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The economy of material flow cycling in anthropized and anthropogenic systems

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Abstract. *The dematerialization of the development of anthropized and anthropic systems/complexes represents an objective of maximum importance for ensuring the coevolution of human activities and the natural environment, from the perspective of sustainability requirements. In this context, the use of methods for analyzing the reciprocal flows between the natural environment as a system and the socioeconomic system, in physical and energetic expression, provides us with the information support necessary to adopt measures to reduce specific consumption of ecosystem goods, respectively pressure on biophysical support of socio-economic systems, regardless of the spatial scale at which they are identified.*
Approaches in the field of industrial ecology, but not only, have highlighted the need and possibility of material flows cycling, but this is a first step towards dematerializing the development of anthropogenic and anthropic systems/complexes. From the perspective of global performance, research is needed on cost/benefit analysis of decisions in this regard and evaluation of effects/impacts on structural and functional processes at the level of technical-productive organizations.

Keywords: system, material flows cycling, dematerialization, coevolution, sustainable development.

Introduction

The transition from the optimized economy to the heuristic economy, based on punctual multidimensional decisions, not validated in terms of generalization, imposed by a diversified and very complex casuistry/reality, tends to determine a revision of the relations between the civilization of private profit and that of social profit. A growing private profit on a planet Earth of all people, but increasingly poor, loses its significance. Against this background appeared the idea of better management of environmental costs that brings to the fore the need to cycle material flows resulting from the metabolism of anthropized and anthropic systems, a necessity that is to be synthesized by the phrase "circular economy".

The situation to which the idea of "circular economy" is subsumed (by its content and not by its form) is represented by the triggering and amplification of the degradation of the relations between the economic systems and the natural environment. Causally, the main triggers of the conflict state between the two systems (Figure 1) are related to the socio-human capital, the technical-productive factors and the factors of knowledge; their analytical effects are manifested by the decrease in the support capacity of the natural environment doubled by the amplification of socio-economic imbalances.

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Therefore, the economy of material flow cycling must be promoted from the perspective of contributing to reducing the risk of increasing the scarcity of ecosystem goods and declining economic competitiveness, inequitable distribution of wealth, the latter being reflected in deteriorating state and functional parameters of technical and productive organizations, affecting the partnership for the natural environment, the multiplication of social conflicts.

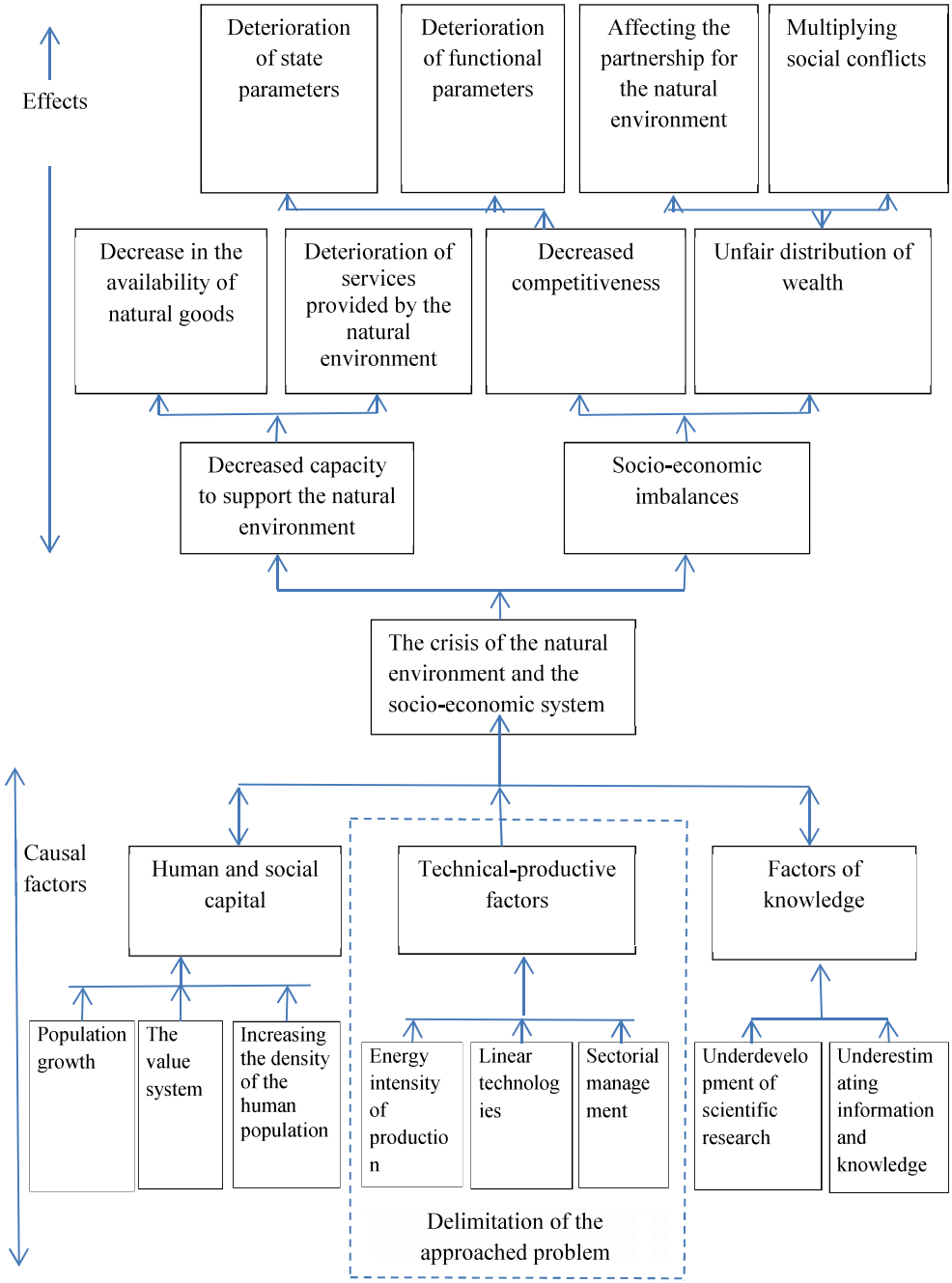


Figure 1. Dematerialization of the development of socio-economic complexes

Source: Negrei (2016).

Literature review

We appreciate that in order to overcome the theoretical and practical limits of economics, in the case of sectoral approaches, mainly quantitative, it is necessary to make greater use of new scientific accumulations in the field of systemic ecology, which must be the basis of adaptive management (Vădineanu, 2004), condition of ensuring the coevolution (and not the subordination) of the environment and the socio-economic system (Negrei, 2004). Thus, systemic ecology provides us with the knowledge necessary to understand the complete development cycle of a system (natural, anthropogenic) and the connectivity between development cycles within the ecological hierarchy - Panarchy (Vădineanu, 2004). The application of these scientific accumulations in the field of relations between the socioeconomic system and the natural environment, as a system, leads to the promotion of the concept of socioecological complex - elementary spatial unit of design and operationalization of matter and energy flows between the two systems.

The parameterization of this process (Figure 2) highlights the existence of absolute restrictions that define the irreversibility of the economy as a system (excludes circularity). Of course, we take into account the fact that the systems of lower hierarchical level can evade to a certain extent the law of entropy (the second arrow of time), at the level of the hypersystem, of the Ecosphere, the entropy increasing continuously (the first arrow of time).

Natural capital (CN) provides renewable (SER) and non-renewable (SEN) ecosystem services in the form of material flows. Their quantity, quality and structure are conditioned by the observance of the correlations between the regeneration rate (rr) and the feeding rate (ra) on the one hand and the sampling rate (w) on the other hand. Otherwise, it leads to the situation of overexploitation of ecosystem services and thus to the vulnerability of the natural base of the socio-economic system. Anti-anthropic flows (fa) generated by natural capital measure the volume of ecosystem services accessed (SEA) subject to transformation (TF) in line with consumption requirements (C). The three processes (SEA, TF, C) also generate entropic flows (fe) in the form of waste (D). Some of these are recovered, reused, recycled (anti-entropy flows, in line with the circular economy) contributing to the balancing of SEA and C. "Uncirculated" waste is treated (T) resulting in a certain volume of residue (E). They are reintroduced into the natural circuit by the natural environment, but within the limits of its ability to "process" pollutants (A). If $E > A$, entropic flows (fe) appear which accentuate the crisis of the natural environment and undermine consumption. Beyond the extent to which the three categories of constraints are met ($w < ra$; $w < rr$; $E > A$), SEA, TF, C and T processes involve unidirectional (entropic) energy consumption as well as material loss (E). Under these conditions, the economic system is irreversible and we cannot speak of a circular economy.

From a practical point of view, the promotion of non-linear technical-productive systems, as well as natural systems, with the general objective of accentuating the process of dematerialization of economic development, involves finding solutions to "close" as much as possible the specific flows of different economic-social activities. In this way, the circular economy is placed in the area of corrective and not preventive actions, which limits its level of efficiency. That is why a concerted approach is needed, along with reducing the share of waste deposited in total waste production, and economic practice should focus (as a matter of priority) on mechanisms to reduce waste production.

This issue needs to be addressed in the light of the scale effect of RRR waste. We consider that waste, especially those with high pollutant potential, are to a lesser extent the object of "self-

consumption", their recovery requiring collection from large areas, generating high economic and environmental costs (due to transport), which will worsen the energy balance of circular economy.

Defining the spatial scale of the circular economy must be followed by setting priorities. In practice, an effort will be needed to substantiate the criteria for setting priorities, such as:

- scarcity of resources;
- ecological vulnerability of the area;
- the importance of different activities for the local, regional, national economy;
- the strategic character of some economic and social captivity.

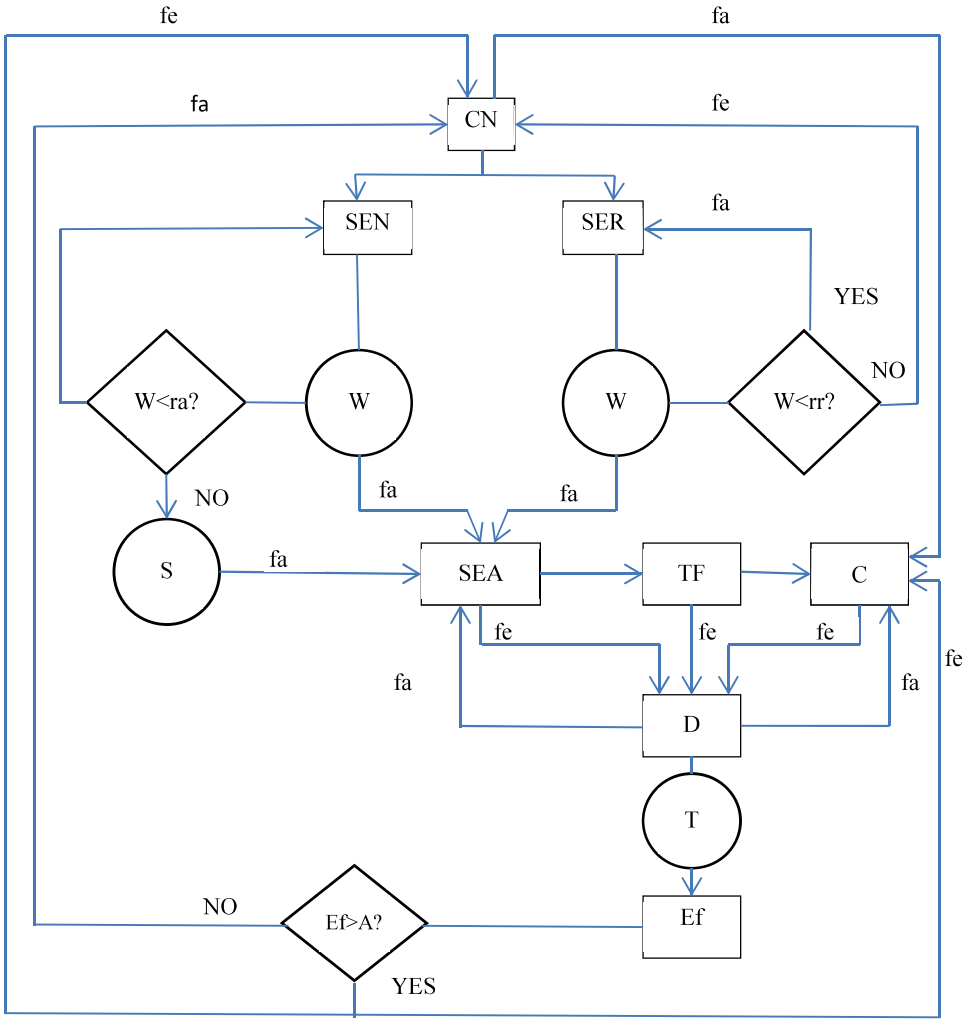


Figure 2. The irreversibility of the socio-economic system

Source: Negrei (2016).

The package of measures developed by the European Commission in 2015 on the circular economy includes tools and mechanisms to accelerate the transition from a consumer economy (an economy of disposable goods) to an economy based on the quality, reliability of products and services. At least in the beginning, such an option will lead to an upward trend in costs/prices, with a negative impact on demand. Therefore, we believe that the solution could be the "economy of functionality" (Bourg et al., 2006) in which to sell not only the products but their utilities

(providing, where appropriate, maintenance), the problem of distribution and management of the responsibilities of the owner of the good and the beneficiary of the utilities remains to be solved.

The extension of the technological interconnection within the organization, imposed by the appearance of the structures that allow the self-consumption of waste / some material flow cycling, will make necessary the revision of the practical processes of specialization and profiling of the material and service production.

It is very likely that the diversification of the technical-material base and of the occupational options will affect the level of competitiveness, diminishing the availability to assume the "circular economy". Overcoming such an obstacle can be based on a better "capitalization" of the benefits of "self-consumption" of waste (which will help to balance the balance of materials and reduce environmental damage) by stimulating technical and productive organizations in this regard.

For the systemic analysis of material flows, as a premise for identifying the possibilities and limits of their cycling, in accordance with the requirements of global performance, can be used the model "control factors-pressure factors-state-impact-response" (DPSIR), edifying being in this sense the matrices of the relations “control factors-pressure factors” and “state-response impact / transition” (Negrei, 2019). Among the drivers we find the input market (including ecosystem goods) and the output market (including waste), and the channels of pressure include: production structure, production intensification / extension, production specialization (which are the result of structural and functional processes), overexploitation natural resources, pollution.

The impacts of the control factors, via the channels of exerting the pressure and the pressure receivers, are manifested in economic, social, of the natural environment, involving answers of legislative, economic, technical-managerial and social nature.

We appreciate that the economy material flow cycling must be dimensioned taking into account all these aspects, so that the values of the indicators of the global performance of the technical-productive systems are inscribed on a positive curve. For example, environmental performance indicators (component of overall performance) can be structured into three categories, including (Negrei, 2019).

Table 1. Environmental performance indicators

1.1.	**Utilization of ecosystem services**
1.1.1.	Total natural material inputs
1.1.2.	Energy inputs consumed within the organization
1.1.3.	Energy inputs consumed outside the organization
1.1.4.	Specific energy consumption
1.1.5.	Water consumption, by source
1.1.6.	The volume of water recycled and reused
1.1.7.	Agricultural area used, by categories of use and ecological importance
1.1.8.	Number of endangered species on the IUCN and nationally protected species that have inhabited areas affected by the organization's activities
1.2.	**Improving waste management**
1.2.1.	Volume and structure of produced waste
1.2.2.	Waste production / ton product / 1000 lei income
1.2.3.	Recovered waste
1.2.4.	Material inputs from reuse / recycling of waste
1.2.5.	Waste recovered outside the organization
1.2.6.	Landfilled waste
1.3.	**Reduction of ecological accidents / pollution (damage) of the natural environment**
1.3.1.	Investments to reduce pollution of the natural environment
1.3.2.	The ecological potential of the agricultural industries

1.3.3.	The area of agricultural land subject to cross-compliance and agri-environment payments
1.3.4.	Amounts allocated to measures to reduce the negative impact on biodiversity
1.3.5.	The amount of greenhouse gases emitted directly
1.3.6.	Amount of greenhouse gases emitted indirectly (related to utility consumption, business travel, etc.)
1.3.7.	Intensity of greenhouse gas emissions (emissions per unit of product)
1.3.8.	Amounts allocated to measures to reduce GHG emissions
1.3.9.	Amounts allocated to measures to reduce emissions of pollutants harmful to the ozone layer
1.3.10.	Amounts allocated to measures to improve air quality
1.3.11.	Volume of (wastewater) discharged, by types of pollutants contained and receptors (surface water, public network, etc.)
1.3.12.	Neighboring areas affected / potentially affected by the waste produced
1.3.13.	Number and amount of penalties for non-compliance with natural conservation requirements
1.3.14.	Number of complaints regarding the impact on the natural environment that have been received and resolved
1.3.15.	Consumption of chemical fertilizers
1.3.16.	Pesticide consumption
1.3.17.	Volume of works per hectare

Source: Negrei (2019).

Such indicators are found in the management of the logistics system; for the determination of the necessary supply, the recoverable, reusable and recyclable resources are taken into account, as part of the internal resources, together with the resources obtained from own production and the quantities attracted from oversized stocks (Istudor, 2011).

Through its content, the material flow cycling aims at decoupling the growth and economic development from the increase of the material and energetic intensity, as an approach meant to potentiate the global performance of the anthropized and anthropic systems.

At the same time, we emphasize the identity between the content of the circular economy and the economy of material flow cycling, the contradiction between the form and the content of the phrase "circular economy" remaining obvious, because we cannot talk about an "economic perpetuity" without ignoring the second law of thermodynamics.

Methodology

The elementary functional unit of elaboration, testing and application of the concepts, models and tools necessary for the knowledge and diagnosis of the metabolism of anthropized and anthropic systems is represented by the cybernetic model of the socioecological complex. The operation of the two systems is conditioned not only by the level of self-consumption but also by the reciprocal material flows. The level of socio-ecological complex operating parameters is reflected on the one hand in available bioproductive area and on the other hand in necessary bioproductive surface (ecological footprint), the size relationship between indicating a trend towards durability or non-durability of socioecological complex.

Material and method

The economy of material flow cycling in anthropized and anthropic systems is a practical approach, which is based on methods and techniques of analysis of material flows, in physical and energetic expression, whose decisional purpose depends on the accuracy of using integrative models, such as the model "factors control-pressure factors-state of the system-impact on the system-response of the decision-maker" (DPSIR).

Regardless of the aggregation/detail and the spatial scale of identification of anthropized and anthropic systems, the methods and techniques of material flow analysis were developed in accordance with the hierarchical organization of reality and the coevolutionary nature of the relationship between the natural environment and socioeconomic system.

To eliminate certain ambiguities, we consider the natural environment as representing the system of natural, semi-natural and anthropogenic components that influence economic and social activities, organized at different scales of space and time, components that, in turn, are influenced by those activities. Therefore, the elementary functional unit of elaboration, testing and application of the concepts, models and tools necessary for the knowledge and diagnosis of the metabolism of anthropized and anthropic systems is represented by the socio-ecological complex (Figure 3).

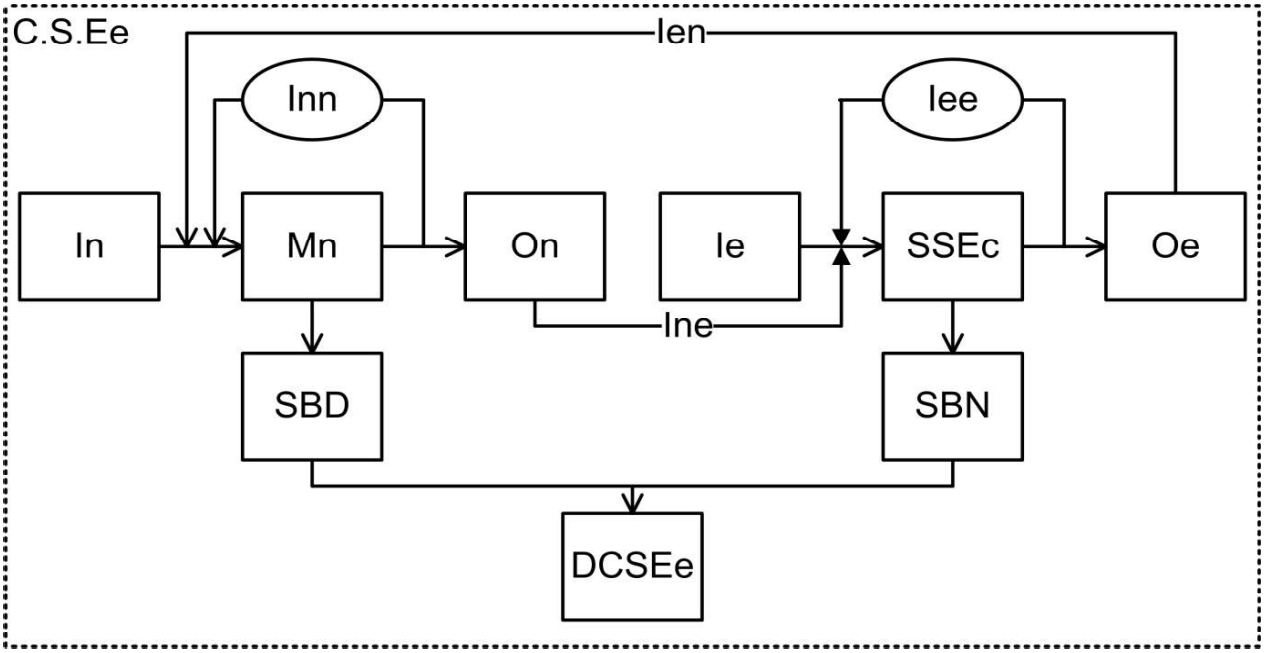


Figure 3. The cybernetic model of the socioecological complex

Source: Negrei (2018).

Note:
CSEe – socioecological complex
Mn – natural environment
SSEc – socio-economic system
SBD – available bioproductive area
SBN – necessary bioproductive surface
DCSEe – development of the socio-ecological complex
In – inputs for Mn
Inn – natural inputs for Mn (self-consumption)
Ine – natural inputs for SSEc
Ie – inputs for SSEc
Iee – economic inputs for SSEc (self-consumption)
Ien – economic inputs for Mn

The functioning of the two systems (MN and SSEc) is conditioned not only by the level of self-consumption (Inn, Iee) but also by the reciprocal material flows (Ine, Ien). The level of CSEc operating parameters is reflected on the one hand in SBD and on the other hand in SBN (ecological footprint), the size relationship between indicating a trend towards durability or non-durability of CSEc. The available bioproductive surface/ecological foundation includes in its structure:

- the surface necessary for the transformation of the solar kinetic energy into potential energy (in the form of goods and services: agricultural, forestry surface, surface covered by waters;
- built area;
- the surface necessary for the absorption of pollutants resulting from the metabolism of the socio-economic system.

The necessary bioproductive surface is the surface that must ensure:

- consumption of goods and services specific to the socio-economic system;
- supporting the infrastructure of the socio-economic system;
- processing the by-products of the metabolism of the socio-economic system.

The biophysical support/absorption basin / ecological foundation of any activity is ensured both by the area where it takes place (internal natural capital) and outside the area (external natural capital), and the analysis of material flows will allow us to identify trends towards sustainability or non-durability:

- the ecological foundation is ensured in a significant proportion of internal natural capital, within the limits of its net yield, tending to be sustainable,
- the ecological foundation is ensured in a significant proportion of the internal natural capital, but its net yield is surpassed, tending to be non-sustainable,
- the ecological foundation is ensured in a large proportion by the external natural capital, the tendency being towards non-sustainability.

Through its content, the analysis of material flows (AFM) / mass transfer provides us with the necessary information to assess the material/energy intensity of various economic and social activities and substantiate decisions to improve their compatibility with the rules of the natural environment.

For the use of AFM it is necessary to elaborate a diagram in which will be mentioned:

- sources and nature of material flows, both external and internal;
- stocks of internal resources, which can be mobilized to a certain extent;
- main processes/activities;
- functional relations between processes/activities, including feedbak relations;
- main, secondary and vial flows (waste, residues) as a result of metabolism;
- stocks of internal resources, which can be mobilized to a certain extent;
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Material flows must be parameterized in terms of quantity, quality, rarity, renewable/non-renewable character, etc. When material flows are expressed in energy units of solar origin (emergence) there is the possibility of determining specific indicators:

- net emergent yield (REN), $REN = Y/F$
- rate of emergent investment (RIE), $RIE = F/xE$
- rate of emergence externality (REM), $REM = xE/(xE+F)$

in which:

Y = emergent output

F = commercial emergent input
xE = natural emergent input.

The DPSIR model confers AFM finality and allows the calibration of the direct and indirect effects and impacts and implicitly the orientation of the efforts, the establishment of the priorities by the decisional factors, as it results from Figures 4 and 5 (on the example of the agricultural system (anthropized system).

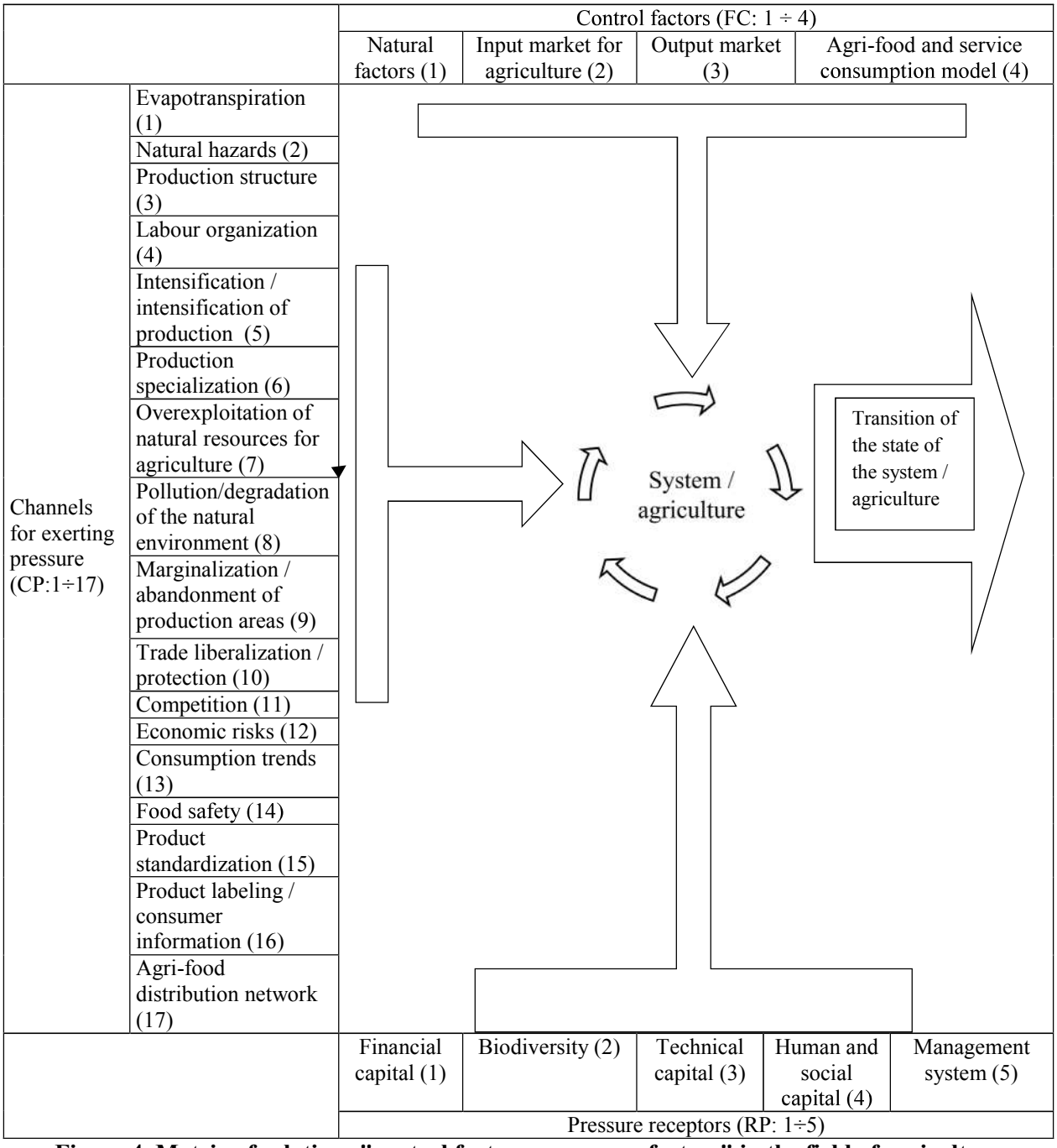


Figure 4. Matrix of relations "control factors – pressure factors" in the field of agriculture

Source: Negrei (2019).

The matrix of "impact/state transition" relations includes the 3 types of ecological impact (economic, social, on the natural environment) and 15 forms of impact against which the decision-making process/responses can be formulated in legislative, economic, technical-managerial and social terms.

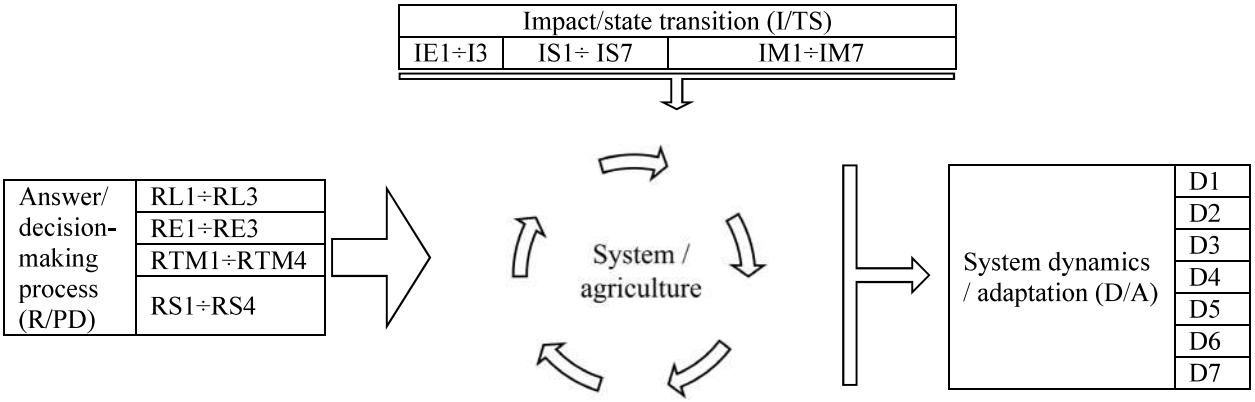


Figure 5. The matrix of the relations "impact/state transition - response" in the field of agriculture
Source: Negrei (2019).

IE = economic impact on:
1. expenses / costs;
2. agricultural income;
3. taxes, duties, subsidies.

IS = social impact on:
1. the structure of the workforce;
2. income of farmers and shareholders;
3. jobs;
4. working conditions;
5. socio-human identity;
6. social stability/rural desertification;
7. the health of farmers.

IM = impact on the natural environment, regarding:
1. productive capacity of the soil;
2. mobility of land structures;
3. water quality;
4. air quality;
5. biodiversity;
6. climate resources.

RL = Legislative response on:
1. food safety;
2. regulation of the resource market (soil, water, pesticides, etc.);
3. establishing responsibilities.

RE = Economic response:
1. economic and financial incentives;
2. investment expenses; agri-environmental measures.

RTM = The technical managerial answer regarding:

1. technological progress;
2. participatory management;
3. risk management;
4. cross-compliance.

RS = Social response to:

1. the profile of the entrepreneur / farmer;
2. human capital;
3. working conditions; institutional intercorrelation.

D = system dynamics / adaptation

1. hierarchical connectivity;
2. predictability;
3. commercial production/output;
4. presence on the market and food and nutrition safety;
5. private profit;
6. credibility/organizational identity;
7. decisional transparency.

Results and discussions

Any scientific approach must be at least exemplified, if not validated, even when decisions are based on a heuristic algorithm and not a mathematical one.

In the analyzed case, we test the possibilities of using some of the theoretical-methodological approaches related to the wine system, a system appreciated as achieving a high level in the material flow cycling (based on concrete discussions with technicians in the field).

The secondary products resulting from the wine production, as well as the possibilities of their capitalization, are presented in Table 2 (based on the analysis made by Boris Gaina et al., 2018).

It is observed that the diversity of by-products is doubled by an equally great diversity of products that can be obtained based on them, as well as the directions of capitalization: improving the quality of drinking water and wine, human health, food industry, pharmaceuticals, cosmetics, etc.

This finding is an important argument for the effort to assess the impacts on the product chain, so as to obtain a more complete picture in terms of the economy of material flow cycling in this area.

The delimitation of the two categories of by-products is meant to draw attention to the main processes/activities in the diagram of the wine system, so that we can perform a segmentation/ analytical evaluation of the material flow cycle.

Table 2. Capitalization of secondary products in the wine field

Secondary products	Products obtained	Areas of capitalization
I. From viticulture		
dry ropes	natural absorbents (coal)	drinking water treatment wine treatment detoxification of the human body
green shoots	malic acid	food industry, winemaking
green grapes	natural acidifier	food industry
II From vinification		

pressed marc	ethanol, ethyl alcohol	food industry, cosmetics, pharmaceutical
lees	salts of tartaric acid liquid fraction (25-30%)	natural tartaric acid, vinification obt. B vitamins
Seeds	Oil	pharmaceutical, cosmetic, food industry

Source: adaptation after Gaina et al. (2018).

The structural and functional diagram of the wine system in energy expression (Figure 6) highlights:

- sources and nature of material flows, both external and internal;
- main, secondary and final flows (waste, residues) as a result of metabolism, expressed in emergent units (Table 3), on the basis of which the specific efficiency indicators can be calculated:
  - net emergent yield (REN)
    REN=Y/F= 973.1/608.1=1.6 emj/ha
  - emergent investment rate (RIE)
    RIE=F/xE=608.1/365.8=1.67
  - rate of emergence externality (REM)
    REM=xE/(xE+F)= 365.8/973.9=0.38

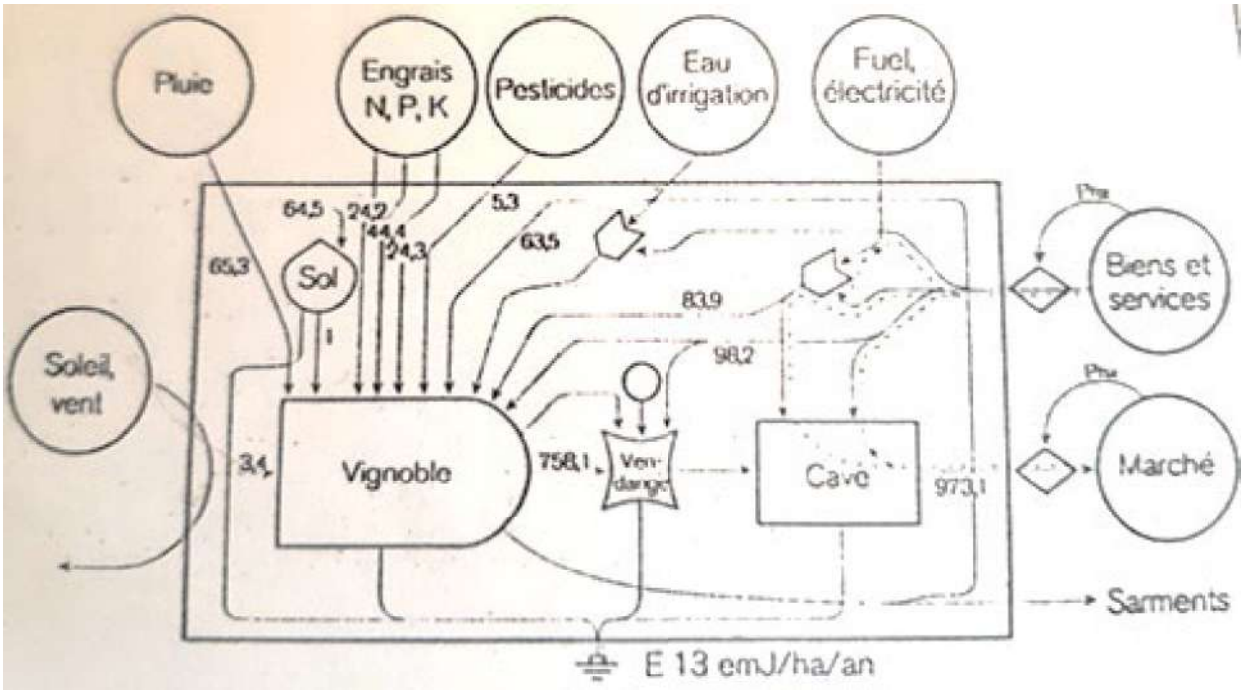


Figure 6. Diagram of the wine system

Source: Gonzague (1993).

Table 3. The eco-energy value of the flows in the wine system

Form of energy	Eco-energetic value (solar jouli x E13/Ha)
I. Viticulture	
1. Natural external energy	
1.1 Solar radiant energy	3.4
1.2 Rain	65.4
Total I.1.	68.8
2. Natural internal energy	
2.1 mineralized organic matter	164.8
2.2 undecomposed organic matter	201.0
Total I.2.	365.8
Total natural energy (I.1. + I.2.)	434.6
3. Commercial energy	
3.1 nitrogen/ potassium/ phosphorus/ magnesium	24.2/24.3/44.3/0.8
3.5. pesticides	5.3
3.6. oils	83.9
3.7. machines, equipment, installations	40.0
3.8 working capital, labor	385.3
Total I.3.	608,1
Total energy consumption I (I.1. + I.2. + I.3.)	1042.7
II. Vinification	
Total energy consumption II	98.2
Total energy consumption (I + II)	1140.2
Marketable wine	973.1
Potential energy losses (dried ropes, green shoots, green grapes, pressed cabbage, yeast, seeds)	167.1

Source: Gonzague (1993).

In conclusion:
- a commercial emergency unit contributes to an emergency output per hectare equal to 1.6 emj;
- 1.67 commercial emergency units are required for the capitalization of a natural emergency unit;
- the share of natural emergence in total emergent consumption represents 38%;
- emergency losses/ uncycled material flows represent 16% of the total emergency consumption.

Conclusion

From the analysis we can mention that the phrase "circular economy" expresses a contradiction between form and substance and has no scientific support. Material flow cycling is a potential way to reduce the scarcity of ecosystem goods and increase competitiveness. As well, the material flow cycling can determine the modification of the structural and functional relations of the anthropic and anthropized systems

The elementary functional unit for the analysis of material flows is the socio-ecological complex. In order to operationalize the economy, the material flow cycling requires at least the following research directions:

1. determination of the spatial scale of the circular economy, taking into account:
• scarcity of resources;
• ecological vulnerability of the area;
• the importance of different activities for the local, regional, national economy;
• the strategic character of some economic and social captivity.

2. establishing the energy balances of the material flows cycle.

References

Bourg, D., Grandjean A., Libaert, T. (2006). Environnement et Entreprises, Pearson Education France, Paris.

Gaina, B., Gobirman, G., Golubi, R. (2018). Produse secundare de origine vitivinicola si utilizarea lor, AKADEMOS1/2018.

Gonzague, P. (1993). Economie Ecologique, Georg, Geneve.

Istudor, N. (2011). Managementul sistemului logistic agroalimentar, Bucharest University of Economic Studies, Bucharest.

Negrei, C. (2004). Economia si politica mediului, Bucharest University of Economic Studies, Bucharest.

Negrei, C (2016). The nature of the Economy and Economy of the Nature, *Quality-Access to Success*, 17(SI), p64-68.

Negrei, C. & Istudor, N. (2018). Economia circulară între teorie și practică, *Amfiteatru Economic*, 20(48), p498-509, https://doi.org./10.24818/EA/2018/48/498.

Negrei, C. (2019). Productivitatea muncii si performanta in agricultura, Romanian Academy Publishing, Bucharest.

Vădineanu, A. (2004). Managementul dezvoltarii-o abordare ecosistemica, Ed. RRS DOCENDI, Bucharest.