 3.** The use of aggregate income of institutions in Portugal in 2015.

In turn, the main source of the Government's income is current transfers from domestic institutions (62.8%) in general and from households (53.4%) in particular. Taxes on production and imports, net of subsidies also have a significant share of 37.3%, which helps to compensate the negative share of compensation of factors of production due to the high amount of interests to pay.

Thus, households are the only institutional sector that receives compensation of labour, which represents 29% of the total aggregate income. In the latter case, current transfers from households represent 15.8%, and from the Government, 12.4%. These three items represent more than half of the aggregate income of Portugal in 2015, meaning that changes in them will certainly have non-negligible effects.

From **Table 3**, it can be seen that final consumption is the main (69.1%) destination of households' income, followed by current transfers to the Government (21.7%), in which taxes on income are included. In turn, the Government uses almost equal shares of its aggregate income in final consumption (48.7%) and current transfers to households (47.1%), in which social benefits are included. Both for households and for Government, all the other items identified as destinations of income have a residual or non-existent meaning.

## 4. Studying the effects of the increase of households' income with two different origins

In the Introduction, it was defined that the purpose is to study the impact of the introduction of a social policy measure of the increase on households' income, on the socio-economic activity of a country, and on the associated institutions' income. Social policy measures are usually implemented by the Government through current transfers to households, namely, through the social security system. In our application, as was seen in the previous section, the current transfers from the Government to households represent 19.1% of the total.

However, because it is important not to neglect the indisputable role of the generated (or gross national) income received as compensation of factors of production, representing 73.8%, our study also includes a simulation with the increase in the compensation of labour, that is, the compensation of employees, which is the main component of generated income, representing 47.7% of that total (see **Table 2**).

Therefore, to study the effects of the increase of households' income, two scenarios are constructed according to the origin of the increase. Both scenarios involve increases of 5% of households' aggregate income: one with its origin in the current transfers, from the Government to households, and other in the compensation of labour, received by the households.

Our SAM-based approach also involves an algebraic version of the SAM presented in Subsection 2.1, with the disaggregation described in Section 3. This version or model allows the calculation of accounting multipliers, whose methodology is described in ([11], Section 5.1). According to that methodology, in both of the abovementioned scenarios, the rest of the world and the capital and financial accounts were set as exogenous. The current account of the Government was also set as exogenous in the scenario that involves the increase of current transfers, and the (factors of production) labour in the scenario that involves the increase in the compensation of labour. From SAMs organised into endogenous and exogenous accounts, the accounting multipliers calculated represent quantitative approximations of the effects of unitary changes (positive or negative) on the income of endogenous accounts, *ceteris paribus*. These approximations were then applied to increases of 5% of households' aggregate income (8251 million Euros) and new SAMs, and the corresponding macroeconomic aggregates and balances were then calculated.

**Table 4** summarises the impact of these scenarios using percentage changes of the macroeconomic aggregates and balances and data regarding aggregate income and final consumption. These changes were calculated from the earlier described calculations, and these are provided in Section 2.

| | | Origin of the increase of households' income | |
|---|---|---|---|
| | | **Current transfers, from Government** | **Compensation of labour** |
| Gross domestic product (GDP) | | 3.58 | 4.14 |
| Gross national income | Total (GNI) | 3.47 | 6.87 |
| | Households | 3.48 | 8.14 |
| | Government | — | 4.16 |
| | Other institutions | 3.32 | 3.84 |
| Disposable income | Total (DI) | 3.35 | 6.64 |
| | Households | 7.77 | 7.33 |
| | Government | — | 5.79 |
| | Other institutions | 3.68 | 4.37 |
| Gross saving | Total (S) | 4.95 | 5.03 |
| | Households | 7.77 | 7.33 |
| | Government | — | 5.79 |
| | Other institutions | 3.68 | 4.37 |
| Aggregate income | Total (AI) | 8.30 | 6.52 |
| | Households | 7.77 | 7.33 |
| | Government | — | 5.79 |
| | Other institutions | 3.68 | 4.37 |
| Final consumption | Total (FC) | 5.99 | 6.92 |
| | Households | 7.77 | 7.33 |
| | Government | — | 5.79 |
| | Other institutions | 3.68 | 4.37 |

Source: Own calculations.

**Table 4.** Percentage changes resulting from the impact of the 5% increase of households' aggregate income.

Therefore, the impact of an increase of households' aggregate income depends not only on its amount, but also on its origin. **Table 4** shows the different impacts that the same increase of 5% in households' aggregate income has according to two different origins.

Thus, at the level of totals, the increase with origin in the compensation of labour has a greater impact, except in the case of aggregate income.

At the level of institutional sectors, it is not possible to make any comparison for the Government because in the first scenario its account is set as exogenous, which prevents the identification of changes in some of the corresponding components. In turn, for households, the scenario with the increase with origin in the compensation of labour is only favourable for generated income, that is to say, GDP and GNI, whereas for other institutions, this scenario is generally more favourable.

Higher levels of disaggregation, namely of the households, would be needed to find out more about these effects; however, from this very simple approach, although with many limitations, two main ideas should be emphasised regarding the impact of possible changes (increases and decreases) in the institutions' income—resulting from social policy measures or not. First, the origin of these changes is not indifferent, either for the target they are intended to achieve, or for the rest of the economy. Second, changes in income directed to specify groups should not neglect the corresponding multiplier effects for which the structure of the use of that income should be considered.

## 5. Summary and concluding remarks

A study of the effects of a social policy measure of the increase in households' income is made by adopting a SAM-based approach applied to Portugal. The national accounting rules and the nomenclatures, defined by the adaptation to European Union of the latest version of the System of National Accounts [2, 3], underlies the SAM structure, whereby numerical and algebraic versions are defined and worked out, with the purpose of supporting this study.

This chapter presents and applies a methodology that has been researched by the author with the aim of defining a method that allows a better knowledge of the different aspects of the activity of a country, as well as carrying out experiments on its functioning. For this, the data of the flows associated with market transactions and transfers, measured by the national accounts, are organised in a matrix form, in such a way that origin, use, and distribution of income can be worked together. Thus, focusing the attention on the parts to be studied, the structural features can be evidenced and multiplier effects of changes on the involved flows can be accounted for. This is carried out in this chapter.

In order to show the comprehensiveness and consistency of the tool used, our study begins with the presentation of the highest aggregated level of a matrix form of the national accounts—a macro SAM. Covering the different types of flows in seven accounts, or rows and columns, from that matrix, it is possible to identify practically all the transactions and transfers, that is, the nominal or monetary flows, measured by the national accounts, within the (domestic) economy, and between the same and the rest of the world, which occurred in a particular geographical space, during a given time period. As illustrated for Portugal in 2015, a first snapshot of the activity of a country can be taken from this macro SAM, which is complemented by the main macroeconomic aggregates, calculated outside that matrix, but with the data of its cells.

From the description of the seven accounts (rows-columns) of the macro SAM, it is possible to identify the current account of institutions as being the part to be focused on for the study of the institutions' income. In turn, for the study of the effects of a social policy measure of the increase in households' income, it is also possible to conclude that, on the one hand, households and the Government in this (current) account could also be identified, and, on the other hand, the labour in the factors of production account can be identified. From this disaggregation, the origin and use of the aggregate income of institutions, namely, of households, the Government, and other institutions, is studied.

Regarding the origin of income, the compensation of labour is the source of about half of the households' income, with the current transfers from the Government representing a little less than a quarter of the same. In turn, current transfers from households are the source of more than a half of the Government's income, with net taxes on production and imports of more of a quarter of the same.

With regard to the use or destination of aggregate income, households use much more than a half of the same in final consumption and just under a quarter in current transfers to the Government, in which the taxes on income are included. Final consumption and current transfers to the households, in which social benefits are included, are the destination of almost all the aggregate Government income, each of which by almost a half.

From this knowledge of the structure of origin and destination of the aggregate income, it was possible to achieve the purpose of studying the impact of the introduction of a social policy measure of the increase on households' income, on the socio-economic activity of a country, and on the associated institutions' income. Therefore, on the one hand, having identified the two main sources of the aggregate income of households, the need for two scenarios was also identified. On the other hand, the identified structures of the origin and use of income, together with the network of linkages that underlie the SAM framework, allowed for a better understanding of the effects portrayed in each of the scenarios.

From the results of these scenarios, it was possible to conclude that the effects of increases in the households' income depend on its origin and the corresponding multiplier effects, which are in turn influenced by the structure of the use of this income. These effects may be more favourable for a specific group or sector, but less so for the whole economy, as shown in our application.

Accordingly, changes (increases and decreases) in the institutions' income, especially in households' income—resulting from social policy measures, or not, directed to specific groups, should not neglect the corresponding structures of origin and use, as well as the macroeconomic impact of the same. To this end, the SAM-based approach introduced in this chapter is a possibility.

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Chapter 2

# Sustainability Reporting and Income Smoothing: Evidence from Saudi-Listed Companies

Lassaad Ben Mahjoub

Additional information is available at the end of the chapter

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**Abstract**

A unique definition of sustainability, or sustainability reporting, does not exist, but it continues to progress and has emerged as one of the most critical issues in the business area. It is correlated with several contemporary social and disclosure practices, including corporate social responsibility (CSR), environmental disclosure, corporate citizenship, green economy, and sustainable entrepreneurship. All these concepts are studied in an accounting context; in other words, accounting and its branches are adapted to the new phenomena of sustainability. This study focuses on the effect of sustainability reporting in earnings quality, using income smoothing as a proxy of earnings quality. I apply this study to Saudi Arabia because it is a petroleum country where notions of sustainability must be studied. Empirical results show an important level of reporting of sustainability that positively affects the practice of income smoothing.

**Keywords:** sustainability, reporting, Saudi companies, income smoothing, CSR, environment

## 1. Introduction

Today, the close link between the economy and the environment is recognized. Indeed, the economy must draw its raw materials from the environment to develop goods and services, but it also dumps garbage back in. Hence, there is a growing interest from the international community on sustainable socioeconomic development that respects the environment. Two world events reflect this concern [1]. The Earth Summit in Rio de Janeiro in 1992 marked a turning point in adopting Agenda 21 for Sustainable Development, which introduced the concept of environmental accounting as an instrument for implementing coherent policies in this area. Then, in 2002, the United Nations Conference in Johannesburg stressed the importance of adopting adequate environmental controls and information systems at different levels in countries that can be used as a basis for political decisions, mainly through the Global Reporting Initiative (GRI) and the Global Compact.

The World Bank is not far behind; it has published recommendations and offers courses to raise corporate social responsibility (CSR) awareness among companies. The Organization for Economic Co-operation and Development (OECD) has made simple recommendations but is a forerunner with papers dating back to 1976. Environmental accounting provides more information and promotes transparency and accountability for political action for the environment by bringing the economy and the environment closer together.

On another hand, green or universal accounting is slowly entering the world of finance. Global warming, biodiversity, pollution, water consumption, noise pollution, employability, and the fight against discrimination are beginning to be integrated into accounting plans. The objective, in addition to financial performance, is the company's ability to live in harmony with its physical and social environment. An important change in the economic model was evident, and the subject is taken very seriously by a handful of auditors, experts, and researchers.

## 2. Literature review and hypotheses development

### 2.1. Accounting and sustainable development

Traditional accounting tools do not provide information tailored to the specific needs of environmental issues. Environmental information is often embedded in aggregates of costs and revenues, which do not allow the benefits and losses inherent in this area to be identified. This inefficient allocation of costs complicates the decision-making process.

The occurrence of environmental accounting is consistent with the improvement of environmental awareness that started in the 1970s. The unawareness of different leaders about environmental concerns has given way to rebuff. Increasingly, the focus of firms progressed toward mindfulness, and the appearance of a commitment vis-à-vis the protection of the environment emerged [1].

The need to integrate environmental considerations into decision-making is one of the basic strategies for sustainable development. Sustainability requires taking greater responsibility for decisions, which calls for changes in the legal and institutional frameworks to emphasize the public interest. The law alone cannot impose the public interest; this requires broad public participation in decision-making that affects the environment. When the environmental impacts of the proposed project are high, it requires that there be mandatory public scrutiny of such projects [2].

Income smoothing is one of the most common forms of earnings management, and managers try to maintain the stability of net income by influencing the timing of certain financial events or by selecting specific accounting methods or both. Companies generally prefer to show a stable trend in income growth and do not want to show the volatility of profits, the rise in some periods, and decline in others. To achieve this balance, companies try to maintain income stability.

Management is based on the relative performance of the company now and in the future. When current profits are low and expected future profits are strong, the manager borrows profits from the future period for use in the current period. When current profits are good, management tends to save them for potential use in the future.

Several studies have dealt with the concept of preparing income for study and analysis. Fudenberg and Tirole [3] referred to the concept of income as all the methods and processes are used by management in business organizations to reduce income to reduce the degree of risk in the company's investments. Ashari et al. [4] referred to the introduction of income as a set of mechanisms whereby profits are reduced in periods of a significant increase in income and they increase in periods where income falls significantly.

### 2.2. Relation between sustainability reporting and income smoothing: hypothesis development

A growing number of organizations are making sustainable development a major focus of communication. If sustainable development is designated as the ideal new structure or "skeleton" of a society going through a global crisis, communication is the blood that feeds it. I know the magnitude of the operational challenges that companies face when trying to understand and use this new approach. However, developing an integrated approach to sustainability based communication is an equally difficult challenge. There are perceptions of issues of concern: understanding stakeholder expectations varies, and traditional structures are firmly established.

Indeed, accounting allows the aggregation of all the financial information of the firm and communicating it to stakeholders with interest in the financial management of the company. Accounting can also be used to measure other types of financial information about the company's environmental and social performance, helping managers to make strategic decisions [5]. Several concepts have appeared in parallel with this concern for sustainability, for example, eco-accounting, the "green economy," the carbon footprint among others.

Eco-accounting is a reworking of the traditional accounting system, integrating the internal and external environmental and social and economic costs inherent in the total life cycle of the product. This practice allows managers to review the profitability of their products by considering the environmental and social impacts. For example, an executive could recognize the cost of managing and disposing of waste by property or by department and thus review its profitability. The attribution of a specific cost to an environmental or social effect makes it possible to measure the inefficiency of current methods and to identify new sources of potential savings [6]. However, some costs are difficult to quantify. In this case, the company may allocate an approximate cost to them.

A majority of the sustainability literature relies on institutional theory, which states that firms establish actions for external legitimacy. Conferring to the legitimacy theory, firms attempt to justify their activities as reliable with the norms and values “required” by society because they are permitted to continue their actions through a social treaty. If a firm does not act according to society’s rules, a legitimacy gap appears, affecting the firm’s very durability [7]. Legitimacy is insight or postulation that the actions of an organization are needed or suitable within some focus on the norms, values, and beliefs in the social area. It increases when society and pertinent stakeholders enhance a company’s behavior as correct and convenient; consequently, firms communicate to the relevant public that they work in tandem with norms and values of society. A firm may also report its envisioned objective in social matters along with the use of reporting to adjust the discernment of its actions or hide unethical comportment or the weak quality of its financial information to protect or enhance its legitimacy [8].

According to the institutional theory, sustainability reporting is observed as one of the central concepts that organizations rely on to prove that they work with society’s rules [9]. A company’s legitimacy is influenced by its sustainability reputation, as well as by its financial situation; sustainability reporting and financial reporting are instruments that outline the stakeholders’ insights of these two reputational features [10].

Firms use signaling of their qualities and then act dependably with ethical values. As stated by signaling theory, a pertinent signal should be noticeable to the community. Sustainability reporting is a visible signal to socially responsible behavior. Likewise, it is a costly behavior and cost rise with the volume of the given information.

Regarding the impact of CSR on financial performance, some studies in stakeholder theory suggest a positive link between the two concepts (social impact hypothesis) since it is supposed to improve the satisfaction of the whole. The company’s stakeholders, and consequently, the reputation of the company, favor better economic and financial performance. Others, belonging to a liberal trend, establish a negative link (trade-off hypothesis), a socially responsible commitment of the company increasing costs and leading to misuse of capital, causing competitive disadvantages.

According to the signal theory, the incentives emanating from sustainability reporting and unethical comportment, such as income smoothing, have been well documented. Based on the following theories, propositions, and arguments, I can present the following hypothesis:

*Hypothesis:* The more companies disclose about sustainability, the more their managers are motivated to smooth income.

## 3. Data and methodology

### 3.1. Population and sample

I apply this study to Saudi Arabia not only because they represent the Gulf countries but also because of its place in the petroleum organizations, the core economic driver of the Middle East and strategic world supplier of oil and gas. This study examines the sustainability reporting made by Saudi firms through the companies’ websites. I also believe the choice of Saudi Arabia will fill the gap between developed and developing countries on sustainability framework.

A final sample of 94 of the 146 nonfinancial listed companies was obtained (see Appendix 1). I discarded companies created after 2008 and those that do not have a website.

### 3.2. Variables and measurement

#### *3.2.1. Independent and explanatory variables*

In this section, I describe the variables of the study beginning with the principle variables (dependent and explanatory) and then the control variables.

Sustainability reporting represents the dependent variable, which is measured by an index. The index includes many items related to CSR, economic, and environmental governance, updated to the new guidelines of the International Organization of Standardization (ISO) 26000. These items are measured via content analysis, grouped in dimensions that describe social and environmental areas.

In the field of management sciences, the most commonly used method in the analysis of qualitative data, especially interviews, is content analysis [5, 11, 12] as pointed out by [13], p.202: "The place of content analysis is becoming increasingly important in social research, particularly because it offers the possibility of methodically dealing with information and testimonies that have a certain degree of depth and complexity, such as semi-directive interviews."

The sustainability reporting score is obtained after an analysis of the quality and quantity of published sustainability information. The assessment of the quality of the information content delivered by the company consists of coding the content delivered according to two modalities: quantitative information and general information. Quantitative information is of better quality and reliability than general information because it is considered to have better informational influence [14].

To measure the sustainability reporting index, I evaluate the degree of firm communication by coding a grid of items relating to sustainability, assigning values from zero to four dependent on the quantity or quality of reported information in the firm's website. The rating of the grid of items related to sustainability reporting is based on a score from zero to three; three points are given for an item described in monetarily or quantitatively, two when an item is described precisely, one for an item discussed in general, and zero for no information about the item [15, 16]. Two persons made the valuation of items, and then I made a rapprochement between the two results [17].

Regarding the explanatory variable, income smoothing, the firm is supposed to smooth its results if it presents low variability results as referenced to a level considered normal. From a methodological point of view, it is necessary to define the object of smoothing, the duration of study of the smoothing, and the statistical tool allowing evaluation of the variability of the result.

I use the ratio of cash flow volatility to earnings volatility to measure income smoothing. This measure presents the extent to which accrual accounting has smoothed out the underlying volatility of the firm's operations, which is reliable with previous research on income smoothing [8, 18]. Cash flow (earnings) volatility is the standard deviation of cash flows from operations (earnings before extraordinary items) scaled by the average total assets estimated at the annual level over the 3 years, t-5 to t-1, with a minimum of 2-year data. Large values of income smoothing indicate greater income smoothing practice.

After reviewing the literature related to income smoothing, different measures were used. I use the measure confirmed by Leuz et al. (2003) and Francis et al. [18]. These authors use smoothness as a proxy for earnings management. The model of the income smoothing measurement is presented as follow:

$$\text{SMTH} = \left(\beta(\text{NI it}/\text{Assets it})\right)/\left(\beta(\text{CFO it}/\text{Assets it})\right)$$

Where:

β i = firm i standard deviation;

NI i,t = firm i, time t net income before extraordinary items;

CFO i,t = firm i, time t operating cash flows;

Assets i,t = firm i, time t average total assets.

*3.2.2. Control variables*

In order to explain the relationship between the level of sustainability reporting and income smoothing, and after a review of the literature, I chose the control variables.

The first variable is firm size, as it is considered a significant determinant of CSR and sustainability. Larger firms are more noticeable than smaller firms and thus face more pressure to engage in and report on the consequences of their activities on the environment and society [17]. I measure the firm size by the total assets, which is the most used measure in the literature.

The second variable is sector sensitivity. Refs. [19, 20] argue that the economic sector plays an important role in determining the level of social and environmental disclosure. Sensitivity is related to sectors controlled by governments, and their activities are controlled by the social and environmental regulations in the country, such as the rate of gas emissions and the laws related to the protection of workers' rights. I give a one for the sensitive sector and zero for the nonsensitive sector.

After presenting the variables of this study, the principle model is as follow:

$$\text{SMTH} = a^{*}\,\text{SR} + b^{*}\,\text{SIZE} + {}^{*}\,\text{SECT} +$$

where

SMTH: income smoothing.

SR: sustainability reporting.

SIZE: firm size.

SECT: sector sensitivity.

### 3.3. Hypothesis test and results

#### *3.3.1. Descriptive statistics*

**Table 1** summarizes the descriptive statistics of the variables; Panel A shows the continuous variables, and Panel B shows the dummy variable. The main conclusion of **Table 1** is the score of sustainability reporting (47.566). I conclude that the score is high comparing it with scores in other similar studies. Loh et al. [22] obtained a score of 43.6 for sustainability reporting among the 186 firms that communicated sustainability.

#### *3.3.2. Hypothesis test*

This study is applied to a sample of 94 Saudi firms in a 3-year period from 2014 to 2016, and the hypothesis test is conducted via a regression of the panel data. For this regression, it is necessary to start by checking the conditions relating to the robustness of the econometric model, heteroskedasticity and multicollinearity.

After the significance test of the empirical model, I test for Heteroskedasticity, via the White Test. According to **Table 2**, I conclude the absence of Heteroskedasticity. Furthermore, I test the presence of multicollinearity using a variance inflation factor. **Table 3** shows that multicollinearity is not a problem.

Moreover, I perform a test of normally distributed variables and residuals. For this, the Jarque-Bera Normality Test is the most used. This test estimates whether the skewness (S) and kurtosis (K) of the sample match a normal distribution. The results show that there is not a problem related to normality.

Finally, I conduct the linear regression for panel data to test the relationship between sustainability reporting and income smoothing. **Table 4** shows these results.

| **Panel A: Descriptive statistics for continuous variables** | | | | | |
|---|---|---|---|---|---|
| Variables | Observations | Mean | Standard deviation | Minimum | Maximum |
| SMTH | 282 | 0.894 | 0.630 | 0.005 | 2.435 |
| SR | 282 | 47.566 | 26.838 | 0 | 88 |
| SIZE* | 282 | 11.226 | 3.458 | 4.559 | 19.119 |
| **Panel B: Descriptive statistics for dummy variables** | | | | | |
| Variable | Groups | Frequency/ companies | Frequency/ observations | Percent cumulative percent | |
| SECT** | 0 | 50 | 150 | 53.13 | |
| | 1 | 44 | 132 | 46.87 | |

*The values of total assets are logarithmic.

**Sensitivity sector, usually considered as the petroleum, chemical, metals, and paper industry [21].

**Table 1.** Descriptive statistics for all variables.

| **Heteroskedasticity test for the model** | | | |
|---|---|---|---|
| **Test** | **Statistic** | **df** | **p > Chi2** |
| White test | 32.66 | 18 | 0.000 |

**Table 2.** Heteroskedasticity test.

| **Multicollinearity test (variance inflation factor) for model** | | |
|---|---|---|
| **Variables** | **VIF** | **Tolerance** |
| SMTH | 1.77 | 0.56 |
| SR | 1.44 | 0.69 |
| SIZE | 1.09 | 0.91 |
| SECT | 1 | 1 |

**Table 3.** Multicollinearity test.

| **Dependent variable** | **Relation between income smoothing SMTH and sustainability reporting (SR score)** | | | | | |
|---|---|---|---|---|---|---|
| **(SMTH)** | **Coeff.** | **Std err.** | **t** | **P > \|t\|** | **[95% conf.** | **interval]** |
| SR | 0.056 | 0.042 | 2.773 | 0.041** | 0.027 | 0.069 |
| SIZE | 0.007 | 0.002 | 2.053 | 0.091*** | 0.061 | 0.163 |
| SECT | 0.108 | 0.099 | 2.097 | 0.001* | 0.083 | 0.112 |

*Significance at 1%.
**Significance at 5%.
***Significance at 10%.

**Table 4.** Hypothesis test—linear regression.

The above scores improve slightly over the 3-year period (2014–2016): sustainability reporting positively and significantly affected the income smoothing practice made by Saudi-listed companies at the 5% level. Furthermore, the effect of firm size on the income smoothing practice is significantly positive at a level of 10%. Concerning the role of the sector sensitivity, I also note a significantly positive effect on income smoothing at the 1% level.

## 4. Discussion and conclusion

Sustainable development is a complex concept that opens the door to many interpretations and topics on the usefulness and credibility of accountability of sustainable development.

The study tried to explain the link between earnings quality (attributes) presented by income smoothing and the sustainability communication made by Saudi-listed companies. Empirical results show a significant effect of sustainability reporting on income smoothing.

Obtained results can enrich literature in both empirical and theoretical area. From a managerial point of view, this research can lead to several lessons for both business managers and organizational consultants. A manager can find innovative, differentiated, and heterogeneous social responsibility practices, including integrating new organizational concerns into business management, as well as new organizational standards (ISO 26000).

This study may be of interest to several actors, in particular companies, in general, and companies following a social responsibility approach, in particular. Rating agencies are also concerned, as this research can help to think about the societal rating system in Saudi Arabia.

## 5. Limits and perspectives of research

This research suffers from certain limitations associated with the adopted methodology. The limited number of variables and the sample chosen does not allow a generalization of the results on the advantages and disadvantages of the societal commitment of companies labeled as sustainable in Saudi Arabia.

Several avenues can be considered to continue this research. I can treat this issue by targeting both labeled and unlabeled companies as a comparative study of these two types of companies in terms of added value. In other words, I can conduct a comparative study in the same domain between Gulf countries.

## Appendices and nomenclature

## Appendix 1: Sample companies

| Company | Sector |
|---|---|
| Advanced Petrochemical Co. | Petrochemical industries |
| Alujain Corp. | Petrochemical industries |
| Methanol Chemicals Co. | Petrochemical industries |
| Nama Chemicals Co. | Petrochemical industries |
| National Industrialization Co. | Petrochemical industries |
| National Petrochemical Co. | Petrochemical industries |
| Rabigh Refining and Petrochemical Co. | Petrochemical industries |
| Sahara Petrochemical Co. | Petrochemical industries |
| Saudi Arabia Fertilizers Co. | Petrochemical industries |
| Saudi Basic Industries Corp. | Petrochemical industries |
| Saudi Industrial Investment Group | Petrochemical industries |
| Saudi International Petrochemical Co. | Petrochemical industries |
| Saudi Kayan Petrochemical Co. | Petrochemical industries |

| **Company** | **Sector** |
|---|---|
| Yanbu National Petrochemical Co. | Petrochemical industries |
| Al Jouf Cement Co. | Cement |
| Arabian Cement Co. | Cement |
| City Cement Co. | Cement |
| Eastern Province Cement Co. | Cement |
| Hail Cement Co. | Cement |
| Najran Cement Co. | Cement |
| Northern Region Cement Co. | Cement |
| Qassim Cement Co. | Cement |
| Saudi Cement Co. | Cement |
| Southern Province Cement Co. | Cement |
| Tabuk Cement Co. | Cement |
| Umm Al-Qura Cement Co. | Cement |
| Yamama Cement Co. | Cement |
| Yanbu Cement Co. | Cement |
| Abdullah Al Othaim Markets Co. | Retail |
| Al Hammadi Company for Development and Investment | Retail |
| Aldrees Petroleum and Transport Services Co. | Retail |
| Alkhaleej Training and Education Co. | Retail |
| Dallah Healthcare Holding Co. | Retail |
| Fawaz Abdulaziz Alhokair Co. | Retail |
| Fitaihi Holding Group | Retail |
| Jarir Marketing Co. | Retail |
| Mouwasat Medical Services Co. | Retail |
| National Agricultural Marketing Co. | Retail |
| National Medical Care Co. | Retail |
| Saudi Automotive Services Co. | Retail |
| Saudi Company for Hardware | Retail |
| Saudi Marketing Co. | Retail |
| United Electronics Co. | Retail |
| National Gas and Industrialization Co. | Energy and utilities |
| Saudi Electricity Co. | Energy and utilities |
| Al-Jouf Agricultural Development Co. | Agriculture and food industries |
| Almarai Co. | Agriculture and food industries |

| Company | Sector |
|---|---|
| Anaam International Holding Group | Agriculture and food industries |
| Ash-Sharqiyah Development Co. | Agriculture and food industries |
| Bishah Agricultural Development Co. | Agriculture and food industries |
| Halwani Bros. Co. | Agriculture and food industries |
| Herfy Food Services Co. | Agriculture and food industries |
| Jazan Development Co. | Agriculture and food industries |
| National Agricultural Development Co. | Agriculture and food industries |
| Qassim Agricultural Co. | Agriculture and food industries |
| Saudi Airlines Catering Co. | Agriculture and food industries |
| Saudi Fisheries Co. | Agriculture and food industries |
| Saudia Dairy and Foodstuff Co. | Agriculture and food industries |
| Savola Group | Agriculture and food industries |
| Tabuk Agricultural Development Co. | Agriculture and food industries |
| Wafrah for Industry and Development Co. | Agriculture and food industries |
| Al Abdullatif Industrial Investment Co. | Industrial investment |
| Al Hassan Ghazi Ibrahim Shaker Co. | Industrial investment |
| Al Sorayai Trading and Industrial Group | Industrial investment |
| Astra Industrial Group | Industrial investment |
| Basic Chemical Industries Co. | Industrial investment |
| Filing and Packing Materials Manufacturing Co. | Industrial investment |
| Middle East Paper Co. | Industrial investment |
| National Metal Manufacturing and Casting Co. | Industrial investment |
| Saudi Arabian Mining Co. | Industrial investment |
| Saudi Chemical Co. | Industrial investment |
| Saudi Industrial Export Co. | Industrial investment |
| Saudi Paper Manufacturing Co. | Industrial investment |
| Saudi Pharmaceutical Industries .. | Industrial investment |
| Takween Advanced Industries Co. | Industrial investment |
| The National Company for Glass Industries | Industrial investment |
| Abdullah A. M. Al-Khodari Sons Co. | Building and construction |
| Al-Babtain Power and Telecommunication Co. | Building and construction |
| Arabian Pipes Co. | Building and construction |
| Bawan Co. | Building and construction |

| Company | Sector |
|---|---|
| Electrical Industries Co. | Building and construction |
| Middle East Specialized Cables Co. | Building and construction |
| Mohammad Al Mojil Group | Building and construction |
| National Gypsum Co. | Building and construction |
| Red Sea Housing Services Co. | Building and construction |
| Saudi Arabian Amiantit Co. | Building and construction |
| Saudi Cable Co. | Building and construction |
| Saudi Ceramic Co. | Building and construction |
| Saudi Industrial Development Co. | Building and construction |
| Saudi Steel Pipe Co. | Building and construction |
| Saudi Vitrified Clay Pipes Co. | Building and construction |
| United Wire Factories Co. | Building and construction |
| Zamil Industrial Investment Co. | Building and construction |

## Appendix 2: Terms of sustainability reporting index

| Dimensions | Terms |
|---|---|
| Expenditures and risks | • Investments |
| | • Operation costs |
| | • Future investments |
| | • Future operating costs |
| | • Financing for investments |
| | • Environmental debts |
| | • Risk provisions |
| | • Risk litigation |
| | • Provision for future expenditures |
| Laws and regulations conformity | • Litigation, actual and potential |
| | • Fines |
| | • Orders to conform |
| | • Corrective action |
| | • Incidents |
| | • Future legislation and regulations |

| Dimensions | Terms |
|---|---|
| Pollution abatement | • Emission of pollutants<br>• Discharges<br>• Waste management<br>• Installation and process controls<br>• Compliance status of facilities<br>• Noise and odors |
| Sustainable development | • Natural resource conservation<br>• Recycling<br>• Life cycle information |
| Land remediation and contamination | • Sites<br>• Efforts of remediation<br>• Potential liability remediation<br>• Implicit liability<br>• Spills (number, nature, efforts of reduction) |
| Environmental management | • Environmental policies or company concern for the Environment<br>• Environmental management system<br>• Environmental auditing<br>• Goals and targets<br>• Awards<br>• Department, group, service affected to the environment<br>• ISO 14000<br>• Involvement of the firm in the development of environmental standards<br>• Involvement in environmental organizations<br>• Joint projects with other firms providing environmental management services |
| Labor practices and decent work | • Absenteeism and reasons<br>• Employment opportunities<br>• Labor rights/job creation<br>• Rehiring, accompanying, social communication<br>• Equity programs<br>• Human capital development/training<br>• Accidents at work<br>• Health and safety programs<br>• Employee savings |

| Dimensions | Terms |
| --- | --- |
| Society | • Regional development<br>• Gifts and sponsorships<br>• Business ethics/measures anticorruption<br>• Strategic alliances<br>• Community involvement<br>• Dispositions of the International Labor Organization<br>• Relations with stakeholders (environmental groups, consumer associations, …) |
| Consumer and product responsibility | • Purchases of goods and services<br>• Product-related incidents<br>• Product development and environment<br>• Consumer health and safety/product safety |

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Chapter 3

# Methodologies for Assessing Sustainability in Farming Systems

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Additional information is available at the end of the chapter

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**Abstract**

Development of composite indicators is considered an important approach for evaluating sustainable development. For agriculture, different indicators have been developed such as Delphi, IDEA, MESMIS, MOTIFS, RISE, or SAFE. For its construction, usually bivariate and multivariate statistical techniques were employed. These are pragmatic tools used to simplify the description of complex systems by the use of three functions: to simplify, to quantify, and to communicate easily. Criteria for indicator selection include policy relevance, validity, accessibility, and measurability. However, operational evaluation of agricultural sustainability presents problems, because it requires analyzing the future production of goods and services, which need to be observed on a reasonable time horizon, and other difficulties involve interpreting the combination of indicators required for such analyses. This chapter realizes a review of these methodologies and its applications.

**Keywords:** sustainable development, indicators, index, organic, natural resources

## 1. Introduction

The meaning of sustainability and sustainable development is different. Neufeldt [1] mentioned that sustainability is the ability to "keep in existence; keep up; maintain or prolong." Hildebrand [2] suggested that it may be interpreted as the length of time that a system can be maintained. Monteith [3] added the possible interaction of changes in input and output levels. And according to the Brundtland report, sustainable development is defined as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" [4]. The formalization of this concept was completed by three pillars—social, environmental, and economic—described in the World Summit on Sustainable Development in 2002 [5].

According to Hamrin [6], natural resources and the environment "constitute the ultimate foundation upon which all future economic activity must be construed. From this, it follows that future economic progress will be increasingly dependent on the sustained integrity of the resource and environmental base." The economic crisis shows that maintaining economic growth is an essential objective accepted and growth has been the most important policy goal across the world; it is the reason why it is difficult to find a balance between sustainability and the economic growth [7].

Social sustainability requires that the cohesion of society and its ability to work towards common goals are maintained. Social sustainability (social values, identities, relationships, and institutions) is probably the most important and critical long-term "pillar" of sustainable development for survival of civilization as shown in the study of past (and contemporary) societies [8, 9].

Environmental sustainability seeks to protect the sources of raw materials ensuring that the sinks for human wastes are not exceeded to prevent harm to humankind [10]. This conceptualization fits into the resource-limited ecological framework and "limits to growth" described by Meadows et al. [11]. OECD [12] considered criteria like regeneration (renewable resources should be used efficiently and their use should not be permitted to exceed their long-term rates of natural regeneration), substitutability (non-renewable resources should be used efficiently and their use limited to levels which can be offset by substitution with renewable resources or other forms); assimilation (releases of hazardous or polluting substances into the environment should not exceed their assimilative capacity); and irreversibility.

There is a recognition that the three pillars of sustainable development need to be complemented by institutional, cultural, or ethical dimensions and including governance, efficiency, motivation, values, and other factors that may be important for sustainable human prosperity. It is essential to maintain the ecosystem and nature's services to assure the human well-being. Sustainability science must research the most significant driving forces, impacts, and their causal relationships and identify the relevant indicators to the points in the system where management actions would be most effective. Compiling many separate indicators cannot provide an adequate measure of the systems sustainability. But modeling systems help to explore resilience and tipping points or developing alternative scenarios to anticipate vulnerabilities in the natural, social, and economic dimensions. Indicators at the individual level are relevant to the changes in personal motivation and their behavior and essential for a sustainable society [13].

The aim of this paper is to review the main methodologies for assessing sustainability in farming systems.

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## 2. Sustainable agriculture

Conventional agriculture is characterized as a system with intensive use of capital, large-scale, highly mechanized agriculture with monocultures of crops and extensive use of artificial fertilizers, herbicides, and pesticides, with intensive animal husbandry [14]. This has led to an increase in the use of fertilizers, synthetic pesticides, antibiotics, hormones, and fossil fuels and consequently led to an increase in environmental problems [15]. The problems associated with "conventional agriculture" were perceived as unsustainable [16]. These impacts, such as depletion of non-renewable resources, soil degradation, environmental effects of agricultural chemicals, inequity, declining rural communities, loss of traditional agrarian values, farm worker safety, decline in self-sufficiency, and decreasing number and increasing size of farms, reflect the goal of promoting alternatives.

The definition of "sustainable agriculture" is an activity that permanently satisfies a given set of conditions for an indefinite period of time [17]. Sustainable agriculture has been described as a term encompassing several ideological approaches including organic farming, biological agriculture, ecological agriculture, biodynamic agriculture, regenerative agriculture, permaculture, and agroecology [16, 18–20]. Neher [21] considered it as an approach or a philosophy that integrates land stewardship with agriculture, where land is managed with respect to allow a future for next generations. This philosophy guides the application of prior experience and the latest scientific advances to create integrated, resource-conserving, equitable farming systems [22].

A sustainable agricultural system is often defined as one that fulfills a balance of several goals including some expression of maintenance or enhancement of the natural environment, provision of human food needs, economic viability, and social welfare through time [17]. This multidimensional character inherent in the concept of sustainable development requires from the triple perspective of profitable operation, fair and equitable distribution of the generated wealth, and its compatibility with the maintenance of natural ecosystems [23].

For agriculture with alternative practices, Beus and Dunlap [24] listed values like community, independence, decentralization, diversity, and harmony with nature. Social values such as equity, self-sufficiency, preservation of agrarian culture, and preference for small owner-operated farms have been incorporated into definitions of sustainability [22, 25].

Excessive chemical input levels degrade natural resources through accumulation, while inadequate levels degrade resources through exhaustion. Zandstra [26] and Stinner and House [27] in sharp contrast described sustainability as a function of chemical input levels.

In general, the society accepted that organic production may contribute to mitigate environmental problems. Organic farming practices help to promote the sustainable land use and improve environment conservation, animal welfare, and products' quality [28–30]. As a general principle, this organic agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of future generations and the environment [31].

Sustainable land use management is necessary to shorten the gap between planning practice and research regarding landscape [32–34].

## 3. Methodologies for assessing sustainability in agricultural systems

The methodological problems imposed by the temporal nature of sustainability have hindered the development of approaches for its characterizing. Sustainability involves future outcomes that cannot be observed in the time frame required for intervention [35, 36].

Environmental sustainability is the maintenance of natural resources. These can be expressed as environmental objectives: water, soil, and air quality and maintenance of biodiversity. At the farm level, an agricultural system is sustainable if it conserves the natural resources provided by its ecosystem [10, 37, 38].

In order to maintain the production, it would be useful to follow a method to evaluate the degree of approximation between different systems and identify aspects to improve on each farm. This method should be broad and multidimensional [39, 40] and should address the management of animals, soils and vegetation, as well as environmental, economic, and social aspects. They should be expressed through indicators so as to compare different farms in a region or country and analyze the evolution over time [41].

Spohn [42] identifies two main approaches for sustainability assessment:

- The "bottom-up" approach, which requires systematic participation to understand the framework as well as the key sustainable development indicators.
- The "top-down" approach, which enables to define the overall structure for achieving the sustainability, and subsequently, it is broken down into a set of indicators.

There have been developed a large number of sustainability assessment tools to gain insight into the sustainability performance of farms. These tools generally integrate a wide range of subjects and indicators to develop a holistic view on farm-level sustainability and are used for different purposes, such as monitoring, certification, consumer information, farm advice, and research [43–46]. Moreover, after a sustainability assessment, additional efforts are needed to discuss the assessment outcomes with farmers and other stakeholders and translate these into meaningful decisions for change [43, 44, 47].

Creating a tool requires collaboration between researchers and farmers; input from farmers needs to be accepted as being complementary to traditional scientific knowledge [48]. Sustainability indicators are often developed by scientists, expressed in technical language. It is commonly accepted that if the stakeholders, who will ultimately benefit from indicators, are involved in indicator conceptualization and development, then it is far more likely that they would use and appreciate the results [49, 50]. One of the main roles of indicators is communication with stakeholders. Hence, several authors [48, 51] agree that the participation and consultation of farmers is a key element in building and developing indicators. However, different types of stakeholders can interpret indicators differently, due to different values, interests, or cultural and academic context. Most of the literature on stakeholder participation associated with sustainability indicators focus on participation in the design and development of indicator systems or in data collection for indicator calculation [52]. According to Jackson et al. [53], a useful indicator must produce results that are clearly understood and accepted by scientists, policy makers, and general public [54].

At another related level, self-assessment approaches used by local communities are examples of complementary approaches to the more traditional use of indicators for measuring and communicating sustainability-related issues. Community-based monitoring refers to a range of activities through which concerned citizens gather and record systematic observations about social or environmental conditions, often in collaboration with academia, industry, government, or community institutions [55]. Through participatory monitoring and evaluation, research in the late 90s has revolved around finding ways to help different people to identify clearly their information needs and acceptable forms of assessing information [56]. Stakeholders' own assessment of sustainability performance could be used to make qualitative comparative analysis with the formal technical assessments that are provided by indicators. As an indirect way of evaluating the strengths and weaknesses of the technical indicator sets and concluding about its overall utility, an evaluation of sustainability indicators by stakeholders can be used. Significant gaps between indicator data and stakeholders' perceptions can point to a failure in fulfilling that role. The credibility of sustainability self-assessment and the related procedures and outcomes analysis is a relatively underexplored issue, but it could be of particular importance [57].

Sustainability indicators are a tool that can be used by farmers at the farm or field level to assess the effects of managerial changes [58]. Many indicators are purely theoretical, in which modeling, equations, and simulations are used to provide an evaluation and cannot be used directly as a decision tool by farmers. At the farm level, complex tools that require a lot of information and expert knowledge to provide environmental estimates are generally not suitable. Many indicators for other kinds of assessment or monitoring are transferred to agriculture to let farmers assess and evaluate farming systems [59].

As Van de Fliert and Braun [60] attest, farmers have a critical role to play in assessing sustainable agriculture because their responsibilities for managing natural resources are increasing. Zhen and Routray [61] proposed that assessments should be closely linked to the context of specific farming systems. Several frameworks that assess sustainability include the development of indicators [38, 62, 63]. According to the context, the framework can change with different end-users and it should incorporate characteristics that can be generally applied under different conditions [38].

Girardin et al. [64] reported that the environmental impacts of an agricultural practice can be compared with reference values. These reference values can be a target value, defined as an optimal level, or as the minimal level required for sustainability [63]. Reference values provide guidelines to improve farm systems.

To deal a challenge with measurement for sustainability and its dimensions, a variety of methods or agri-environmental indicators have been developed [43, 44, 51, 65–69]. For instance, some researchers focused on investigated environmental phenomena related to farming systems and/

or farming practices [43, 44, 51, 61, 70–73]. The indicator accounting methods in the literature have usually been proposed for specific farming sectors, such as arable farms (i.e., method AEI by Girardin et al. [64] evaluating the impact of practices on agroecosystem and its environment); crops, livestock, and forestry (i.e., method LCAE by Rossier [74] or SD by Pointereau et al. [75] evaluating the environmental impact); and for specific target groups (i.e., method IFS by Vilain [76] or MOP by Vereijken [77]) such as farmers, farm advisers, policy makers, or researchers [70, 78, 79].

Agroecological studies have recognized the importance of analyzing environmental impacts as an aspect for measuring environmental sustainability in agriculture [38, 64, 69, 78, 80]. Different environmental objective groups (or attributes) were assessed in these studies. Notably, the Agro-Ecological System Attributes (AESA) and the Statistical Simulation Modeling (SSM) approaches covered three environmental objective groups. The Response Inducing Sustainability Evaluation (RISE) and Scenario Based Approach (SBA) incorporated only two environmental objective groups. Some agroecological sustainability indicators have been formulated considering any environmental objective group. For instance, Farmer Sustainability Index (FSI), Sustainable Agricultural Practice (SAP), Sustainability Assessment of the Farming and the Environment (SAFE), Environmental Sustainability Index (ESI), and Multi-scale Methodological Framework (MMF) methods [81].

## 4. Indicators for assessing sustainability

An indicator is a variable that reflects or explains other variables that are more difficult to understand or quantify [82]. Indicators are a pragmatic tool used to simplify the description of complex systems. They can be used individually, as part of a set, or aggregated within a set to increase understanding by end-users [83]. Indicators are only as good as the data behind them [13]. The three functions of an indicator are to simplify, quantify, and communicate easily. At the farm level, indicators may be the best approach for assessing sustainability directly and assessing the environmental status of farm resources [59].

Indicators simplify, quantify, and analyze the complex and complicated information [84]. When the indicators are defined, they have to be measured by quantitative and qualitative techniques. The main difficulties related to obtaining the indicators are their selection, interpretation, and use. They can be used to determine a trend to have a notion of what is acceptable or to establish a baseline [7, 85, 86]. The existence of a target is of key importance, regardless of the type of target. Even a vague, qualitative target may be an important policy driver. The benefit of specific, quantitative, time bound targets is then straightforward; the indicators can be linked to these and interpreted clearly on a distance-to-target basis. Targets can be based on international treaties, agreements, or derived from environmental and public health standards developed by international organizations, national governments, or expert opinion (i.e., 2015 United Nations climate change conference), and they represent an ideal state [7]. Stieglitz et al. [87] mentioned that humans need an assessment of how far they are from sustainable targets.

The indicators are adopted by countries and corporations because of their ability to condense the enormous complexity of the dynamic environment to a manageable amount of meaningful information [88].

The selection of sustainability indicators is essentially a political process [89, 90]. This implies reconciling "expert-led" and "community-led" perspectives on sustainable development priorities [91]. OECD [92] included criteria for indicator selection as follows:

- Policy relevance: It should address issues considered of importance for policy making.
- Validity: It may be viewed from a variety of perspectives, including those of scientists, farmers, rural residents, and consumers. Therefore, a valid indicator must be able to reconcile the need for sound scientific analysis with a requirement to be recognized as legitimate by other non-scientist.
- Accessibility: The selection of an indicator must match to the scale that is appropriate to those decision-makers avoiding relevance at only a particular scale.
- Measurability: To monitor policy impact, the importance is the availability or easy acquisition of data.

There have been consistent efforts at international level to identify appropriate sustainability indicators. The United Nations Commission on Sustainable Development (UNCSD) has derived a list of 58 indicators for all countries to use. Booysen [93] defined the following general dimension of measurement for the classification and evaluation of indicators:

- Aspects of sustainability measured by indicators.
- Methods for development of indexes (quantitative/qualitative, subjective/objective, cardinal/ordinal, unidimensional/multidimensional).
- Indicators comparing sustainability measure across "time-series" or "cross-section," absolute or relative manner.
- Measuring sustainability in terms of input ("means") or output ("ends").
- Clarity and simplicity in its content, purpose, method, comparative application, and focus.
- Availability of data.
- Flexibility for allowing change, purpose, method, and comparative application.

The accuracy and credibility related with the evaluation of sustainability indicators are an essential aspect of their development process. The progress towards a more sustainable agricultural production can only be made when the objectives defined by different stakeholders can be translated into practical measures.

A major aspect of the design of indicators is the use of participatory processes. Expert participation provides a preliminary validation of the indicator set. Compromises between feasibility, practicability, and relevance of measurements should be considered including spatial and temporal scales. The farmers validate the tool by evaluating their own results. Through this validation, reference values will need to be established as farmers adopt new practices [59].

## 5. Compound indexes

The construction of composite indicators involves selection of various methods at different stages of development process [94]. Development of composite indicators is considered to be a unique approach for evaluating sustainable development. Composite indices can be constructed with or without weights depending on its application. Indices are very useful in focusing attention and often simplify the problem [95]. The selection of the appropriate methods depends on the data and the scope of the study. After aggregation of indicators, an index requires to be checked for robustness and sensitivity.

There is a critical need to develop indicators to assess the relative degree of sustainability of the production systems, especially those throughout the rural sector of the developing world [62]. This is important for the Natural Resource Management Systems (NRMS) in the peasant context, because despite being highly resilient, diverse and based on the use of renewable local natural resources, have been undervalued on the basis of criteria that focus on short-term economic benefits. Its complexity has been alluding to the tight interactions among the different activities related to natural resource management and their repercussion in the satisfaction of a multiplicity of economic, environmental, and social objectives [96, 97].

For constructing a composite index, policy goal has to be clearly defined [93]. When empirical analysis is used for selection, bivariate and multivariate statistical techniques can be employed. Bivariate analysis measures the correlation between all pairs of variables using correlation matrices, while multivariate analysis assesses the strength of any set of variables to measure any other variable, using discriminant, principal component, and factor analyses. The objective of these techniques is to determine the number of key variables that influence the composite index [98].

For performing the scaling for composite indexing purposes, Booysen [93] defined that the use of standard scores (z and t values) can be employed for composite indexing, it can be transformed in the form of ordinal response scales for surveys results, or it can be scaled on conventional linear scaling transformation method.

Weighting system and method employed in aggregating component scores plays a predominant role for development of composite index [93]. Multivariate techniques provide relatively better option for weight selection. Some of the key methods of aggregation employed are principal components analysis, factor analysis, distance to targets, expert's opinion (budget allocation), and analytic hierarchy process. Principal component analysis is one of the widely used multivariate analysis tools for weighting of components based on the proportion of variance. Once the weights have been assigned to each indicator and this is transformed into component score, these scores are aggregated into a composite score [93]. Sensitivity analysis along with proper validation should be done on composite indices [99]. Based on the validation results, indices need to be improved and adjusted. Validation is normally performed by using either item analysis or external validation [93]. There is always a requirement for demonstrating proper evidence through the reliable results while using composite index [100].

Using composite indices does not solve the problem, as there are controversies for defining the weight attached to each indicator. Methodological frameworks are needed for the selection of appropriate indicators and in the integration and transformation of the information to set the basis for the design of more sustainable alternatives. Conway [101] and Garcia [102] suggested that for an interdisciplinary analysis it has to produce insights that significantly transcend those of the individual participating disciplines. Systems theory holds that certain principles stand for all systems regardless of its hierarchical level [101, 103]. Identifying a set of central systemic attributes (or properties) that holds across disciplines or scales is therefore fundamental to keep the evaluation of sustainability and the derivation of indicators theoretically consistent.

The development of evaluation frameworks and indicators that make explicit the environmental, economic, social, and cultural advantages and disadvantages of the different NRMS let to improve not only the system's productivity or profitability but also the stability, resilience, reliability of resources management, adaptability, equity, and self-reliance [62].

To provide useful indicators based on benchmarking, trend analysis, and decoupling, Kovanda and Hak [104] developed Material Flow Analysis (MFA), and other attempts to conceptualize sustainable resource management were developed based on the idea of '*carrying capacity*' [105] to express the idea of biophysical limit to use of resources. Wackernagel and Rees [106] developed the Ecological Footprint (EF) indicator based on the amount of biologically productive land and water area required to support a population at its current level of consumption. EF is used to estimate environmental sustainability at national and global level. And the Eco-Index Methodology [107] measures the impact of different products, services, and lifestyles. It takes care of entire life cycle data for assessing the EF conversion factors for most of the key components. The ecological footprint (as measured using global average yields) is normalized by the application of equivalence factors. **Table 1** presents some of the environmental indices developed through the time.

| Index | Description | Reference |
|---|---|---|
| Ecological Footprint (EF) indicator | Footprint is calculated based on either compound or component or combination of these methods | [106] |
| Living Planet Index (LPI) | It tries to assess the overall state of the Earth's natural ecosystems, which includes human pressures on natural ecosystems arising from the consumption of natural resources and the effects of pollution | [108] |
| Eco-Index Methodology | Utilizes "bottom-up approach" methodology | [107] |
| Environmental Sustainability Index (ESI) | ESI scores are based upon a set of 20 core indicators each of which combines 2–8 variables for a total of 68 underlying variables. Its permits cross-national comparisons of environmental progress | [109, 110] |
| Environmental Performance Index (EPI) | It aims to evaluate a set of environmental issues monitored through 6 policy categories | [111] |
| Environmental Vulnerability Index (EVI) | This comprises 32 indicators of hazards, 8 indicators of resistance, and 10 indicators that measure damage | [112] |

**Table 1.** Some environmental indices used.

Rockstrom et al. [113] have introduced the concept of *planetary boundaries*. It is based on the knowledge that the Earth's subsystems react in a nonlinear way and often are particularly sensitive around the threshold levels of variables such as $CO_2$ concentration. The authors identified nine processes and thresholds associated to an unacceptable environmental change: climate change, rate of biodiversity loss (terrestrial and marine), interference with the nitrogen and phosphorus cycles, stratospheric ozone depletion, ocean acidification, global freshwater use, change in land use, chemical pollution, and atmospheric aerosol loading.

The degree of complexity with which each indicator is obtained, for example through field measurements, mathematical models, and simulation models, also presents drawbacks in the comparison between systems evaluated by different methodologies. Many of the mentioned indicators lack the capacity to predict the state and the variation of the human system with the natural system, having to be looked at together with other indicators to obtain those properties, complicating the understanding of the results [114].

## 6. Methods to evaluate sustainability in farming systems

Also for agriculture and livestock systems, different indicators have been developed (**Table 2**). Some indicator-based farm monitoring tools are visual integration tools, aggregating scores of a set of sustainability indicators into radar graphs [66] or bar graphs [129]; others are numerical

| **Method** | **Description** | **Reference** | **Examples** |
|---|---|---|---|
| Delphi | This technique is normally used to solve complex problems or generate strategies. It was adapted in agriculture to consult experts and to build and select the indicators | [48, 115] | Dairy farm sustainability in Quebec [59] |
| MESMIS (Marco para la Evaluación de Sistemas de Manejo incorporando Indicadores de Sustentabilidad; in English: Management Systems Assessment Framework Incorporating Sustainability Indicators) | The method does the characterization of the systems, the identification of critical points, and the selection of specific indicators for the environmental, social, and economic dimensions of sustainability. The information obtained by means of the indicators is integrated through mixed (qualitative and quantitative) techniques and multicriteria analysis | [62, 116] | Extensive livestock farming in Spain [117]<br>Low input maize systems in Central México [118] |
| IDEA (*Indicauters de Durabilité des Exploitations Agricoles*; in English: Agricultural Sustainability Indicators) | It assesses whole-farm sustainability with agri-ecological (18 indicators), socio-territorial (18 indicators), and economic (6 indicators) scales | [119] | Small ruminants in Liban [120]<br>Sheep farming systems in Morocco [121] |
| RISE (Response-Inducing Sustainability Evaluation) | This tool is also designed to be used with all types of production and evaluates three aspects of sustainability with a set of 12 indicators. Each indicator includes a state measure and a driving-force measure | [79, 122] | Dairy farms in China [79]<br>Tea farms in Southern India [47]<br>Armenian dairy farms and agriculture [123] |

| Method | Description | Reference | Examples |
|---|---|---|---|
| SAFE (Sustainability Assessment of Farming and the Environment Framework) | This is based on the goods and services provided by agricultural ecosystems, resulting in the primary level of the hierarchy, the principles that are correlated with the three dimensions of sustainability: economic, social, and environmental | [38, 124] | Belgian farms of Dairy, Poultry, Beef and Crop production [124] |
| MOTIFS (Monitoring Tool for Integrated Farm Sustainability) | It allows to monitor farm progress towards integrated sustainability, taking into account economic, ecological, and social aspects | [125] | Flemish dairy farms [126] |
| OLPI (Organic Livestock Proximity Index) | Nine indicators integrated in a global index: Nutritional management, Sustainable pasture management, Soil fertility and contamination, Weed and pest control, Marketing and management, Disease prevention, Breeds and reproduction, Animal welfare, and Food safety | [41] | Dairy Goat in Southern Spain [41] Dairy systems in Mexico [127] |
| SASM (Sustainable agricultural spatial model) | Take into consideration the land use, geomorphology, and the five factors of sustainability: productivity, security, protection, economic viability, and social acceptability. Mathematical formula expressing sustainability index as a result of the various criteria | [128] | Agriculture in Northern Sinai [128] |

**Table 2.** Methods for evaluate sustainability in farming using composite indicators of agricultural sustainability (CIAS).

integration tools, aggregating values into a single composite index [83]. Clark and Dickson [130] identified saliency, credibility, and legitimacy as three characteristics that determine the effectiveness and success of an assessment tool. The relevance or value of an assessment tool is the use in decision-making. Credibility is authoritativeness of the information and conclusion of the tool. Finally, legitimacy relates to the perceived fairness and openness of the assessment process to political constituencies.

Hardi and Zdan [131] described the “Bellagio Principles” as guidelines for practical assessment of progress towards sustainable development. The assessment should reflect a view of the linkages between the social, environmental, and economic aspects. Essential elements like equity and disparity, economic development, and ecological conditions should be considered. The process of developing the assessment tool should be open, with an effective communication and a broad participation; it should be a continuous, iterative, and adaptive process that provides ongoing support in the decision-making process. An effective model expresses its credibility with the potential users’ confidence and the information derived from it. When occur the translation of the experience of model validation to indicator validation, it is important to consider two aspects: an evaluation of the indicator’s accuracy and an evaluation of its credibility [126].

Nevertheless, a conceptualization of agricultural sustainability presents problems with regard to its operational concretization. First, sustainability requires analyzing the future production of goods and services by agriculture, a requirement that need to be observed on a reasonable time horizon. Secondly, it is difficult to identify what specific demands agriculture needs to satisfy in order to be sustainable. The greatest difficulty involves interpreting the combination of indicators required for such analyses. Applying various methods of aggregation, the combinations of multidimensional indicators into indices or composite indicators were the contributions of van Calker et al. [132], Hajkowicz [133], and Qiu et al. [134], among others. Composite indicators are an opportunity to identify which aspects of agricultural sustainability are relevant in practice and these are called CIAS (composite indicators of agricultural sustainability) (**Table 2**).

In the context of multicriteria decision-making, most applications require criteria to be weighted according to importance [135]. The literature shows a plethora of techniques available to build sustainability indices. Some guidance regarding the construction of composite indicators consider a selection of relevant indicators based on strict quality criteria and accurate data gathering to calculate empirical values of these indicators. Before any aggregation, transforming base indicators into dimensional variables (normalization) is required. For this purpose, the use of multiple attribute utility theory and reference values is suggested [23, 93]. According to the importance for each dimension/indicator, the composite indicator had the assignment of weighting. Although there exist a wide variety of functional forms that permit indicators to be aggregated, the use of indices should be done with caution in all cases. All such attempts must be regarded as partial representations of a complex reality. Individual treatment of different agricultural systems allows introducing methodological differences such as the choice of indicators for the evaluation of the empirical sustainability of each case study and the individual treatment of the results [23].

The *Delphi technique* was used to consult experts or advisers (i.e., researchers in different areas of expertise, farmers, and stakeholders from different backgrounds) to build and select the indicators. Indicators were selected and developed through a series of consecutive steps using a combination of bottom-up and top-down approaches. According to King et al. [48], combining both approaches is necessary and provides good results. This technique is normally used to solve complex problems or generate strategies [136]. The main features of the technique are its anonymity, to reduce the influence of "super-experts," and its contribution to the objectivity of the results [137, 138].

The *MESMIS* (for its acronym in Spanish—Marco para la Evaluación de Sistemas de Manejo de recursos naturales incorporando Indicadores de Sustentabilidad) has an operative structure: Characterization of the systems, identification of critical points, and the selection of specific indicators for the environmental, social, and economic dimensions of sustainability. These information are integrated through mixed (qualitative and quantitative) techniques and multicriteria analysis to obtain a value judgment about the resource management systems and to provide suggestions and insights aimed at improving the socio-environmental profile [62]. The framework is based on the following premises:

- Sustainability is defined by attributes of NRMS: productivity, stability, reliability, resilience, adaptability, equity, and self-reliance.

- Sustainability evaluations are only valid for: a specific management system in a given geographic location; a previously circumscribed spatial scale; and a previously determined time period.
- The evaluation of sustainability is a participatory process requiring an evaluation team with an interdisciplinary perspective. The team should include external evaluators and internal participants (farmers, technicians, community representatives, and others involved).
- Sustainability can be seen through the comparison of two or more systems. The comparison can be made cross-sectionally or longitudinally.

The *IDEA method* is used widely in Europe and assesses a farm sustainability with agri-ecological (18 indicators), socio-territorial (18 indicators), and economic (6 indicators) scales [139].

*Response-Inducing Sustainability Evaluation* (RISE) is an indicator-based sustainability assessment tool developed by Häni et al. [79]. Its aim is to provide a holistic evaluation of sustainability at the farm level and support the dissemination of sustainable practices. RISE has been applied in over 2500 farms in 56 countries [140]. RISE 2.0 assesses the sustainability performance of a farm for 10 themes (soil use, animal husbandry, nutrient flows, water use, energy and climate, biodiversity, working conditions, quality of life, economic viability, and farm management) and 51 subthemes. The sustainability performance of each subtheme is based on an aggregation of various indicators. These indicators are normalized for each subtheme and can include comparisons between farm and reference data. The score at the theme level is based on the average of the scores of the 4–7 subthemes included in each theme. Scores on theme and subtheme level range from 0 to 100 and are visualized in a polygon.

A hierarchical framework based on the goods and services provided by agricultural ecosystems is the base of the *SAFE method (Sustainability Assessment of Farming and the Environment Framework)*, resulting in the hierarchy, the principles that are correlated with the three dimensions: economic, social, and environmental [38].

The *Monitoring Tool for Integrated Farm Sustainability (MOTIFS)* allows monitoring farm progress towards integrated sustainability, taking into account economic, ecological, and social aspects [125]. This tool offers a visual aggregation of indicator scores into an adapted radar graph, defining to rescale indicator values into scores between 0 (indicating a worst-case situation) and 100 (indicating assumed maximum sustainability). This allows for a mutual comparison of the indicators for different sustainability themes.

MOTIFS is a sustainability monitoring and management tool, and it allows positioning the strong and weak aspects of a farm; hence it can be used to perform a SWOT analysis (strengths, weakness, opportunities, and threats). It has major assets that could be incorporated in any indicator-based system. It can provide information to farmers for helping them to take action and make decisions. Also, it can guide through the process of assembling and understanding from information and data [126].

Different studies report indicators that have been used to analyze farms' sustainability [141–144] or differences between organic and conventional farms [145, 146]. Considering the sustainability of organic farming and agroecology, there are few methods proposed for evaluating the possibilities on the conversion to organic farming. The *Organic Livestock Proximity Index (OLPI)* is a methodology proposed by Mena et al. [41] and Nahed et al. [127] based on the multicriteria approach for weighting and aggregating multidimensional information. The OLPI of each farm was the sum of its weighted indicator values. The weighting coefficient assigned to each indicator (between 0 and 1) was defined as a function of: its importance according to the principles of organic livestock farming and agroecology and the difficulty in fulfilling the requirements of the European standards on organic production. In this sense, the indicators for assignment of the weights are nutritional management, marketing, soil fertility and contamination, weed and pest control, breeds and reproduction, and animal welfare.

The global OLPI for all case study farms is the average of the indicators. Weights of indicators are based on the importance conferred to them by the experts and are transformed to a percentage scale. As the weighting coefficients must be adjusted in accordance with specific local criteria, OLPI should not be considered if it is used to compare farms of different regions [41]. Some methods based on fuzzy measures have been used in the field of subjective multicriteria evaluation, because the theory of fuzzy logic provides a mathematical means to capture the uncertainties associated with human cognitive processes [147, 148], but in spite of their immense value, fuzzy integrals are difficult to apply to real situations [135]. Mena et al. [41] considered the main advantage of the OLPI method over fuzzy logic in multicriteria analysis is that it is easy to calculate. Once the method proposed has been applied to many farms, the researchers will have a precise idea of the relationship between different criteria and conditioning factors, and therefore, it can be used for decision-making.

*Sustainable agricultural spatial model (SASM)* integrates five factors (productivity, security, protection, economic viability, and social acceptability) using geographic information system (GIS), analytical tools for the purpose of combating and tackling sustainable agricultural constraints, and optimum land use planning [128].

In the end, the sustainability of agroecosystems depends on their basic characteristics and how, why, and through which variables are affected within each dimension. Convenience in the analysis of agroecosystems should not be viewed from an anthropocentric point of view but rather in a broader (holistic) way that favors the sustainability of production systems and that takes into account the hierarchy and complexity of agricultural systems. The use of the property as a unit of study is satisfactory to the extent that the interactions of the different activities carried out are considered and evaluated, along with externalities, complementarity, and interference with adjacent farm activities [149].

## 7. Conclusions

Productivity, security, protection, viability, and acceptability are the main factors of sustainable land management. But, implementing sustainability remains a hard event in many agricultural

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situations, and the concept of sustainability needs to integrate a comprehensive assessment of ecological, economic, and social dimensions to achieve sustainable agriculture.

Sustainability evaluation is a multidimensional issue involving huge amounts of complex information. Therefore, perfect evaluation is uncommon; in this sense, there is a need to systematically reduce the complex information to a more concentrated form while constructing the pyramid of information aggregation, at the base of which are raw data and at the top the indexes.

The first generation sustainability indexes do not incorporate interrelations between the components of a system. Examples are environmental indicators, as $CO_2$ emissions, deforestation or erosion. The second generation use composed indicators, normally with four dimensions: economic, social, productive, and environmental. Now, there are coming the third generation, indicators that it is necessary to build. They correspond to binding synergistic or transversal indicators, which simultaneously incorporate several attributes or dimensions of sustainability.

The assessment of sustainability needs to continue exploring in agriculture systems an integrated approach, and in the future, the set of multidimensional indicators (economic, ecological, social, and technical indicators) will be evaluating both separate parts of the system and their relationships.

## Abbreviations

| | |
|---|---|
| NRMS | Natural Resource Management Systems |
| EF | Ecological Footprint |
| MOTIFS | Monitoring Tool for Integrated Farm Sustainability |
| SWOT | strengths, weaknesses, opportunities, and threats |
| OLPI | Organic Livestock Proximity Index |

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Chapter 4

# Accounting for Mineral Depletion Under the UN-SEEA Framework

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Additional information is available at the end of the chapter

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**Abstract**

The scarcity factor of non-renewable resources is absent in conventional accounting methodologies. This chapter proposes an approach for accounting for abiotic resource depletion through the second law of thermodynamics. It is postulated that each chemical element has associated a cycle that should be closed either naturally or technologically. Once a mineral is extracted from the Earth, the cycle starts. The overall process from mining to dissipation is the cradle-to-grave path and is generally well characterized and accounted. However, to close the cycle, we need to account for an imaginary path through the "grave-to-cradle" approach. This semi-circle is a debt we acquire with future generations. It represents the effort that we should invest in returning minerals from a dispersed state to the initial conditions found in nature, and hence, it is a measure of depletion. This is calculated through exergy replacement costs, which indicate the energy effort required to close the cycle from the grave with prevailing technologies. The grave is the model of degraded Earth (called "Thanatia"), which was developed previously. This chapter concludes proposing the inclusion of this approach in the System of Environmental-Economic Accounts (SEEA), converting it into a "Global System of Environmental-Thermo-Economic Accounts" (SETEA).

**Keywords:** exergy, SEEA, economic accounting, minerals, depletion, SDG12

## 1. Introduction

Mining, smelting, and refining processes have important environmental impacts: they deplete natural resources, minerals and fossil fuels that cannot be replaced; they use land that affects landscapes and their ecosystems; they discharge wastes into air, waters, and soil; and they can influence in the depletion of renewable natural resources such as biota or ground waters.

These activities have accompanied the development of man from the early stages of civilization. To such an extent that the stages of civilization have been named by the prominent resource that supported the era: bronze, iron, coal, and oil Ages. When nature was abundant, the side effects were not taken into account. However, the intense technological development of the twentieth century has forced society to realize them.

In this ambition, environmental economists have developed methods to evaluate the economic effect that has the use of natural resources to support our economic activities. They convert physical assets and impacts on ecosystems into monetary accounts, which are added or subtracted from the aggregated accounts, and finally, from the gross domestic product (GDP). The advantage of using monetary units is that it allows comparing among other environmental assets and aggregating them to look for their contribution of the wealth of a country.

However, as an agreement among economists is difficult to attain, and it is of paramount importance to yearly account for the human appropriation and use of nature, the United Nations proposed to develop a System of Environmental-Economic Accounts (SEEA). It consists of a satellite account system for reflecting the environmental deterioration proposed to adjust the System of National Accounts (SNAs). This is an optimum reference framework to follow in the description of economic valuation methods.[1] In fact it is an important tool to manage appropriate resources and thus ensure sustainable consumption and production as advocated by the UN Sustainable Development Goal Number 12.

This chapter explains the capabilities and drawbacks of the system of environmental and economic accounts. Subsequently, we describe an alternative approach for assessing abiotic resource depletion through the second law of thermodynamics. Finally, a proposal for accounting depletion based on the organized structure of the SEEA is provided.

## 2. SEEA accounts

"The System of Environmental-Economic Accounts (SEEA) is the United Nations statistical framework that provides internationally agreed concepts, definitions, classifications, accounting rules and standard tables for producing internationally comparable statistics on the environment, and its relationship with the economy. The SEEA framework follows a similar accounting structure as the 'System of National Accounts' (SNAs) and uses concepts, definitions, and classifications consistent with the SNA in order to facilitate the integration of environmental and economic statistics."[2] The international community agreed to elevate the SEEA-2003 from a manual of best practices to an international statistical standard on par with the System of National Accounts. For attaining this objective, an iterative revision process was initiated by the United Nations Statistical Committee, relying on a broad global experts' consultation. The revised SEEA is organized into three main parts: the Central Framework, Experimental

[1]See https://www.un.org/sustainabledevelopment/sustainable-consumption-production/ [Accessed: June 2018].
[2]See http://unstats.un.org/unsd/envaccounting/seea.asp [Accessed: June 2018].

Ecosystem Accounts, and Extensions and Applications. The Central Framework, consisting of the internationally agreed standard concepts, definitions, classifications, tables, and accounts was completed in 2013.

### 2.1. General considerations about the SEEA

In particular, the Central Framework of SEEA intends to be a universal single measurement system information on water, energy, minerals, timber, soil, land, ecosystems, pollution and waste, production, and consumption of all interactions that society makes with nature. It recommends presenting the yearly accounts for these interactions in an organized manner parallel to the System of National Accounts. The basis consists of defining and systematically accounting the concept of "environmental assets," which are defined as "the naturally occurring living and non-living components of the Earth, together comprising the biophysical environment that may provide benefits to humanity." These assets are presented in both physical and monetary data. The Central Framework claims that it facilitates comprehension of data by scientists and economists and brings a bridge between them.

Universally organized statistics is perhaps the main value of the SEEA, and economists have developed well established procedures to rely on them. To start with, the economists define flows and stocks.

Natural inputs are physical flows moving from the environment to production processes. They are mineral, energy or timber resources, also renewable energy resources and finally inputs from soil, water, and air resources. At the same time we produce products, we produce wastes. These are flows discarded, discharged or emitted in the production processes, and absorbed by the environment in the form of solid, liquid or gaseous materials and energy.

Stocks, in physical terms, refer to the total quantity of individual environmental assets at a given point in time. "These assets are defined by their material content without specific reference to their constituent elements." This is a major drawback since tons of a given metal do not tell about its wealth. Its mineral composition, ore grade, accompanying minerals or burden for instance can be very variable.

The physical units of these flows and stocks vary with their type and are measured according to the System of International units, mass, length, volume, joules, etc.

The way the physical flow is accounted follows the structure of monetary and use supply tables that are used to show transactions in products between different economic entities like industries, households, government, and the rest of the world. The structure of the physical supply and use tables (PSUT) adds another entity: the environment. This is made by adding columns and rows that consider the flows going into and leaving from it. In addition, the tables show separate accounts for materials flows, water and energy sub-systems.

Energy and water flows are accounted in physical units in a cradle-to-grave way. The physical flow accounts for materials are a complex subject for SEEA; this is because of its diversity as compared to energy and water flows. The SEEA uses the mass basis for each type of material.

Insofar as materials can react and mix with other materials to produce new materials, the trace of physical flows may be very complex in its cradle-to-grave description. In some cases, it is possible to track flows of elements such as mercury because of their hazardous nature.

To provide an aggregate overview in tons, the economy-wide material flow accounts (EW-MFA) are used. These accounts describe the materials input-output of an economy including the environment and the rest of the world as subsystems.

Converting these units into money allows, in theory, comparison among different assets. The preferred approach of SEEA to the valuation of assets is the use of market values. "Strictly, market prices are defined as amounts of money that willing buyers pay to acquire something from willing sellers."

However, valuating assets at market prices have an important problem since there are "few markets that buy and sell the assets in their natural state and hence determining an asset's economic value can be difficult." Therefore, the central framework recommends using the net present value (NPV) approach for estimating market prices for non-marketed assets. This approach also named as the discounted value of future returns approach, "uses projections of the future rate of extraction of the asset together with projections of its price to generate a time series of expected returns."

**2.2. Asset accounts for mineral and energy resources in the SEEA**

Mineral and energy resources are non-renewable resources whose extraction leads to depletion, and subsequently, the end of the industrial activity. Therefore, their asset accounts must organize the information about stocks, flows of extraction, depletion, and discoveries, as well as of monetary estimates of the value added, operating surplus of the extracting companies, and depletion adjusted value-added measures. This is briefly described here.

Known deposits of mineral and energy resources are classified by SEEA according to the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009)[3]. The UNFC-2009 classifies deposits with triple dimension criteria: economic and social viability (E), field project status and feasibility (F), and geological knowledge (G). The first criterion (E) establishes the commercial viability of the project. The second criterion (F) indicates where the technical extraction project is on the road from exploration to market. The third criterion (G) designates the level of certainty in the geological knowledge and potential recoverability of the quantities. Each criterion is further numbered as high (1), moderate (2), and low (3) or very low (4).

Besides of that, known deposits are categorized into three classes: class A for commercial projects with recoverable Resources, i.e., the case of E1 deposits and projects F1; class B for potentially commercial projects with recoverable resources when deposits fall in the category E1 or E2 and projects in F2; and class C for non-commercial, and other known deposits. In these three classes, the geological knowledge may be G1, G2, or G3.

[3]See http://www.unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/UNFC2009_ECE_EnergySeries39.pdf [Accessed: June 2018].

The SNA limits its scope to commercially exploited deposits, whereas SEEA opens the scope for having a broader picture on the availability of the stock of these resources.

Notwithstanding this, these criteria consider the mining wealth in an economically simplified and present-day view. It misses the fact that geology is more complex than what statistics reflect. Consequently, there is no internationally agreed detailed classification for mineral and energy resources suitable for statistical purposes. For instance, there are many types of minerals and combinations of them with specific geological structures. In addition, the exploitation may result in recovering burden, tailings, and residues that were previously discarded as a function of market demand, for instance.

Thus SEEA simply proposes a compilation of the physical asset accounts for mineral and energy resources by type of resource including estimates of the opening and closing stock and changes in the stock over the accounting period. The type of measuring units indicates the roughness of the accounting system. They are measured in tons, cubic meters, or barrels. There is neither homogeneity in units nor specificity in the type of mineral. In fact, “it is noted that a total for each class of deposit across different resource types cannot be meaningfully estimated due to the use of different physical units for different resources. For certain sub-sets of resources, for example, energy resources, an aggregate across certain resource types may be possible using a common unit such as joules or other energy units.”

As explained previously, all mining activities, either for extraction of mineral or energy resources impact on environment. Their effects are on air, waters and soils in form of pollution and degradation of environmental reservoirs. They also affect the landscapes, the ecosystems, and the local human settlements. The SEEA tries to organize these costs into a framework that allows valuating and yearly trace these impacts. In theory, the revenues caused by mining should overcome the temporal or permanent loss of environment. The only way to know that is by monitoring and accounting all these impacts in an organized and standardized way. This is the highest contribution of SEEA. Unfortunately, the loss of (i) landscapes, (ii) ecosystems supporting particular biotas, or (iii) local communities, might not be captured by these impassive accounting systems. Another problem is the lack of single and universal measuring units.

The structure of the monetary asset accounts largely parallels the structure of the physical asset accounts. “The valuation of the stocks uses of NPV approach at the level of each individual resource type, and ideally for specific deposits of the resource, and then summed over the range of different resources in order to obtain a total value of mineral and energy resources.”

The application of NPV approach requires specific considerations in the estimation of the resource rent. First, the resource rent should be limited to the extraction process itself excluding the refinement and processing of the extracted resource. Accordingly, the extraction process includes the typical mining activities like mineral exploration, evaluation, mining, and beneficiation. Commonly, the mineral deposit contains several types of resources. For example, an oil well containing gas or, nickel sulfide deposits often found with copper ores, where cobalt is also obtained as a by-product. In that case, the resource rent should be allocated by commodity.

An important problem in valuation is the frequent fluctuation of the market price of mineral commodities while operating costs are quite foreseeable. Consequently, the resource rent may be composed of a quite volatile time series. Mineral exploration and evaluation costs are treated as a form of gross fixed capital formation. Moreover, decommissioning costs reduce the resource rent earned by the extractor over the operating life of the extraction site.

The physical extraction rate is usually constant along the life of the resource if there are no reappraisals. However, as resources approach depletion, there will be a decline in the ore grades and the environmental and energy costs associated with extraction will increase, thus avoiding extraction of yearly constant quantities. Even the central framework of SEEA warns that there is no reason why the extraction rate should necessarily be constant. In practical terms an important physical fact is ignored: the extinction of the mine is not constant along the extraction period but follows the law of diminishing returns.

### 2.3. Final comments on the SEEA

We find two main objections to the SEEA. First, dividing nature into assets does not reflect all interactions among natural systems themselves. For instance, converting a forest into a stock of timber does not reflect other benefits coming from it, like floods protection, clean air, being a life-supporting system, or even its recreational purposes. Numbers will never reflect causality and may provoke greed for rapid exploitation of natural resources. For the SEEA central framework, the whole is exactly the sum of its parts. It resigns holism in favor of reductionism.

Second, SEEA and SNA are firmly based on market price methods. Even if money has the power of easy comparisons among different issues, it reflects social values rather than objective values. They vary with time and from nation to nation. Money reflects the purchasing power of man in society. We pay people, not nature, and if nature claims nothing for its services, the monetary accounting system will only reflect present man´s interests. The implicit paradigm behind is: if we could extract and use all present environmental capital and convert it into money, it would be better than having physical assets not yet exploited. This is an absurd reductionism, and only the impossibility of having enough money to extract and convert nature into money inhibits that insanity. On the other hand, if everything is converted into money, the value of money itself would depreciate. Therefore, those that have retained their resources would become the wealthiest. The willingness to pay weakens with abundance and strengthens with scarcity. Yet the lack for a better numéraire excuses the use of money.

In fact, an important problem in SEEA is that it uses physical accounts without homogeneity in units or specificity in the type of mineral/material. This makes very confusing the trace of physical flows throughout its life cycle since materials react, mix, and decompose. Converting these units into exergy values would facilitate materials trace analyses through Sankey diagrams.

That said, the SEEA constitutes an impressive initiative for putting numbers to the man-nature interactions in a rational and global way. Universally organized statistics is perhaps the main value of the SEEA, and economists have developed well established procedures to rely on them.

In what follows, we present an alternate method for assessing natural non-renewable resources from a thermodynamic perspective.

## 3. Closing material's cycles: the view "down the rainbow" (DTR)

We have seen in the previous section that SEEA accounts for physical flows in a cradle-to-grave perspective. However, in the cradle-to-grave path, there is information that these accountancy systems will never supply: depletion. Neither the economic nor physical accounting systems are efficient enough to assess the depletion of natural resources.

Something lacks in a global view: the mineral endowment and the non-renewable resources of the Earth are constantly decreasing. Each time non-renewable resourcesare extracted and not replaced we lose them irreversibly. And the only thing we can measure is its yearly decrease, not its lost value. There is no way of appraising what valuable things mankind is losing forever. Scarcity and the effort needed to replace non-renewable resources is absent in conventional accounting methodologies. Indicators for Materials recycling, substitution and consumption decrease also lack in the credit list. It could be argued that having an indicator of scarcity per chemical element could be enough to solve the problem. However, the myriad of inorganic products we can extract from mine Earth and the huge amount of chemical products that these materials can be converted into, makes impossible to have a decent accounting of the material cycles of all chemical elements.

In our view, there is a lack of theory rather than a lack of indicators. Partial or total cradle-to-grave assessments are the half part of the cycle. We name them "over the rainbow" (OTR) accounting methodologies. They lack the other side: the grave-to-cradle assessment. In the same way that imaginary numbers can hardly be explained in the real space, some phenomena like depletion may be better explained in the "down the rainbow" (DTR) approach [1].

The planet works in cycles driven by solar energy: carbon, oxygen, nitrogen, phosphorus, sulfur, and water have their cycles but, to our knowledge, there are no postulated cycles for metals and chemical elements in general. Those elements related with life have short closing cycle times even if they have reset times measured in geological scale times. However, such elements that do not form part of biological life will hardly be reset. They are constituents of our exosomatic organs, and they are in danger of being scarce for future organs because of dispersion. In practical terms, both types of chemical elements must have their own cycle. And the human being must allocate a major effort to close and accelerate their closure. Sustainable development requires the closing of all chemical elements in the planet either for endo or for exo-somatic organs. Their closing cycle velocity, and the effort required must be a function of how intense is their use with respect to their physical scarcity. If man alters the cycles, closing them corresponds to man.

By extracting the ore from a mine, the exergy (i.e. physical utility) of the ore increases, even though we spent a lot of exergy (i.e. useful energy) to remove it. From the standpoint of future generations having the raw material in a store instead of having it in a mine would be a good inheritance. All environmental costs would be a matter of the past. This is something similar to leaving for the future the pyramids or the cathedrals. Clearly, if we use this raw material and then recycle it, we would be using it temporarily.

The problem arises with dispersion. What is dispersed and, of course, the increase in demand needs to be replaced with more extraction. That increases the size of the cycle to be closed, and the energy debit increases over and down the rainbow. The over the rainbow part is a real consumption, and the down the rainbow is a debt we acquire with future generations. Anything that reduces the new extraction is positive: substitution, miniaturization, recycling, the efficient use of materials, and indeed the extraction efficiency.

Dispersion of raw materials has not been sufficiently considered in economic analyses. It has been ignored as a materials availability loss, but rather it is seen as a pollution problem. As it happens with heat in energy balances, it is obtained by difference. The dispersion is thus accounted by material balance: what is extracted minus what is recycled is equal to what is dispersed. But in reality there is no universal care in having a systematic accounting of the cycles of elements.

Dispersion is the key for understanding the phenomenon of raw materials. The raw material backpack has two components: one is the overall impact of its extraction and the other, the acquired debt for avoiding dispersion. Each particular raw material has an environmental cost for dispersal. Under this light, substitution of a raw material for another would make sense if both parts of the backpack decrease. These assessments must be essentially physical. It is important to highlight that while the OTR side can be restored directly by nature in timespans of several generations - provided that our wastes should not exceed the assimilative capacity of the biosphere; the DTR side needs geological eras to naturally closing the cycle for each particular element. Restoring the planetary mines as they were before civilization would only be possible with the internal heat of Earth through volcanism. It is something beyond imagination. The "easiest" mineral resources to restore would be fossil fuels. However, fossil fuels have a formation time of the order of million years. Giampietro and Pimentel [2] gave a value for fossil energy productivity of the Earth as low as 0.016 $MJ/m^2/day$ or 1000 kcal/0.7 $m^2/year$.

## 4. Thermodynamic approach for accounting the Earth's mineral capital

Ecological economists have learned that entropy is closely related to economics [3, 4]. It tells us about the direction to which economical fluxes (as part of the natural environment) go. However, entropy is a very difficult property to understand, and it is often used and "misused" in a metaphorical manner. In this way, we can find statements such as "mines of low entropy become mines of high entropy." However, the latter assert even if correct, does not provide much information. How can we overcome this deficiency? The answer is with exergy. Through this property, we are able to convert metaphors into real numbers. A good management of our finite concentrated mineral deposits needs to be based on reliable, objective and strong information sources, and removed away from market subjectivities.

This has been the motivation for the development of the Exergoecology approach [5, 6]. The fundamental instrument of the latter is the calculation of exergy replacement costs as a way for evaluating the "effort" that nature put into play for concentrating substances from a completely dispersed state to the concentrated conditions of the minerals found in the deposits. As the ore grade tends to zero, the exergy required to extract a mineral from the mine tends to infinity. Thanks to the fact that nature provides us with mines, the exergy needed to produce minerals is infinitely lower than if we would need to obtain them from the "bare rock." However, as extraction continues, the state of the deposits approaches to the bare rock, and future generations will have to deal with very low-grade ores, needing increasing amounts of energy for their exploitation [7]. Therefore, if we add an additional asset in the accountancy of minerals, namely the replacement costs in a "down the rainbow" view, we will consider the scarcity factor. This way, depleting high-grade ores is penalized since the exergy required to replace them with current technology would be very large. It should be noticed, that this point of view goes in the opposite direction of current practices: the larger the ore grade, the more cost-effective is its exploitation since production costs are much lower. However, this criterion enhances the depletion of high-grade ores since the future scarcity is ignored. Both aspects, replacement costs and conventional processing costs give a broader and more equilibrated vision of "sustainability" in the mining sector and closes the cycle of materials, covering the OTR and DTR paths.

Note also that these two indicators do not need speculations about the remaining mineral capital on Earth. No matter how much mineral remains to be exploited and the level of depletion, what we can assess is the "avoided" cost humanity had for exploiting the mine instead of doing it in the bare rock. These indicators also provide the exhaustion and the speed of exhaustion of all minerals we are extracting today in the planet. It is done in fully additive energy units instead of money units. Besides of that, the exergy replacement cost can easily be converted into money units since the price of each actual operation is available. That said, converting the replacement exergy into money units is senseless since the reversible processes to convert the bare rock into the mineral as in the mine are purely theoretical.

### 4.1. Thanatia: a model of the dispersed Earth

Exergy measures the quality of systems with respect to a reference. When the system under analysis reaches the conditions of the reference, then it loses completely its distinction, i.e., its exergy [8, 9]. Therefore, the more separated the system from the reference, the more exergy it has. In the case of a mineral deposit, the more concentrated the mine, the more "quality" it has. Therefore, which should be the reference for the assessment of the mineral capital? In the end, when a mine has been completely depleted, its concentration would have theoretically reached that of the average crust. Hence, it is clear that our reference should be an Earth, where all minerals have been depleted, and all fossil fuels have been burnt. That model of Earth, that we named the "Crepuscular Planet" or "Thanatia" (from the Greek Thanatos, death), was developed by the authors and is extensively described in [10, 11]. Basically, it consists of a degraded atmosphere, hydrosphere, and continental crust. The atmosphere of Thanatia is obtained assuming that all conventional fossil fuels are burnt and all $CO_2$ is released. As a result, it has a $CO_2$ concentration of 683 ppm and a mean surface temperature of 17°C. The degraded hydrosphere was assumed to have the current chemical composition of seawater at 17°C (poles and glaciers melted). And for the upper continental crust, we proposed a model of bare rock defined by the composition and concentration of 324 substances in which 292 are minerals, and the remaining are mainly diadochic elements included in the crystal structure of other minerals.

As explained in [11], Thanatia should not be mixed up with the reference environment (RE), such as the one proposed by Szargut [12] for the calculation of chemical substances. In fact, both concepts constitute a reference for calculating exergies, but there are determinant differences. The assumption of assuming one substance per chemical element, which is common for all global RE, radically invalidates the use of the RE as a substitute of the model of crepuscular planet. We need a model of dispersed Earth where all commonly found substances appear.

The former only provides the chemical composition of the environment. The concentration factor is very important for assessing the mineral capital on Earth since as we explained before, the exergy of a mineral deposit increases exponentially with its ore grade. The greater the difference between the concentration of the mineral in the mine and in the dispersed crust, the more exergy (the greater value) will have the deposit. Hence, not only the composition of the "dead environment" is required, but also the concentration at which the substances are found in it.

That said it should be stated that conventional REs are still needed and constitute a tool for calculating chemical exergies. In fact, Thanatia has chemical exergy with respect to a defined RE. And as Szargut's approach is the most internationally recognized, we have adopted it with some improvements.

### 4.2. Methodology

Exergy measures the minimum (reversible) work required to extract and concentrate the materials from a RE to the conditions found in nature. The approach named Exergoecology [13]. allows to assess natural resources taking advantage of both thermodynamics and thermoeconomics principles. When minerals are extracted from Earth through the separation of it from the ore by means of different process like mining, beneficiation, roasting, smelting, refining, etc., the exergy associated to the mineral increases but this process requires the consumption of fuel, and other materials, whose exergy is destroyed after use.

The concentration exergy $b_c$, represents the minimum amount of energy associated with the concentration of a substance from an ideal mixture of two components and is given by the following expression:

$$b_c = -\overline{R}T_0\left[\ln(x_i) + \frac{(1-x_i)}{x_i}\ln(1-x_i)\right] \tag{1}$$

where $R$ is the universal gas constant (8.314 kJ/kmol K), $T_0$ is the temperature of the reference environment (298.15 K), and $x_i$ is the concentration of the substance i. The exergy accounting of mineral resources implies to know the ore grade, which is the average mineral concentration in a mine $x_m$ as well as the average concentration in the Earth's crust (in Thanatia) $x_c$. The value of $x$ in Eq. (1) is replaced by $x_c$ or $x_m$ to obtain their respective exergies, whilst the difference between them represents the minimum energy (exergy) required to form the mineral from the concentration in the Earth's crust to the concentration in the mineral deposits.

This approach includes the irreversibility factor through the so-called exergy cost, which is defined as the total exergy required concentrating the mineral resources from the Thanatia with prevailing technologies.

The concentration of a mineral from the ore grade of the deposit to its commercial grade implies energy consumption completely different to that of concentrating the mineral from the dispersed state of Thanatia to the mine. The exergy cost of concentrating a mineral would require $k_c$ times the minimum concentration exergy (Eq. (2)).

$$b^*_{ci} = k_c \cdot b_{ci} \tag{2}$$

where $k_c$ is a constant called unit exergy cost and is the ratio between the real energy required for the real process to concentrate the mineral from the ore grade $x_m$ to the refining grade $x_r$ and the minimum thermodynamic exergy required to accomplish the same process (Eq. (3)).

$$k_c = \frac{E_{realprocess}}{\Delta b_{mineral\, x_m \rightarrow x_r}} \tag{3}$$

Since the energy required for mining is a function of the ore grade of the mine and the technology used, so it is the unit exergy cost. Then, the exergy cost of concentrating a mineral from the Earth's crust is named exergy replacement cost. Note that fossil fuels are different from non-energy minerals in that once burnt, they cannot be replaced because they have been converted mainly into $CO_2$ and water. The exergy of fossil fuels is commonly accounted for through their High Heating Value (HHV). Pollutant abatement costs in exergy terms can be substracted from the HHV to account for the clean fossil capital on Earth [14].

### 4.3. Case studies

**Table 1** show results from [16] when the methodology is applied to several commodities. It has been assumed a world average ore grade for each metal shown. As can be seen, the exergy replacement costs are not insignificant and have at least the same order of magnitude than conventional mining and metallurgical costs. This way, we can give numbers to the whole cycle of materials: the over the rainbow path, through conventional mining and metallurgical costs, and the down the rainbow path, through the exergy replacement costs.

### 4.4. Summary of the theory

Physical measures fall within science, and a few of them transcend and become socially relevant. To cross this boundary, both the object of measurement and the units must have a set of consistent properties that facilitate understandability, universality, and measurement capability of social evolution.

In this context, the object of measurement is our global depletion of mineral resources at the planetary level. And we postulate exergy as its measurement unit. For doing that we need a theory supporting how this can be accomplished. The fundamentals of such a theory are:

(1) There can be postulated an imaginary degraded Earth planet in which the crust, the hydrosphere, and the atmosphere reached a maximum level of dissipation of all its materials compatible with the Sun´s energy and the internal heat of the Earth. We name this planet Thanatia and is a crepuscular Earth where no mines exist and thus all materials are dispersed and have the composition of bare rocks commonly found in the crust; the hydrosphere contains no poles and is nearly composed by standard salt water; and the atmosphere reached the state predicted by long-term climate change models, with a high concentration of greenhouse gases coming from the complete combustion of fossil fuels. Thanatia is by no means in an equilibrium state, but in a conceivable geological steady state that can be characterized by a reasonable short set of physicochemical parameters. Thanatia is postulated as the ultimate state of the present evolutionary man-induced degradation path of the Earth.

(2) Exergy measures the minimum work needed to convert a thermodynamic state of a system characterized by a constant mass of constituent chemical elements into any other state of that system. Therefore, any state of the planet between the present one and Thanatia can be measured with the knowledge of the physicochemical parameters characterizing the two states. This general definition allows calculating the exergy distance between any two states of any specific mine, no matter what its chemical composition is likely to be. The same occurs when the mineral is converted into a raw material, smelted, refined, manufactured, transported, used, recycled, disposed of in a landfill, and/or dispersed.

(3) Once any two states of the system are characterized, it is possible to calculate the current exergy cost we need to invest with prevailing technologies to reach a final state from an initial one. As our technology is far from being reversible, exergy cost and minimum exergy differ in many cases in several orders of magnitude. History tells us that mining and chemical technologies have changed rather slowly over decades and hence, the exergy costs can be assumed to be constant over a not too short period of time (for some cases over decades). Exergy may be a better indicator for pure scientific purposes. In turn, exergy cost is prone for social interpretations because even if it depends on the state of technology, it is closer to societal perception of value. Both indicators are equally valid on a thermodynamic basis.

(4) We postulate that each chemical element must have its own cycle either naturally powered by direct or indirect Sun´s energy, or geologically powered. Man-made technology can accelerate or decelerate these cycles. Thus metallic elements can be viewed to be somewhere in the geosphere or in the technosphere. One element in mine has not initiated its cycle. Once it is mined, the cycle starts. The more mineral is mined, the larger its cycle. And the shorter the residence time in the technosphere is, the greater it's dissipation. Recovering what was dispersed would require significant amounts of exergy and ingenuity that makes in many cases almost impossible closing the cycle. However, humanity will need to recover more and more elements from bare rock because of its profligate use of previously mined ones. Many rare earths and scarce elements are already obtained from nearly bare rocks. Technology exists accordingly.

(5) Under this light, we propose measuring depletion of a given mineral as the exergy cost needed to close the cycle between the compositions of the constituents in the Thanatia´s dispersed state, and the mineral in the mine at its present state. In addition, its exergy is also a complementary measure of this depletion. We named these parameters exergy replacement cost and replacement exergy, respectively. The overall process from mining to dispersion and dissipation is the well known cradle-to-grave process. This is the part everybody sees, that is why we name it as the "over the rainbow" part. However, there is an imaginary part, "down the rainbow" or grave-to-cradle approach, which can aptly explain and measure how much depletion is going on with all man activities. We have seen that all the attempts to measuring depletion "over the rainbow," either in monetary or in physical terms, collide with the impossibility to put an objective value to physical scarcity. The depletion of the mineral capital on Earth must be measured on a grave-to-cradle basis.

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| Values in GJ/ton of metal if not specified | DTR path<br>Exergy replacement costs, GJ/ton | OTR path<br>Mining and metallurgical costs, GJ/ton |
|---|---|---|
| Aluminium-Bauxite (Gibbsite) | 627 | 54 |
| Antimony (Stibnite) | 474 | 13 |
| Arsenic (Arsenopyrite) | 400 | 28 |
| Barite | 38 | 1 |
| Beryllium (Beryl) | 253 | 457 |
| Bismuth (Bismuthinite) | 489 | 56 |
| Cadmium (Greenockite) | 5898 | 542 |
| Cerium (Monazite) | 97 | 523 |
| Chromium (Chromite) | 5 | 36 |
| Cobalt (Linnaeite) | 10,872 | 138 |
| Copper (Chalcopyrite) | 292 | 57 |
| Fluorite | 183 | 1 |
| Gadolinium-Monazite | 478 | 3607 |
| Gallium (in Bauxite) | 144,828 | 610,000 |
| Germanium (in Zinc) | 23,749 | 498 |
| Gold | 553,250 | 110,057 |
| Graphite | 20 | 1 |
| Gypsum | 15 | 0 |
| Hafnium | 21,814 | 11,183 |
| Indium (in Zinc) | 360,598 | 3320 |
| Iron ore (Hematite) | 18 | 14 |
| Lanthanum-Monazite | 39 | 297 |
| Lead (Galena) | 37 | 4 |
| Lime | 3 | 6 |
| Lithium (Spodumene) | 546 | 433 |
| Magnesite (from ocean) | 136 | 447 |
| Manganese (Pyrolusite) | 16 | 58 |
| Mercury (Cinnabar) | 28,298 | 409 |
| Molybdenum (Molybdenite) | 908 | 148 |
| Neodymium-Monazite | 78 | 592 |
| Nickel (sulphides) Pentlandite | 761 | 115 |
| Nickel (laterites) Garnierite | 167 | 414 |
| Niobium (ferrocolumbite) | 4422 | 360 |
| Palladium | 8,983,377 | 583,333 |
| Phosphate rock (Apatite) | 0.35 | 5 |

| Values in GJ/ton of metal if not specified | DTR path<br>Exergy replacement costs, GJ/ton | OTR path<br>Mining and metallurgical costs, GJ/ton |
|---|---|---|
| PGM (average value for all PGM) | 2,695,013 | 175,000 |
| Platinum | 4,491,688 | 291,667 |
| Potassium (Sylvite) | 665 | 2 |
| Praseodymium-Monazite | 577 | 296 |
| REE (Bastnaesite) | 348 | 384 |
| Rhenium | 102,931 | 156 |
| Silicon (Quartz) | 1 | 77 |
| Silver (Argentite) | 7371 | 1566 |
| Sodium (Halite) | 17 | 41 |
| Strontium | 4.2 | 72 |
| Tantalum (Tantalite) | 482,828 | 3091 |
| Tellurium-Tetradymite | 2,235,699 | 589,405 |
| Tin (Cassiterite) | 426 | 27 |
| Titanium (Ilmenite) | 5 | 135 |
| Titanium (Rutile) | 9 | 258 |
| Uranium (Uraninite) | 901 | 189 |
| Vanadium | 1055 | 517 |
| Wolfram (Scheelite) | 7429 | 594 |
| Yttrium-Monazite | 159 | 1198 |
| Zinc (Sphalerite) | 1627 | 56 |
| Zirconium (Zircon) | 654 | 1372 |

Updated from Valero and Valero (2015); [15].

**Table 1.** Total exergy costs of selected metals: the OTR and DTR paths.

## 5. Do exergy measures accomplish the standards for a good environmental indicator?

With exergy replacement cost we cannot measure the progress to sustainability but the progress to depletion, ultimate to Thanatia. It can be like a watch measure to death. We can decelerate death, but we cannot avoid it. Nevertheless, it can be a good policy guide since it can quantify the annual depletion of the mineral capital and explain crystal clear, what are the needed measures to stop it or at least to slow it. The only question is to prove that the indicator undertakes the requirements for a good one.

The Organisation for Economic Co-operation and Development (OECD) [17, 18] proposed a set of criteria for having a good environmental indicator: policy relevance, analytical soundness, and measurability.

Concerning policy relevance, a good indicator must be: (a) easy to interpret, (b) show trends over time, (c) be responsive to changes in underlying conditions, and (d) have a threshold or reference value against, which conditions can be measured.

Exergy as the available energy is easy to interpret since it is what laypeople call energy. As a matter of fact, we pay exergy not energy. The exergy replacement cost and the exergy cost indicators can show either aggregated or disaggregated trends over time just being responsive to any kind of variation in amounts of extraction, improvements in processes efficiency, substitution, recycling, and whatever changes in the element cycle. Finally, Thanatia as a threshold is the best provider of reference values to which evolutions on depletion can be measured. Therefore, our indicators are policy relevant according to OECD.

Concerning analytical soundness, indicators should be well supported in technical and scientific terms. It is obvious that exergy indicators are well based on the second law of thermodynamics.

Concerning measurability, indicators should be: (a) calculated from data that are readily available or available at reasonable cost, (b) data should be documented and of known quality, and (c) data and indicators should be updated at regular intervals.

The data for calculating exergy replacement costs must come from data provided from the physical SEEA tables. Assets providing amounts of extracted material, composition, ore grades, amounts of processed, smelted, refined chemicals, amounts of recycled material with its composition, etc., available in the PSU tables are what exergy costs need for their calculations. The data obtained for exergy replacement costs will be as reliable as the data provided by SEE accounts. And the calculations required are easily available with adequate computer programs. International agreements could be reached in order to update both data and indicators as well as improve interpretations and act accordingly. As exergy is an additive property, it has the capability of integrating and aggregating a large variety of causes of variation including how substitution, recycling, and nanotechnologies positively improve our global management of the mineral capital. Conversely, each country, company or mine could use the exergy replacement cost to account for the attained depletion level. And this cost can easily be converted into money units just by multiplying it by some previously agreed energy price. Money accounts are useful at the micro level from companies to countries, but at a global scale and throughout time, exergy accounts may give a clearer picture far removed from economic vagaries.

Finally, the proposed indicators are complementary with others, especially with cradle-to-grave indicators that close the cycles of elements. All together could provide an overall measure of “unsustainability” and its yearly variation, which could be used as a policy lever.

## 6. Concluding remarks: from SEEA to a global system of environmental-thermo-economic accounts

The depletion of a mineral should not be anymore the difference between its world price and its economic cost of production as economists propose. On the contrary, it should be assessed as the loss of reserves quantified through its replacement cost with prevailing technologies, from the bare rock to the ore grade conditions of the mine. This depletion indicator can be used for all fossil fuels, and minerals no matter their chemical composition and concentration. Fossil fuels must be replaced with renewable energy sources and need to be accounted for such progress. In the same way, stopping depletion of metals will largely come from techniques such as designing for recyclability, reducing the number of alloys used, avoiding the design of monstrous hybrids, designing for disassembly, symbiosing industrial complexes, increasing the efficiency of smelters to avoid metal losses in slags, increasing the throughput of scrap, etc., (see [19, 20]). All these techniques decrease depletion and must be accounted for too.

The idea of replacement, restoration, remediation or repair exergy could easily be extended to indicate the depletion of many other non-renewable resources of biogeological origin like the loss of forests, landscapes, fertile soil, subsoil waters, fisheries, climate change, etc. The amount of work needed to restore what was degraded should be accounted for, even if it will hardly be restored. It is like a debit account for future generations. Each time we learn how to accomplish replacements or recycling or how to live with less, is like slowing the time machine toward Thanatia.

If "prevailing technologies" are a reflection of embodied knowledge, we will see to what extent they decrease our debt with future generations. Nevertheless, it is not clear that any new technology that directly or indirectly improves efficiency in production processes decrease our debt. The rebound effect goes always in the opposite direction; the more efficient we are the more consumption is promoted (see, for instance, [21]).

Valuing our technological improvements is as important as conservation of resources. Conservation is something else than repair, restoration, or replacement. It requires a change in our lifestyle through education. Education is an indispensable tool for technological innovation and conservation. And it is not clear yet, which of both are more important at any historical moment in man´s life on the planet. Conservation and technological improvement can be accounted for with the proposed theory. Consequently, the second law of thermodynamics ought to be placed at the core of economists' literacy.

If replacement can be calculated and registered for almost any action of man on the planet, we need an international framework to provide concepts, definitions, classifications, accounting rules and standard tables for all countries. The System of Environmental-Economic Accounts (SEEA) of the United Nations may well provide such statistical framework. As explained previously, the System of National Accounts (SNA) is an established system for producing internationally comparable economic statistics, which imposes the organization and standardization of domestic accounts. It is widely accepted and established worldwide. Bureaus of statistical office (BSO) for data recovering and economic accounting exist in almost any country. Companies and countries report economic and physical data following the established accounting procedure, and BSOs integrate them. It is a huge infrastructure. From households to companies and to countries, these accounts are presented in money values. SEEA follows the accounting structure of the SNA thus facilitating the integration of environmental statistics with economic accounts. Thus, each national BSO needs to take the responsibility for the environmental data recovery and environmental-economic accounting too. However, these offices are mainly composed by economic statisticians, which are used to convert their assets into money values. When describing the physical tables needed for SEEA, we have seen

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that the information recovered is rather poor since tons of materials are not sensitive enough for qualifying most of the physical phenomena. Therefore, at the countries level, both monetary accounts and physical accounts are concurrently needed. Monetization runs well from households to companies. At the countries level the money yardstick is proved insufficient for economic-environmental accounts, and at the aggregated global level accounts, money losses weight in favor of physical accounts. To see the planet´s evolution, monetary accounting is not only insufficient but inappropriate. The aggregation level of accounting determines the numéraire to be used in the accounts.

We propose "replacement" as the keyword for re-producing the planetary global accounts, from households to the whole planet in a comprehensive way. Using the exergy cost measured in international. units as a numéraire. The cost of replacement of non-renewable resources and the cost of restoring deteriorated renewable resources may be used just to account how much effort we should need to close the natural and man-made cycles. Some efforts will be done as we pay our debt, but many others will remain as a debt to future generations. Future generations will need to know this. As the former Deputy Secretary-General of OECD, Ásgeirsdóttir [22] said "the luxuries of one generation are often the needs of the next," and "We need to achieve more sustainable consumption and production patterns, to increasingly decouple environmental pressure from economic growth, to ensure sustainable management of natural resources, and to work together in partnership to reduce poverty." This is in effect, achieving UN Sustainable Development Goal No. 12. For achieving it, SEEA must be the starting point and its framework. SEEA would need a step forward to convert them into a SETEA. A major intellectual effort needs to be done from the concepts stated here. At the end, the real overall accounting unit will be the residence time of the human species on the planet.

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Chapter 5

# Comprehensive Assessment of the Sustainability of Coastal Systems of the Arctic Zone of the Russian Federation

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Additional information is available at the end of the chapter

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**Abstract**

This chapter deals with the method of comprehensive assessment of the sustainability of coastal infrastructure systems of the Arctic zone of the Russian Federation, which allows analyzing the socioeconomic development of the Arctic regions of Russia in order to ensure national security, as well as forecasting the environmental and socioeconomic situation in the coastal zone of the Russian Arctic using simulation prediction methods. To account for medium- and long-term climate, environmental, economic, legal, and geopolitical changes in the Arctic in assessing the sustainability of coastal infrastructure systems, it is proposed to use a comprehensive indicator system consisting of five-factor subsystems. As a result of the analysis of the possibilities of accounting for medium- and long-term complex changes, a dynamic model of strategic spatial planning of marine activities is implemented in the regions of the Arctic zone of the Russian Federation on the basis of a comprehensive analysis of the sustainability of coastal infrastructure systems. By this model, values of the indicator were received for each of the factors of stability and the complex integral index of sustainability of coastal infrastructure systems of Russian Arctic for modern, historical, and future periods.

**Keywords:** coastal infrastructure systems, Arctic zone of the Russian Federation, sustainability, indicator methods, comprehensive assessment

## 1. Introduction

The importance of Arctic spaces and resources in the people livelihoods and the formation of the global gross product have increased. It is predicted that as a result of global climatic changes in the future, the dominant position in the structure of world trade may emerge commodity flows passing through the high-latitude transport and communication routes of the Arctic. The full-scale development of mineral and energy resources of the richest Arctic continental shelf begins, which is due to the depletion of mineral resources of the continental part of the Earth and directly affects the structure of the world's energy supply. In the near future, according to the scenario forecasts of the UN World Food Organization, there will be a sharp jump in demand for marine industrial fishery products, in the production of which the Arctic region plays a significant role. The global climate-forming function of the Arctic Ocean and its importance in ecosystem dynamics encourage to intensify fundamental research of its nature. Arctic states are actively developing tourism and recreational business [1–5].

Thus, it becomes important to solve the problem of developing the scientific basis for a comprehensive assessment of the sustainability of coastal systems and coastal infrastructure in order to implement the tasks of territorial planning and the analysis of socioeconomic development of the Arctic zone [6–8].

## 2. Background of approaches to the assessment of the sustainability of coastal systems and infrastructure

At present, there is no unified approach to the assessment of the sustainability of coastal systems and infrastructure and their impact on the environment caused by various factors. The existing global and regional concepts on the rules for assessing the sustainability of coastal systems and their impact on the environment are a common set of rules, on the basis of which national and/or local regulatory documents are developed, which reflect the regional characteristics of coastal zones and coastal infrastructure [9].

In different countries, there are different approaches to the valuation and assessment of the sustainability of the coastal zone and located infrastructure and of their impact on the environment. In general, all the countries can be divided by Australia and New Zealand, the USA and Canada, and the European Union.

The Australian approach is oriented for maintaining the quality of the coastal zone and the environment and prevents its violation. In the US, the priority is the principle of the lack of wishes to violate the norms. In these countries, the assessment of the sustainability of coastal systems and infrastructure is based on the fact that any changes require a permit for the conduct of coastal works, which set out all the necessary parameters and conditions.

The European Union framework directives give only general provisions on water quality, soil quality, coastal zone in General and environmental impact, while numerical values are set by the EU countries themselves. Thus, within the EU, there are no uniform standards adopted, and most countries are subject to international agreements such as HELCOM, which is more regional, with detailed methods for assessing the sustainability of the coastal zone and its infrastructure, and their impact on the environment.

Common to all countries are the recommendations of national and/or framework laws, regulations, and existing methods for assessing the sustainability of coastal systems and infrastructure.

On this basis, they develop their regional/territorial regulatory methodologies to reflect the characteristics of the region in order to reduce the negative impact on the coastal zone and the environment as a whole.

The basic principles of such assessment systems, based on international experience, include [10] the following:

- the principle of preventing the wishes to exceed established standards and benchmarks;
- the principle of accumulated unit points, and so on;
- the principle of "reference" system;
- the principle of particularly valuable biotopes.

Modern trends of harmonization of economy and ecology in order to overcome the global environmental crisis require not only to ensure the ecological and economic security of the territory and society but also effective diagnosis, allowing timely and in the required range to identify the problem areas of regional ecological and economic systems, preventing their bringing to the state of pathology and degradation of the entire system or its individual elements.

In the modern world, one of the most important functions of effective management of the development of the region is to assess the level of comprehensive socioeconomic and environmental development of the territory, based on a system of indicators. In other words, indicative planning is an integral part of regional development. Although the scientific foundations of indicative planning were developed in the 1920s, they have not yet found real practical application in Russia [9]. Nevertheless, it should be noted that recently in Russia, the role of indicative planning in regional management is growing rapidly.

The need to develop indicators to assess the state of the state and the direction of its comprehensive development was formulated in 1992 at the UN Conference on Environment and Development in Rio de Janeiro. This is noted in one of the main documents, Agenda 21, Chapter 40, that in order to create a reliable basis for decision making at all levels and to help alleviate the self-regulating sustainability of integrated environmental systems and systems development, it is necessary to develop indicators of sustainable development [11]. Thus, the global interest in the sustainable development of territories necessitates a comprehensive analysis and assessment of all components and indicators that determine the comprehensive sustainable development.

One of the problems solved by the scientific community today is the development of universal indicators assessing the comprehensive components of sustainable development of territories, including environmental, geographical, socioeconomic, and other parameters of development. However, there is still a lack of consensus on the assessment of the sustainability of the development of the territories. In addition, due to methodological and statistical problems, individual characteristics of different territories, the world-recognized comprehensive index does not exist yet [7, 12, 13].

A prerequisite for the assessment of the integrated sustainability of regional development is a comprehensive analysis of data at all levels of the national economic system: inter-country, national, regional (e.g., subjects of the Russian Federation), and local (local municipalities). This procedure concerns both the development of a system of indicators for assessing the sustainability of territorial development and their monitoring [14].

Nevertheless, it should be noted that currently both Russian and foreign scientists are trying to create a methodology for the indicator assessment of development sustainability, which takes into account the impact of economic, social, and environmental factors, which proves the relevance of the problem of creating a methodology for assessing the sustainability of regional socioeconomic and environmental systems. The main requirements to the system of indicators of sustainable development of regional socioeconomic systems, taking into account the characteristics of the regions, acting as the basis for building a system of indicators for assessing the sustainability of regional systems, are the following [7, 15, 16]:

- a systematic approach is required for choosing indicators, which takes into account the interaction of subsystems;
- the number of indicators should be sufficient but, if possible, limited;
- data collection should not be linked to the need for hard, costly, and time-consuming work;
- all indicators should be transparent; and
- indicators should be complementary.

However, indicators are

- used to justify the decision by quantifying and simplifying;
- help interpret changes;
- allowed to reveal shortcomings in environmental management;
- made it easier to access information for different categories of users;
- facilitated the exchange of scientific and technical information.

The indicator is the most applicable to the process of regional management, the totality of which are index, which are the basis of ecological and economic modeling of the territory development process.

The harmonious combination of indicators assessing the quality of the population, the natural environment, the regional business, and environmental policy will avoid the result of the "system degrades," as the timely detection of intermediate States is an important condition for effective environmental and economic modeling of the territory's development process [17].

In general, on the basis of Russian and international experience in assessing the sustainability of coastal systems and coastal infrastructure, in applying to the tasks of territorial planning, it is necessary to take into account the need to use a multilevel system for assessing the sustainability of coastal systems and infrastructure.

## 3. Methodology and concept for comprehensive assessment of coastal systems and infrastructure sustainability

The main purpose of the methodology for the comprehensive assessment of the sustainability of coastal systems and coastal infrastructure of different spatial levels is to identify the conditions for the stability and formation of the potential of the functioning and development of coastal infrastructure of coastal areas as territorial systems of different spatial levels, as well as their interaction with the environment.

The methodology of comprehensive assessment of coastal systems and coastal infrastructure sustainability and analysis of its components can be used for the following tasks [18]:

- identification and study of factors of territorial organization of nature and society within coastal systems;
- study of the structure and functional dependencies between components (factors, indicators, and indexes) of stability, which explain the nature of intra-system links, forming an assessment of the sustainability of the considered coastal system and coastal infrastructure and its variability, both within the system and between the system and the environment;
- obtaining a comprehensive assessment of the sustainability of coastal systems and coastal infrastructure as an assessment of the sustainability of the operation and economic development under the influence of various factors;
- regionalization, zoning, and typology of coastal systems as territorial systems of different spatial levels;
- development of principles of strategic development of coastal systems and coastal infrastructure for a certain period of time; and
- scientific substantiation of coastal territorial systems and infrastructure management.

The methodology of assessment and analysis of the components of the sustainability factors of coastal systems and coastal infrastructure for different spatial levels can allow

- obtain reliable data on the state of coastal systems and infrastructure at various spatial levels;
- provide persons and organizations making decisions with the information necessary for the prospective assessment of living conditions of the population and placement of components of the economic coastal complex;
- to develop strategic development plans for coastal systems of different spatial levels; and
- to make forecasts of the interaction of society and the nature, including an optimum variant of the placement of productive forces and the forecast of a condition of coastal systems depending on the scenario of development.

At the same time, the indicator approach, which is considered as the basis for the assessment and analysis of the components of the sustainability factors of coastal systems and coastal infrastructure for different spatial levels, involves the use of different systems of indicators for the analysis and assessment of the state of stability and development trends of coastal systems. The main critical points of using the existing indicator systems are as follows [7, 18]:

- most indicator systems operate on the absolute values of indicators, without actually conducting a comprehensive integrated assessment of sustainable development;
- there is no uniform approach to the formation of system of comprehensive assessments of a condition; and
- in principle, the specificity of coastal systems is not taken into account in the existing indicator systems.

Assumptions that can be used in the development of indicator subsystems and methods for indicators calculating can be summarized as follows:

- indicator value must be dimensionless and takes values ranging from −1 to +1;
- requires the rejection of the use of weight functions in the calculation of integral indicators, as this will lead to ambiguity and controversy in assessing the importance of each indicator.

There are four main groups of methods to determine the values of various indicators [7, 18]:

**1.** Method of the indicator calculation based on the approximate degree of the parameter value to the maximum value. The maximum value can be defined as the maximum value of this characteristic of all coastal zone of the relevant spatial level. Indicator values are always between 0 and 1.

**2.** Method of the indicator calculation based on the deviation degree of the parameter from the average value. The average value of the considered characteristic of all coastal areas of the relevant spatial level is taken. Indicator values are always more than −1, without loss of the upper limit.

**3.** Method of the indicator calculation based on the deviation degree of the parameter-specific values from the specific values of similar parameters of a higher spatial level. For example, as a parameter of a higher spatial level, it is possible to have a value with the same characteristic of the Russian Subject coastal zone, if the considered parameter refers to the level of the coastal Regional Municipality of the Russian Federation, and so on. Norm-referenced values can be taken, for example, the population of the corresponding level, area square, and so on. Indicator values are always more than −1, without loss of the upper limit.

**4.** Method of the indicator calculation based on the deviation degree of the parameter from the extreme values. As the extreme values can be taken, the maximum and minimum values of the characteristic of all coastal areas of relevant spatial level. Indicator values are always in the range from −1 to +1.

Certainly, the construction and use of indicator systems can be combined by the methods of calculating the indicator values.

A comprehensive value reflecting situation of the coastal regions and its infrastructure condition can be considered as a set of groups of indexes.

As the main approach to the comprehensive assessment of the sustainability of coastal systems and coastal infrastructure, it is necessary to use the GIS-based research method. GIS in this case is a kind of catalyst, which is necessary for solving problems related to the spatial distribution of climatic, environmental, economic, legal, and geopolitical aspects.

Many GIS are related to inventory-type tasks that focus on data and measurements (e.g., land cadastre tasks); others are related to management and decision-making tasks with a focus on modeling and complex data analysis. The first type of task is most important because it accounts for the maximum number of implemented systems, including the largest number of users and the volume of data collected. However, GIS is also widely used as a reference system. Regardless of whether powerful analytical procedures and complex queries are available for working with data, GIS is very often used as a decision-making tool, and the efficiency achieved here is often very high due to the clarity of cartographic visualization of information and ease of access to information.

For the purposes of complex assessment of sustainability of coastal systems and coastal infrastructure of the Arctic zone of the Russian Federation, the concept of GIS-tool "AZRF Coastal Systems" was made. In general, such GIS is a special information system that collects, processes, stores, displays, and distributes spatial data, as well as non-spatial data on the coastal systems of the Russian Arctic including the maritime components.

Structurally, GIS "AZRF Coastal Systems" consists of the following elements:

- multistructural databases (banks of data and knowledge) with the necessary quality of dynamism, that is, the ability to quickly process and continuously update, reflecting all changes occurring in the coastal systems of the Russian Arctic;
- variety of different models, algorithms, and programs for processing and converting data on the coastal systems of the Russian Arctic in semantic spatial information in accordance with certain requirements of processing and visualization in GIS; and
- interface set access to GIS.

GIS "Coast of the Russian Arctic" was implemented at three spatial levels:

- global (spatial–temporal database for the whole set of coastal systems of the Russian Arctic);
- regional (spatial–temporal database on the coastal subjects of the Russian Arctic); and
- regional (spatial–temporal database for coastal municipalities of the Russian Arctic).

GIS at the third local level is currently under development.

## 4. Dynamic model of strategic spatial planning of maritime activities of the regions of the Russian Arctic on the basis of a comprehensive analysis of the sustainability of coastal systems and coastal infrastructure

Dynamic model of strategic spatial planning of maritime activities in the regions of the Russian Arctic on the basis of a comprehensive analysis of the sustainability of coastal systems and coastal infrastructure is a dynamic information system for processing spatial information for short-, medium-, and long-term forecasting of economic activities taking into account climatic, environmental, economic, legal, and geopolitical changes.

The dynamic model is based on the indicator approach, the methodology of which is described in part 3.

To take into account medium- and long-term climate, environmental, economic, legal, and geopolitical changes in the Arctic in assessing the sustainability of coastal systems and the relevant coastal infrastructure of the regional level of management, it is proposed to use a comprehensive indicator system consisting of five-factor subsystems:

### 4.1. Common economic sustainability factors

This group of factors takes into account the level of common economic development of the region, including such factors as the gross regional product (GRP), the amount of attracted investments, the level of foreign economic activity, the economic growth, and industrial production growth values.

Group of indicators of the common economic sustainability factors (index of common economic sustainability) includes:

- indicator of gross regional product;
- indicator of attracted investments;
- indicator of foreign-economic activity;
- indicator of economic growth;
- indicator of industrial production growth.

### 4.2. Sociodemographic sustainability factors

The importance of the sociodemographic characteristic is determined primarily by the possibility of assessing the prospects for the development of the coastal system and infrastructure in terms of the availability and the use of labor resources and social comfort of living. This group is the determining basis for the development of coastal Arctic systems, and, as a consequence, takes into account factors such as the labor resources, population growth, unemployment level, education and health facilities, the level of wages, and the Gini index.

Group of indicators of the sociodemographic sustainability factors (index of sociodemographic sustainability) includes

- indicator of labor resources;
- indicator of population growth;
- indicator of unemployment;
- indicator of educational and health facilities;
- indicator of the amount of wages and the subsistence wages;
- indicator of Gini index.

### 4.3. Resource sustainability factors

The volume and variability of the development and use of resources is determined by the socioeconomic needs of society. The Russian Arctic is characterized by extreme unevenness of resource use which depends on natural and social factors. Highlighting the enlarged areas of the development of coastal Arctic complexes, this group takes into account factors such as the level of development of the gas-oil and mining industry, the industry of biological resources, the value of cargo turnover of port facilities, the level of development of the manufacturing industry, the level of tourist importance, and the level of development of transport infrastructure.

Group of indicators of resource sustainability factors (index of resource sustainability) includes

- indicator of gas-oil and mining resources;
- indicator of marine bio-resources;
- indicator of cargo turnover of port facilities;
- the indicator of manufacturing industry;
- indicator of transport infrastructure development;
- indicator of tourist significance.

### 4.4. Environmental sustainability factors

The importance of the environmental group of sustainability factors of coastal systems and the relevant coastal infrastructure is due to the fact that the geographical environment, being a complex unique formation, has a strong impact on the development and preservation of the environment. This group takes into account factors such as the square-protected natural areas of the region, the level of air pollution and waste water emissions, the value of environmental costs, and the level of morbidity of the population.

Group of indicators of environmental sustainability factors (index of environmental sustainability) includes

- protected area indicator;
- indicator of air pollution;
- indicator of sewage pollution;
- indicator of the cost of environmental protection;
- indicator of morbidity.

### 4.5. Politic-geographical sustainability factors

The essence of this group of factors, which is a part of political regionalism, is the study of spatial (territorial) organization of political life of society and sociopolitical (politic-geographical) systems, their internal structure in the socioeconomic space of the Russian Arctic, taking into account the comfort of human habitation. This group takes into account factors such as the degree of domestic political stability in the region, the level of migration, the level of coastal concentration of population, the level of regional subsidy, and the level of crime in the region.

Group of indicators of politic-geographical sustainability factors (index of politic-geographical sustainability) includes

- indicator of domestic political stability;
- indicator of migration;
- indicator of coastal concentration of population;
- indicator of regional subsidy;
- indicator of crime.

According to the presented methodology (part 3), the comprehensive index value of the sustainability of coastal systems and the relevant coastal infrastructure for Russian Arctic regions are calculated as a medium of five indexes of sustainability.

## 5. Estimation of the comprehensive value of the sustainability of coastal systems and the relevant coastal infrastructure of the coastal Arctic regions

According to the presented methodology, the dynamic model of strategic spatial planning of the regions of the Russian Arctic was developed based on a comprehensive analysis of the sustainability of coastal systems and coastal infrastructure. For calculation of the indicator values were used official information of Federal Ministries and Agencies, including statistical offices and Governments of the coastal Subjects of the Russian Federation.

In particular, for each Subject of the Russian Arctic, the following were calculated and obtained:

- values of the indicators for each of the reduced factors of stability;

- values of sustainability factor indexes and comprehensive index of sustainability of coastal systems and coastal infrastructure for 2016;
- forecast values of sustainability factor indexes and comprehensive index of sustainability of coastal systems and coastal infrastructure for 2025, according to the strategies of socioeconomic development of the Arctic Subjects of the Russian Federation.

At the same time, it should be noted that the boundaries of each Russian Arctic Subject were determined according to the Decree of the President of the Russian Federation. According to these definitions, for the Republic of Karelia, Arkhangelsk Oblast, Krasnoyarsk Krai and Sakha (Yakutia) Republic, the partial (several local municipalities) territorial belonging to these Subjects of the Russian Federation into the Russian Arctic was taken into consideration when calculating indicators and indexes.

Indicators and index values were obtained and visualized by using GIS "AZRF Coastal Systems."

Analysis of the current situation on the index of common economic sustainability showed that the Republic of Karelia is in the worst position of all Arctic regions (the index value is 0.30), which is associated with low economic growth, low investment attraction, and low level of the gross regional product (**Figure 1**). The leader in terms of common economic stability is Yamalo-Nenets Autonomous Okrug (index value 0.74), which is caused by the high level of the gross regional product, industrial production growth, and a large volume of attracted


**Figure 1.** Index of common economic sustainability, 2016.

investments. Interestingly, only the Republic of Sakha (Yakutia) has all the positive values of indicators.

Forecast for the development of the situation on the common economic sustainability for 2025 was analyzed by the basis of the strategies of socioeconomic development of regions of the Russian Arctic. In comparison with the current situation, not all Arctic regions were able to correctly project the development of economic stability. For example, for the Arkhangelsk Oblast, the index is projected to decline to −0.39, from −0.18 in 2016, and for the Chukotka Autonomous Okrug to 0.17 from 0.72. First of all, this is due to the low forecasts for the size of attracted investments, and economic and industrial growth. Also, a serious projected decline was revealed for the Krasnoyarsk Krai: from 0.19 to −0.32. The leading position on this indicator will be the Republic of Sakha (Yakutia).

Index of sociodemographic sustainability in 2016 shows the most stable position in Yamalo-Nenets Autonomous Okrug and Chukotka Autonomous Okrug, with the index values of 0.39, achieved due to the positive values of all indicators except the Gini index in Yamalo-Nenets Autonomous Okrug (**Figure 2**). The high values of the index in the Murmansk Oblast (0.23) and the Republic of Sakha (Yakutia) (0.21) are due to the stability of the regions in all respects, except for the unemployment rate, the values of which are quite high in these Arctic regions. Other regions of the Russian Arctic have lower indices of the sociodemographic sustainability index. It is interesting that the values of the indicator of educational and health facilities are

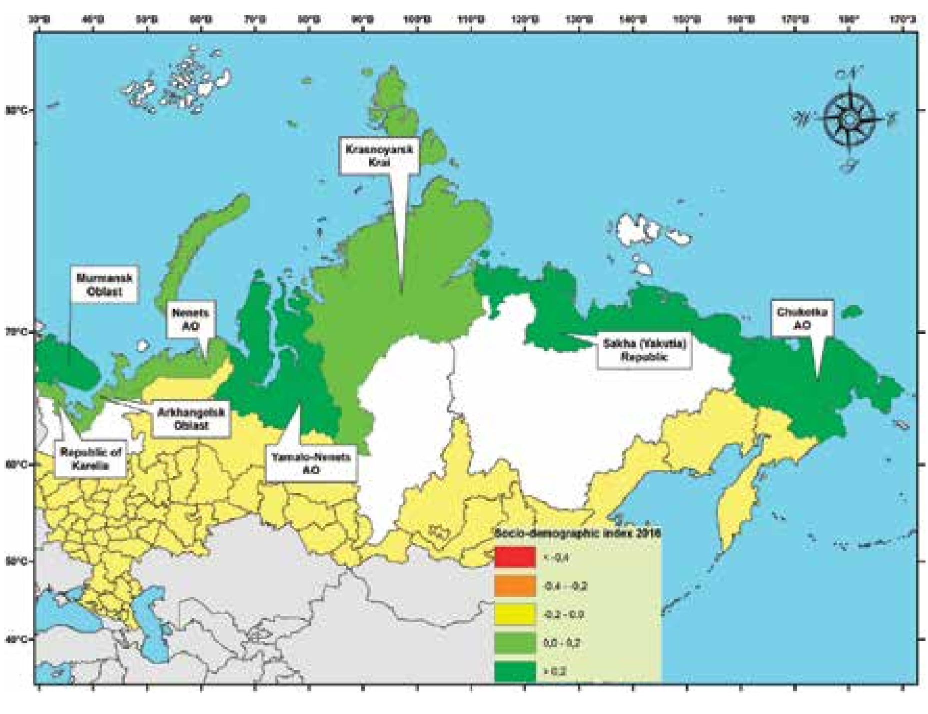


**Figure 2.** Index of sociodemographic sustainability, 2016.

positive for all Arctic regions, and the indicator of population growth has negative values only for the Arkhangelsk Oblast and the Republic of Karelia.

By 2025, in all regions of the Russian Arctic, according to their strategies of the socioeconomic development, the current situation in the Western Arctic regions is projected to continue and the current situation in the Eastern Arctic regions will become worse, most likely due to the underestimation of the possibilities of socioeconomic development. The worsening of the situation in the Republic of Sakha (Yakutia), for which the index value is projected to decrease from 0.21 (one of the leaders in 2016) to −0.05 (the worst situation in the Russian Arctic), is especially planned. Thus, the wage indicator values will be positive only in Yamalo-Nenets Autonomous Okrug, in all regions except the Republic of Karelia, a significant decrease in the unemployment indicator values is predicted.

The current situation in the resource economic sector demonstrates a rather difficult situation in all regions of the Russian Arctic, with the lowest values of the corresponding index in the Republic of Sakha (Yakutia) (index value −0.54), and in the Yamalo-Nenets Autonomous Okrug, Krasnoyarsk Krai and Chukotka Autonomous Okrug, the index values do not exceed −0.45 (**Figure 3**). This situation is connected with the sharp one-sided development of the resource potential of the regions, including a small turnover of port facilities, a low level of the manufacturing industry, and the infrastructure. More positive is the resource sustainability in the Western regions of the Russian Arctic, led by the Murmansk Oblast, for which the value of the resource sustainability index is 0.31, with maximum values of indicators of marine

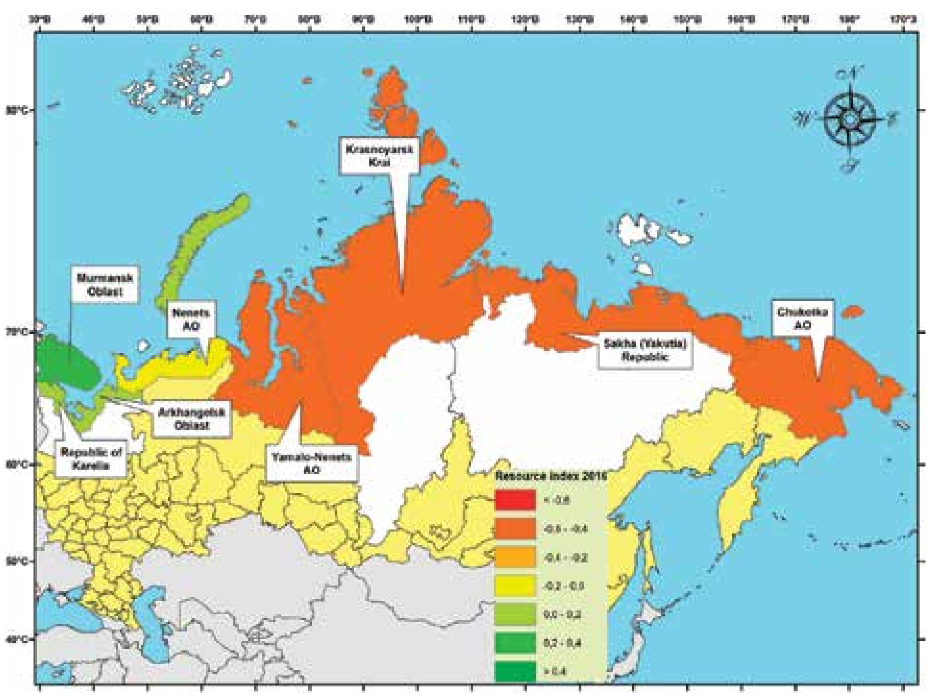


**Figure 3.** Index of resource sustainability, 2016.

bio-resources and cargo turnover of port facilities of the region. The indicator of infrastructure development is positive only for the Arkhangelsk region.

According to the forecasts of the strategies of the socioeconomic development of the Arctic regions, the situation in the regions in terms of resource sustainability index will remain at the same level. Significant growth of the index is projected only for Chukotka, with growth of values of −0.45 to −0.15 (due to the forecast for the development of the manufacturing industry in the region), and Arkhangelsk Oblast with the growth of index values of 0.15 to 0.34, through the development of port activity, growth of manufacturing industry, and the tourist significance in the region.

Examining the current situation in the regions on the environmental sustainability index draws attention to the generally negative situation throughout the Russian Arctic (**Figure 4**). For example, in the Arkhangelsk Oblast, the index value is −0.40, in the Murmansk Oblast, it is −0.38. Against the background of these results, Krasnoyarsk Krai looks best with a positive index value close to 0.

The following indicators have the greatest impact on the environmental sustainability index:

- air pollution indicator is negative for all Arctic regions except the Republic of Karelia;
- sewage pollution indicator is positive only for Nenets Autonomous Okrug, Yamalo-Nenets Autonomous Okrug, and Chukotka Autonomous Okrug;

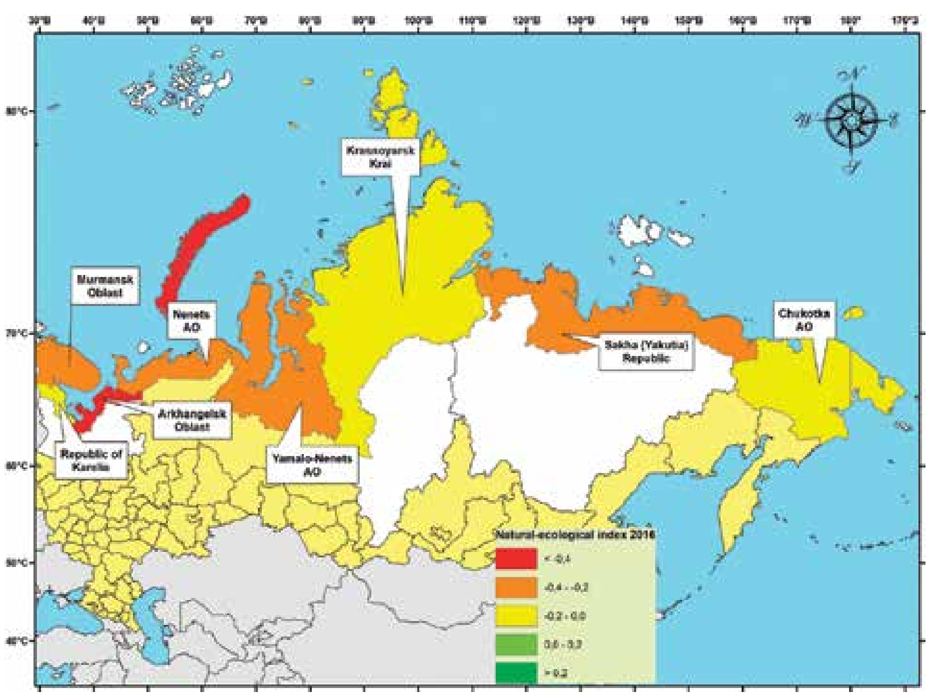


**Figure 4.** Index of environmental sustainability, 2016.

- the indicator of the protected area is positive only for the Krasnoyarsk Krai and Chukotka Autonomous Okrug.

Interestingly, the Nenets Autonomous district is characterized by a low value of the indicator of the costs of environmental protection.

Predicting using the analysis of strategies of the socioeconomic development of the regions of the Russian Arctic environmental sustainability index values for 2025, it is necessary to state the preservation of the current situation in general, and even its slight deterioration, for example, for the Murmansk Oblast and the Arkhangelsk Oblast, a slight improvement of the environmental sustainability index is projected only for the Yamal-Nenets Autonomous Okrug.

The politic-geographical sustainability index, which reflects the comfort of living of the population of the region depending on the administrative policy of the region, for the current situation showed that the least comfortable living in the Republic of Karelia (the index value is −0.69) is associated with a high level of regional subsidy, the level of crime (crime indicator less −0.5), and unstable political situation (the indicator of domestic political stability is less −0.43). On the contrary, the highest and positive index value was registered for Nenets Autonomous Okrug only—just above zero, 0.05 (**Figure 5**). This region, along with the Yamalo-Nenets Autonomous Okrug, has not regional subsidy from the federal budget, and only this region is characterized by the positive value of the migration indicator. It should be noted that for the Republic of Karelia and the Krasnoyarsk Krai, all the values of indicators of this index are negative.


**Figure 5.** Index of politic-geographical sustainability, 2016.

The forecast values of the politic-geographical sustainability index for 2025 show a significant improvement in the situation in almost all Arctic regions, except Nenets Autonomous Okrug and Yamalo-Nenets Autonomous Okrug, for which the situation will remain unchanged. Positive values of the index are also predicted for the Murmansk Oblast and Arkhangelsk Oblast, and the most impressive breakthrough is predicted for the Republic of Sakha (Yakutia): from −0.43 to −0.05. These changes are associated with positive dynamics according to the forecasts of indicators of migration and of regional subsidy.

Considering the totality of all the stability indexes obtained, and calculating on their basis the comprehensive index value of the stability of the Arctic regions, it obtains that at the moment among all the regions of the Russian Arctic, the leaders are the Murmansk Oblast, Yamalo-Nenets Autonomous Okrug, and Nenets Autonomous Okrug, with the values of the complex index in the limit of 0.06–0.09, which is associated with sufficiently high and stable situation for most indexes (**Figure 6**). The most unstable situation is registered in the Republic of Karelia, Krasnoyarsk Krai, and the Republic of Sakha (Yakutia), for which the values of the comprehensive index value of the stability range from −0.12 to −0.15.

In the forecast of the situation for 2025, based on the strategies of socioeconomic development of the Arctic regions, the situation is slightly improving in the Western regions (Murmansk Oblast, the Republic of Karelia, and Arkhangelsk Oblast), which more correctly took into account the weaknesses of the regions in strategies and plans to improve the socioeconomic situation in general (**Figure 7**). At the same time, the Murmansk Oblast will remain the only one that is predicted to

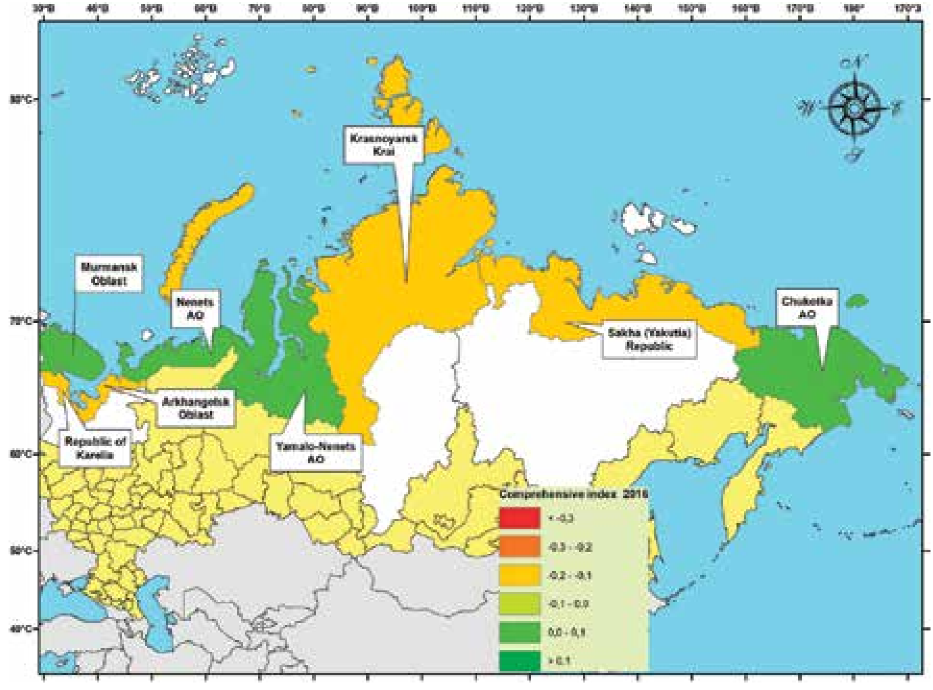


**Figure 6.** Comprehensive index of stability, 2016.

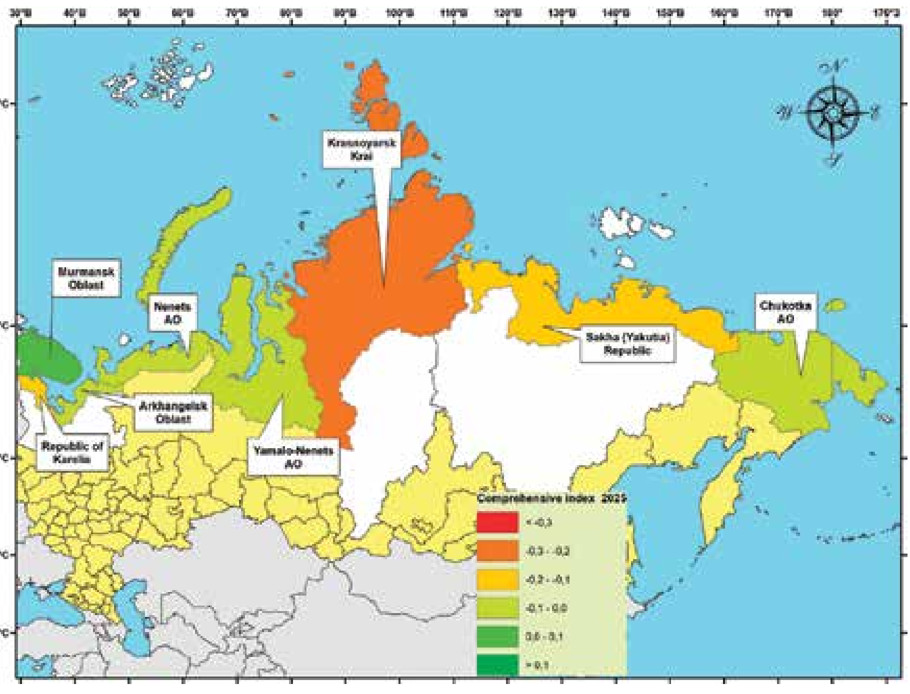


**Figure 7.** Forecast of comprehensive index of stability, 2025.

have a positive value of the comprehensive index value of the stability (0.11). The forecast situation in Yamalo-Nenets Autonomous Okrug (with a decline of the value of the comprehensive index value of the stability from 0.7 to −0.04) and Krasnoyarsk Krai (with a decline of the value of the comprehensive index value of the stability from −0.12 to −0.20) will deteriorate the most. At the same time, the Krasnoyarsk Krai is projected as an absolute outsider in terms of sustainability of development among all Arctic regions of the Russian Arctic.

This current and prediction situation signals the socioeconomic development priorities that are often incorrectly chosen by the Arctic regions and requires adjustment of the strategies of the socioeconomic development of the Arctic regions and their coordination with the directions of the socioeconomic development of the Russian Federation.

## 6. Conclusions

As a result of the research, five indicator groups for different factors of sustainability for the assessment of coastal systems and coastal infrastructure are obtained. This includes methods of their calculation on the basis of the analysis of system principles of sustainability of coastal systems and accounting of medium- and long-term climatic, ecological, economic, legal, and geopolitical changes in the Arctic, from the point of spatial planning and development of coastal territorial systems. On the basis of this methodology, a dynamic model of strategic spatial planning of the Russian Arctic regions and the integrated geographic information system of coastal systems and coastal infrastructure of the Russian Arctic "AZRF Coastal Systems," including the regional component of GIS, were created.

According to the calculation and analysis, at the moment among all the regions of the Russian Arctic, the leaders are the Murmansk Oblast, Yamalo-Nenets Autonomous Okrug, and Nenets Autonomous Okrug, which is associated with sufficiently high and stable situation for most indexes. The most unstable situation is registered in the Republic of Karelia, Krasnoyarsk Krai, and the Republic of Sakha (Yakutia). In the forecast of the situation for 2025, based on the strategies of socioeconomic development of the Arctic regions, the situation is slightly improving in the Western regions (Murmansk Oblast, the Republic of Karelia, and Arkhangelsk Oblast), which more correctly took into account the weaknesses of the regions in strategies and plans to improve the socioeconomic situation in general. At the same time, the Murmansk Oblast will remain the only one that is predicted to have a positive value of the comprehensive index value of the stability. The forecast situation in Yamalo-Nenets Autonomous Okrug and Krasnoyarsk Krai will deteriorate the most, and the Krasnoyarsk Krai is projected as an absolute outsider in terms of sustainability of development among all Arctic regions of the Russian Arctic. These situations signal the socioeconomic development priorities that are often incorrectly chosen by the Arctic regions and require adjustment of the strategies of the socioeconomic development of the Arctic regions and their coordination with the directions of the socioeconomic development of the Russian Federation.

Due to the calculations performed, the applicability of this model is shown not only to assess the current state of the Arctic regions of the Russian Federation but also to predict their development on the basis of scenario forecast.

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