“BABEȘ-BOLYAI” UNIVERSITY OF CLUJ NAPOCA

FACULTY OF GEOGRAPHY

DOCTORAL SCHOOL OF GEOGRAPHY

MARA RIVER BASIN – AN INTEGRATED GEOGRAPHICAL ASSESSMENT FROM THE EMERGY PERSPECTIVE

-PhD thesis sumary-

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2017

Contents

Key words: Mara basin, drainage system, territorial system, energy, energy system, flow of energy, emergy, emergy evaluation method

Introduction

This paper, divided into nine chapters, aims at bringing in the attention of those whose professional duties focus on territorial management and resource allowance that entities defined on the morpho-hydrographical criteria can be considered as a viable spatial alternative for a responsible resource management. The thesis presents and explains an efficient methodological framework that can generate new informational content that could be used in the process of devising strategies for local and regional development.

The theoretical and methodological approach is consistent with the systemic paradigm, applying a method of evaluation that defines territorial resources energetically, based on the premises of Emergy Theory. The methodology proved to be a sound and pertinent instrument in quantifying, in an integrated manner, the energy flows in the Mara River system. The author considers the method as a viable quantitative approach to be used even in geography. On the other hand, this type of analysis can help to generate an evaluation tool to support territorial planning and management actions.

The first two chapters summarize research objectives and purposes, followed by a plea in relating spatial issues to the systemic thinking in order to overcome challenges faced by human communities in the spaces they occupy.

The third chapter details the theoretical and methodological framework of the emergy evaluation procedure , a concept developed in the United States, mainly within of environmental sciences. The author believes in the pragmatism of this approach and in its effectiveness and quantitative capabilities since it allows the integration of GIS platforms to calculate and analyze the spatial distribution of energies that define a system.

The following chapters present the proper analytical approach to the Mara watershed as a systemic entity. The chapters include dexriptive and quantitative characterizations of its components via a conceptual model using the energy systems graphic language.

The defining characteristics of the Mara watershed as a physical and as a systemic entity through its main forms of energy flows and storages were analyzed in chapters four to seven.

The final two chapters present the calculations made for all the important energy flows in the territorial system. The results were used to obtain certain performance indicators that can envisage the state of the system at a certain point in time.

This work has benefited from financial support offered by the project POSDRU/159/1.5/S/132400 "Young researchers – professional development in an interdisciplinary and international context", implemented by Babeș-Bolyai University of Cluj Napoca in partnership with The Romanian Academy - Cluj branch, "Alexandru Ioan Cuza" University from Iași and West University from Timișoara

1. MARA WATERSHED AS ENERGY SYSTEM. AN INTRODUCTION

The management of watersheds has become a major research focus for many institutions that are preoccupied by resource availability and distribution in a given territory, especilally for those subscribing to an environmental paradigm. Entitling this concept, one can understand watersheds through the study of relevant characteristics aiming at the better use and distribution of natural and human-made resources.

From a philosophical point of view, the watershed management is associated with an intelligent, adaptive and integrated process that looks to optimise the ecological, social and economic conditions within it (http://www.rdrwa.ca/node/27, with adnotations). This management approach provides a conceptual and methodological framework that can assist the decision making process when it comes to evaluating resource availability and potential territorial disfunctions. A healty watershed, unbalanced by destabilizing human interventions, functions as a complete and optimal system with a minimum level of risks associated with floodings, erosion, default water contaminants and sediment filtering that can affect the quality of surface and ground water. A vibrant economy, even in remote rural areas, has as a base function clean water resources. Any type of human infrastructure, being it a simple household, an institution or a production system, needs a water connection in order to properly operate. From a social and economical point of view, unbalanced natural areas represent the core of recreational and tourism related activities.

The Emergy evaluation method that is proposed here derives from Howard Odum's observations regarding the study of energy's qualitative variations within ecological systems (Odum, 1987, 1988, 1996, 1998, 2001). The mentioned author stresses the fact that energies flowing through a system have different capacities of doing work, therefore must register variations both in quantity and quality, further suggesting complex methodologies for the process of quantifying them. One method though was emphasized more, mainly due to its versatility and ability to evaluate disparate energy resources both as flows and stocks using a common denominator.

The overall objective of the thesis is the analysis of the Mara Watershed from the systems perspective in order to identify, conceptualize and measure the energetic value and intensity of its resources and their spatial distribution.

- Secondary objectives
  - The identification and graphical representation of the Mara Watershed as a energetic territorial system using the energy systems language;
  - The evaluation of the system's energy / emergy flows through the emergy evaluation procedure;
  - The evaluation of the system's energy / emergy stocks through the emergy evaluation procedure;
  - Finding the average value of the emergy flow supporting the system through a year of reference – the systems steady state;
  - cartographically visualising the new informational content;

2. THEORETICAL SUBSTANTIATION OF TERRITORIAL ENTITIES AS SYSTEMIC STRUCTURES

From the moment rain falls on land, it interacts with the surface topography, creating under the influence of gravity streams that carve the landscape. Wherever an elevation gradient is present, rain water will have the capacity to do work, by eroding, transporting and depositing sediments, creating stream channels and forming one of the most intelligible and visible patterns of natural hierarchical organisation. „Like everything else, the watershed is organised as an energy hierarchy network" (Odum, 2007, p.117). Economically speaking, the geopotential energy of rivers (energy of elevated water) represents the most effective and ready to use energy flow for direct human use.

Systems can briefly be defined as an interactive set of components with al least one relationship (Common et al., 2005). The system's particular forms of organisation and its capacity of developing new and superior qualitative properties tend to draw attention on the systems structure. The self-organising properties determine the characteristics of a system, independent of its individual matter and energy conent (particles, people, landforms, rivers and streams, air masses, etc.)

We consider that the territorial system represents the most adequate lexical category to be used in an integrated geographical study. In the romanian geographical school, the systemic aproach has been theoretisised by Roșu an Irina Ungureanu (Roșu et al., 1977), Donisă (1977), Ichim (1989), Petrea (1998, 2005), Ianoș (2000, 2006), Mac (2000), Șimăndan (2003) through papers that approach space as a fundamental dimension. Promoting a contemporary vision, the above authors consider space not as a container of objects, but as the central variable of a related and connected system ((Ianoș et al., 2006 in Ianoș et al., 2010).

Territorial systems as thermodynamic systems

All systems use matter to build structure and to store energy that flows through the system. Matter (the material form of energy) necesitates energy in order to be processed, because nothing happens in the absence of energy. Enery of all types (chemical, solar, eolian, geothermal, informational etc.) is present in everything (Odum et al, 2001) and represents the mechanically and chemically potential to generate work and heat.

The laws of thermodynamic are essential in understanding the energetic condition of territorial systems. The energy transformation processes involve energy, work and heat and are measured most frequently using the Joule.

3. METHODOLOGICAL AND PROCEDURAL ASPECTS

Emergy theory – an integrated methodological framework

The Emergy evaluation method that is proposed here derives from Howard Odum's observations regarding the study of energy's qualitative variations within ecological systems (Odum, 1987, 1988, 1996, 1998, 2001). The mentioned author stresses the fact that energies flowing through a system have different capacities of doing work, therefore must register variations both in quantity and quality, further suggesting complex methodologies for the process of quantifying them. One method though was emphasized more, mainly due to its versatility and ability to evaluate disparate energy resources both as flows and stocks using a common denominator.

Emergy is the energy used directly and indirectly in the past to create a product or deliver a service (Voora et al., 2010). It can be defined also as the energy incorporated and used as a tool to measure the cumulative actions of energies operating in a chain (Ianos, 2000). The researchers in the field of Environmental Sciences for example, that have used this method in various studies (Ascione et al., 2009, 2011, Brown et al., 2001, 2012, Franzese et al., 2009, 2013, Mellino et al., 2014, 2015, Odum, 1988, 1994, 1996, 2000, 2001, 2007, Pulselli et al., 2008, 2010, 2011, Raugei et al., 2014, Ulgiati et al., 2011, Viglia et al., 2011, etc.) are emergy supportive, saying that it presents itself as an appropriate method in the evaluation process of ecosystem „goods and services", representing the essential amenities used by a community from the surrounding environment in order to function properly.

The emergy content is calculated using the following algorithm (for detailed insight into the calculation proceadure, see appendage 1):

For energy flows and stocks that can be expressed in Joules

Emergy (seJ) = available energy (J) * Transformity (seJ/J)

For energy flows and stock that can be expressed only in units of mass

Emergy (seJ) = available mass (g) * specific emergy (seJ/g)

The Emergy evaluation procedure is based on fundamental elements regarding energy distribution and hierachy. The fundamental principle endorsing this statement posits that energy builds hierachy but also that energy is a hierachy in its own. According to Odum (1988), all known energy transformations can be connected through a series according to the energy quantity of one kind resulted from a transformation process, necesary for the next transformation process. With each transformation step the energy quantity decreases but its quality increases. An energy transformation is nothing else but the conversion of one form of energy into another, as for example solar energy to wind or rain. Respecting the second principle of thermodynamics, in the process, the energy is transformed with loss of heat, representing a degraded form of unusable energy. Where diverse forms of energy converge in order to sustain a natural or anthropogenic process, or even a territory, in order to measure their effects, one must be able to quantify and compare them using a single unit of measure. *The emergy concept and associated procedures resulted out of this necessity.* Total amount of emergy flowing through a system within a year represents a value that characterises the

system's state function at a certain time and is noted with the prefix em (emcalories, emJoules etc.). *Geographically speaking, the spatial distribution of emergy commonly uses the* ***hectare*** *as a surface area unit of reference. In this paper, the emergy distribution is expressed in emJoules and is represented spatially on hectares* using the technical capabilities of GIS 2.6.1 Brighton. The emergy will disappear when the entire quantity is transformed into degraded heat as the system reaches maximum enthropy.

A very important aspect regarding the evaluation procedure concerns the spatial and temporal reference frame. Ussualy, emergy flows are expressed spatio-temporal as value / hectare / year, while stocks are expressed as value / hectare. If the stocks are subjected to depletion actions, then the quantity of outgoing energy is expressed as value / ha / year or simply as value / year.

Following the range of energy transformations within a network, the emergy necessary for the activation of a superior process will carry the emergetic signature (information) of all past processes. As result, a set of hotspot and contour maps was conceived.

Solar transformity – form of universal reductibility to a single unit of measure

Solar trandromity (UEV), after the main unit of measure for emergy, is defined as the quantity of solar emergy necesary to produce one Joule of usable energy empowered within a flow, good or a service. It represents the relation between the quantity of emergy necesary to produce it and its energetic or material content (Odum, 1996). It is expressed as emJoule / Joule (seJ/J) or emJoule / gram (seJ/g), the latter being known as **specific emergy**. The more energy transformation needed in order to obtain that flow, product or service, the higher the transformity / specific emergy will be. Goods and services delivered to societies directly or indirectly need large quantities of emergy to be produced. Therefore, their transformity / specific emergy will be high, although their energy content is low.

Standard units of measure used in the emergy evaluation procedure for this paper

The introduction of the properties and their respective standard units of measure was considerred a necesity mainly due to the great variety of resources approached in the paper. Individual resources were firstly expressed and quantified using their standard unit of measure. Derivative steps meant that primary quantities were scaled based on their properties in order to obtain the energy / mass equivalent expressed in Joules or grams. The emergy could be then obtained by multipliying the energetic / mass content to their respective UEV (from bibliographical sources)

basic derivative properties	standard units of measure (SI)	used units of measure
surface	1 ha = 10^4 m^2 = .01 km^2	m^2 and ha
mass	1 kg = 10^3 g	g and g/yr
volume	1 m^3 = 10^3L	m^3 and m^3/yr
density - mass	1kg/m^3 = 10^3g/m^3	g/m^3
density - water	1 m^3 = 10^6g	g/m^3
density – other liquids	1kg/L = 10^3g/L	g/L
density – air at sea level	1 m^3 = 1.2^3g	g/m^3
time	s = 3.6^3s / h = 3.15^7s/yr	s/yr
distance	1 m = 0.001 km	m
speed	m/s	m/s/yr
pressure	1 atm = 1013.25 mbar = 760 mmHg	mbar și mmHg

temperature	g^0 C	g^0 C
energy	1W = 0.001 Kwh = 3600 Joule	W, kWh and J/yr
energy	1Cal = 1 kcal = 1000 cal = 4187 Joule	J/yr
surface energy flow / radiation	$1W/m^2 = 3600\ J/m^2$	W/m^2 și J/m^2 and J/ha
specific energy	1J/kg = 0.001J/g	J/g

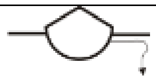
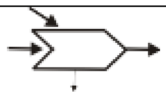
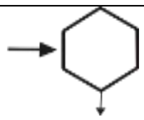
Table 1. Standard units of measure that define the main energetic variables of the Mara River (after Units & Conversions Fact Sheet, Supple. D., MIT Energy Club, http://web.mit.edu/mit_energy; International System of Units (SI), The NIST Reference on constants, units and uncertainty, http://physics.nist.gov/cuu/Units/units.html)

In order to apply the emergy evaluation method for the Mara river system the research tackled several important steps:

- diagramming the Mara River watershed as a system – represents the first step of the procedure and implies literally drawing up a system diagram according to energy systems diagramming rules (see Odum, 1996, p. 73). In its initial phase, the diagram represents a qualitative interpretation of the system's boundaries, essential variables (sources of energy, stocks of energy, production systems, consumers), relations and functions;
- creating a standard table for evaluating the system (see Odum, 1996, p. 79);
- evaluating the incorporated exergy (available energy) / mass of each item, using specific algebraic algorithms. The quantities are expressed according to the nature of the evaluated item using the metrics accepted by the International Systems of Units (see table 1).
- finding or calculating the solar transformity (UEV).

Emergy system language and diagram

The first step towards comprehensive emergy synthesis for any type of system is to draw a system diagram, incorporating the "Energy Systems language", revised for emergy studies by H.T. Odum (2000). Considering the complexity and abundant typology of variables, especially at macro scale, the diagram conceptualizes the system under investigation in a qualitative manner. Therefore, the diagram shows the most relevant variables that define the system's structure and its basic functionality following a simple positioning logic.

symbol	semantic	short description
	energy flow	a flow proportional to the quantity at source or storage
	source of energy	outside source of energy
	energy stock (tank)	energy storage within the system found in steady state (stores a quantity as the balance of inflows and outflows)
	heat sink	dispersion of potential energy as heat resulted from all the transformation of energy
	interaction	interactive intersection of two pathways tp produce an outflow in proportion to the function of both, control action of one flow on another / limiting factor action etc
	consumer	unit that is capable of storing and transforming energy quality and generating feed-back autocatalytically to improve flow

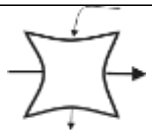
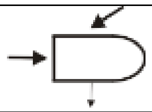
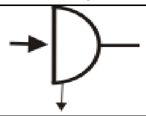
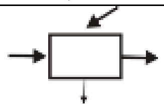
	commutator / switch	one or more switch actions
	producer	unit capable of collecting and transforming low-quality energy under control interactions of high-quality flows
	self-limiting energy receiver	a unit that has self-limiting output when input drives are high because there is a limiting constant quality of material reacting on a circulat pathway within
	alte variabile / funcții	any other labelled variable or function

Table 2. Energy systems language after Odum (1996) that derived the symbols using different systemic models and even programming languages

- *Systemic variables as energetic resources. Stocks and flows*

Based upon the above systems language, a conceptual energy model for Mara river system has been drawn. In the process of establishing the main energetic components that affect forestry inside the Mara watershed as a system, defining morpho-hydrographic, climatic and socio-economic features of the watershed were taken into consideration.

The structural, tectonic and fluviatile relief supporting the system has been conceptualized as a massive stock on energy. This approach has taken into account the fact that the volcanic andesitic rocks from the upper mountain side are primary resources exploited and exported from the system as construction materials. Moreover, the variated topographic index suggests the relief's potential in activating the energetic potential of elevated water.

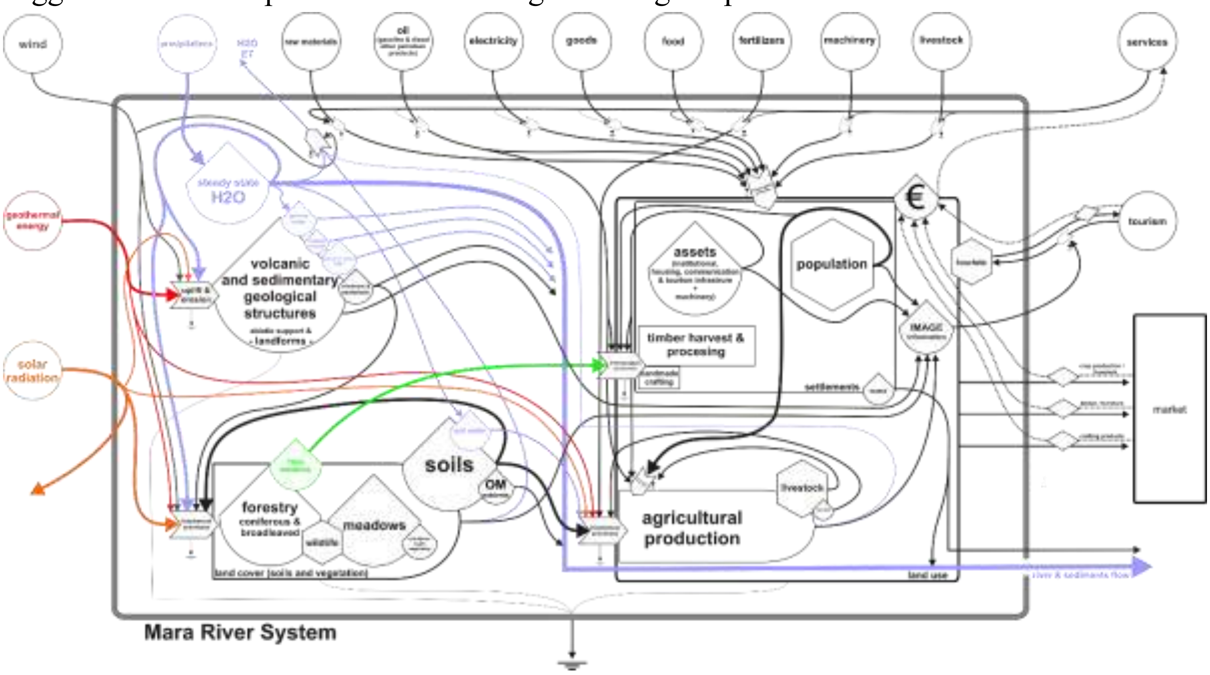


Figure 1. Structural model of the Mara River System

Soils, products of synthesis considered as non-renewable resources are another major control variable taken into consideration and represented on the diagram as stocks of energy. The entire anthropic structure comprising a network of 15 rural settlements organized into six communes has been represented as an agro-pastoral / agro-forestry subsystem. The human-made capital, as a form of energy build-up inside the subsystem is represented in principal by the habitable infrastructure alongside the road network and mechanical features such as vehicles and agro-forestry machinery. The land cover (forestry) and land use (agriculture) have been represented as primary and secondary production subsystems in the Mara watershed. The basic consumption needs of the local population are emphasized by a series of imported products, energy sources and services and reflect the consumption patterns and degree of dependence towards resources found outside the system. The main mass and energy vector in the system, the river Mara, together with its tributary, river Cosău, were represented as a steady state water flow and adjuster of the main energy input - the annual rainfall that falls on land.

- *The division of the watershed surface into homogenous units*

  Due to the fact that the emergy procedure involves expressing emergy intensity factors on hectares as reference areas, in this paper, the DEM for Mara river watershed was recalibrated at a resolution of 100 by 100 meters.

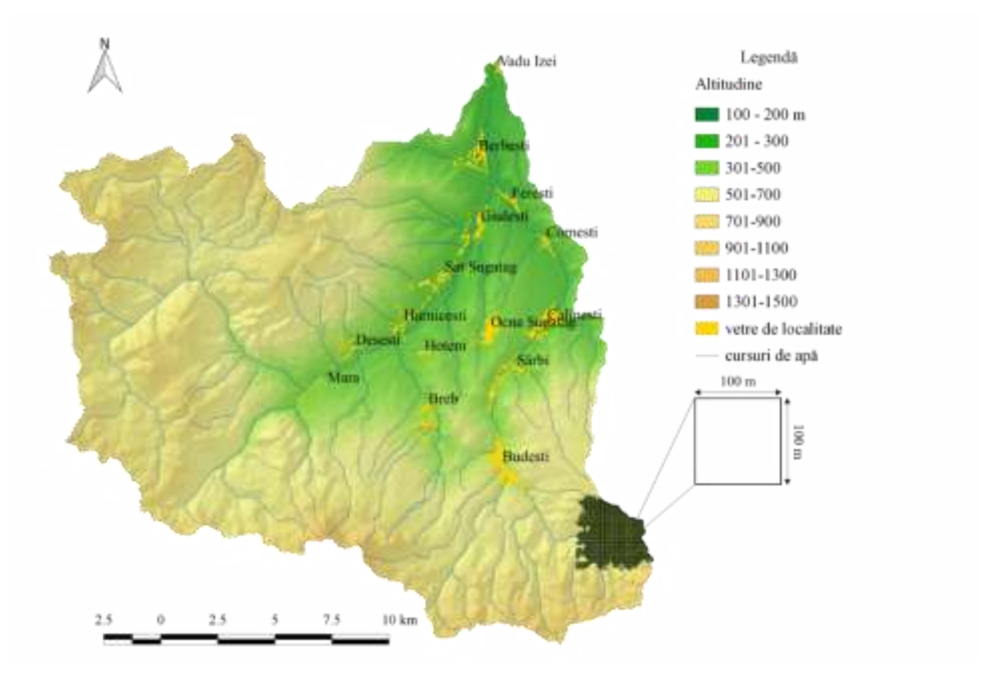


Figure 2. Recalibrated DEM at a resolution of 100 m

- *The emergy evaluation table*

The next step in the evaluation procedure involves setting up a database respecting the 6 column table structure seen above. In this study, the standard table was developed in Microsoft Excel.

1	2	3	4	5	6	7
crt.	item	units J/g/$	data / yr	UEV seJ/unit	UEV references	**emergy seJ/yr**
a line for each flow, storage, process of interest						

Table 3. Standard table structure for emergy evaluations (after Odum, 1996, pp.79)

- *Performance analysis*

All selected items must be separated into four main categories that will be subjected to various combinations reflecting standard performance indicators:

- Renewable flows (R)
- Non-renewable flows (N)
- Imported flows (I)
- Exported flows (E)
- Total flows (U)

The indicators are:

Emergy yeald ratio (EYR = U/I) – represents the ability of the system to use imported emergy from outside the system to activate local emergy processes.

Environmental loading ratio ELR = (N+I)/R – scales up the dependence of the system on non-renewable and imported emergy.

Emergy sustainability index (ESI = EYR/ELR) - assesses the balance of local resources being activated by invested external emergy against the environmental load that generating the emergy yield causes.

Emergy density (U/reference surface) / emery per capita (U/inhabitants) – these intensity indicators provide a useful basis for comparison, particularly when differences in scale of entities being compared mask their similarities.

Data and instruments

The data used in this paper belong to the following categories:

- **Raster data**
- Topographic maps 1:25.000;
- The geological map of Romania 1:200.000 available at www.geo-spatial.org;
- Geological map 1:100.000 Sighet sheet;
- Pedological maps available at http://esdac.jrc. ec.europa.eu/images/Eu dasm/RO/;
- Digital Globe satellite images
- The 30 meter resolution EU-DEM available at www.eea.europa.eu;
- Thematic maps
- Multiple 30 minute resolution raster data available at www.esdac.jrc.ec.europa.eu;
- **Vector data**
- Corine land Cover data for the years 2000, 2006, 2012 available at www.eea.europa.eu și http://land.copernicus .eu/pan-european/corine-land-cover/clc-2012;
- **Statistical data**
- Statistical databases from the portal of General Agricultural Census 2010, Population Census 20111;
- Other numerical data;

4. GEOGRAPHIC DISTINCTION OF MARA BASIN'S TRAITS – SYSTEMIC STRUCTURAL FACTORS

Mara Basin is a third order, medium scale, 41.000 hectare watershed, tributary to the river Iza, a main contributor to the Tisa river, the major denudational axis of historical Maramureș Land, a well known tourism brand (Ilieș et al., 2015), found today in two countries, Romania and Ukraine. The river Mara at its origins drains a typical tectono-structural caldeira in the south-east of Igniș Plateau, delineating itself from the Săpânța Basin in the area of Pleșca Mare Peak throughout an interfluve characterized by petrographic prominences and structural saddles. The watershed limit descends to the depressionary sector and follows to the north-east the piedmont broad ridge that separates the Mara from the Șugău watershed.

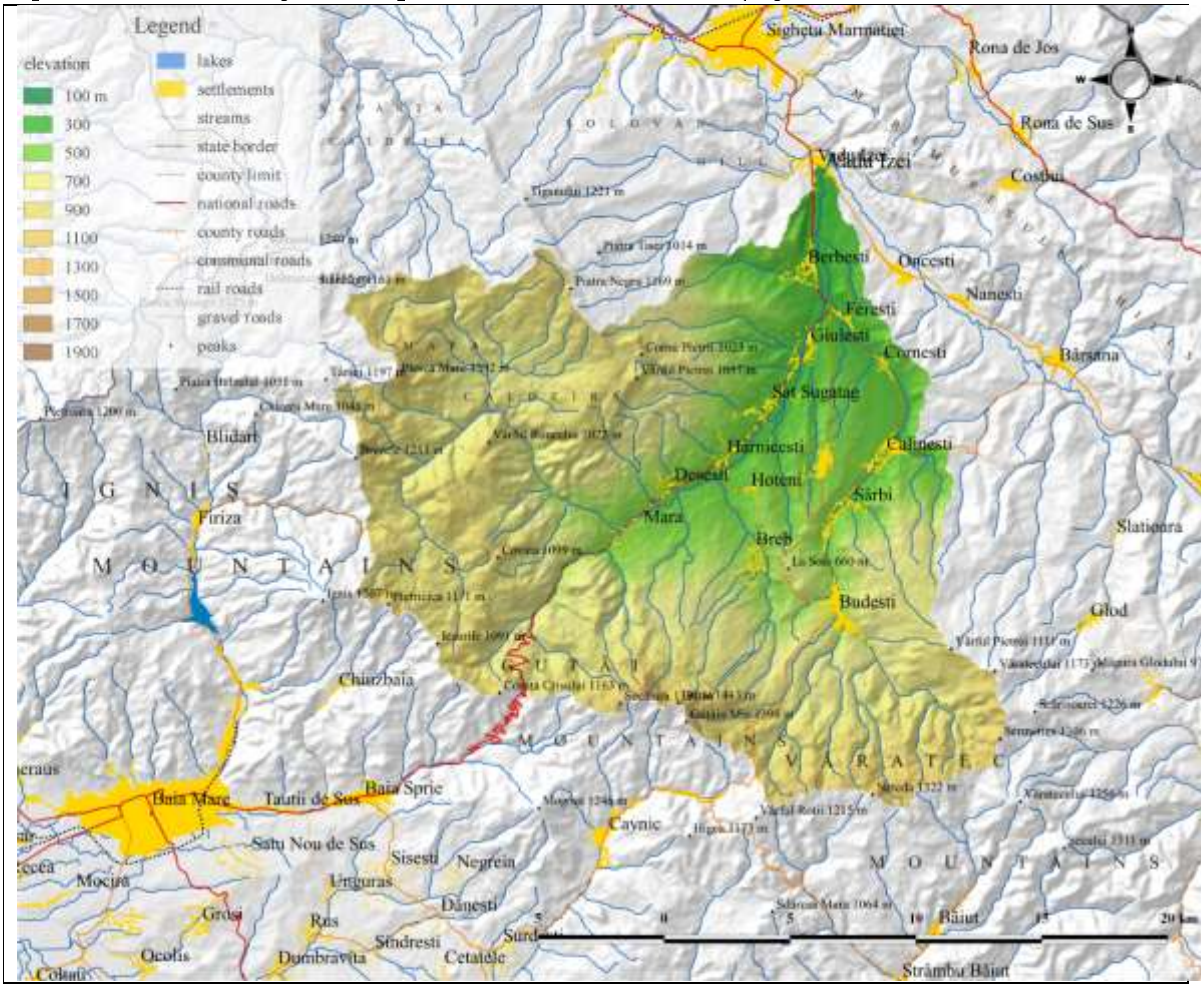


Fig.3 The Mara Watershed – a geographic and spatial reference

5. HYDRO-CLIMATIC DISTINCTION OF THE MARA BASIN

Climatic and topoclimatic features

The regional climatic pattern contributes to the extrapolation of local climatic charateristics individualized by the topographic variations (fragmentation, slope steepness, slope direction) and characteristics of the surface (land cover and land-use patterns, litology etc.). These factors generate distinctive surface features for the entire basin, with direct effects over the it's capacity to receive external natural energy flows (solar radiation, wind, rainfall). Nontheless, the local climatic variations influence the human activities, especially here were agriculture represents the main form of income

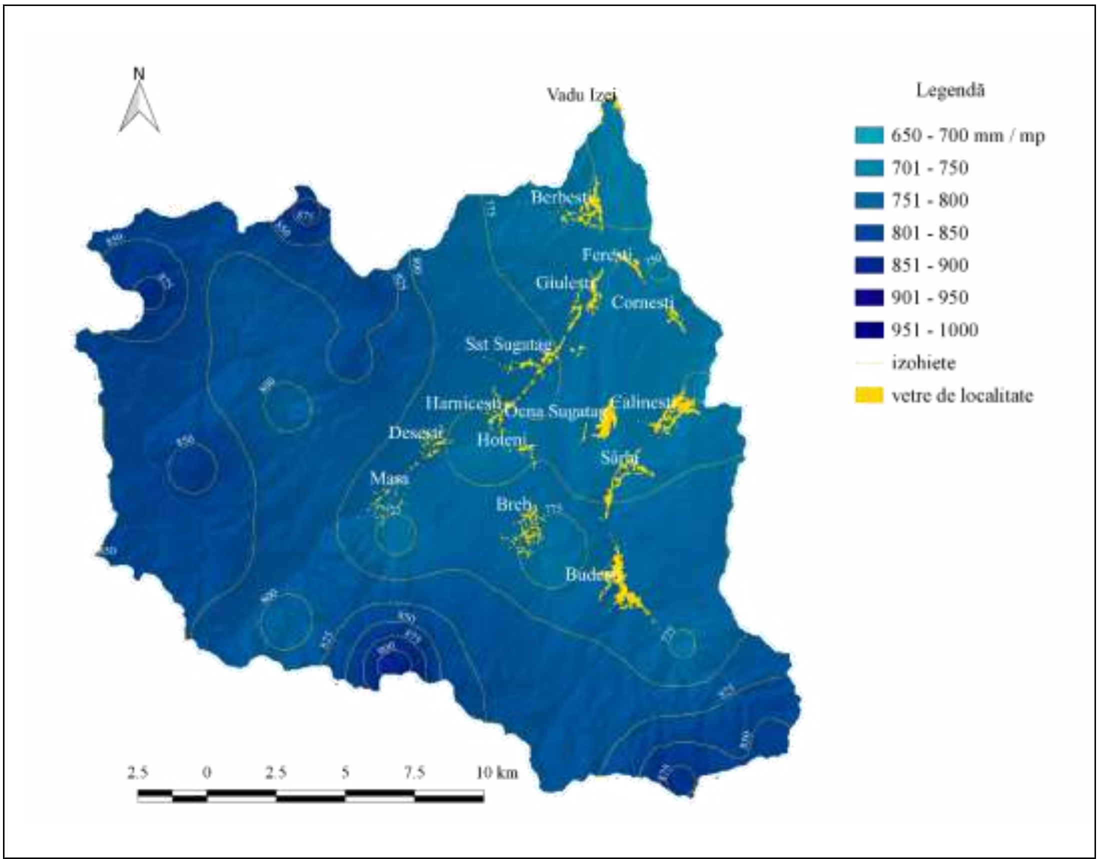


Figure 4. Average multiannual rainfall map (data for the 1950-2000 interval)

Rainfall amounts to quantities between 700 and 1000 mm per year per square meter and represents one of the most important types of energy in the Mara river system.

6. BIOPEDOLOGICAL DISTINCTION OF THE MARA BASIN

Soil diversity

In general, soils are considerred to be a valuable, non-renewable resource (Brown, 2001). For the Mara watershed, good quality soils can be found only in the floodplain areas, fluvial terraces or on low steepness slopes. The soils represent an even more important resource as the local economy is characterized through a agricultural profile.

Soils – energy stocks

Numerous academic studies underline the importance of soils in functionality of territories. The soils are considerred to be a form of **natural capital**.

	standard units of measure (energy / mass)	soil categories				
		ANDOSOLS	EUTRICAMBOSOLS DRISTRICAMBOSOLS	LUVOSOLS	REGOSOLS	ALUVIOSOLS
total surface	ha	1.64E+04	1.61E+04	2.95E+03	2.16E+03	2.57E+03
organic matter's specific energy	Kcal/g	5.40E+00	5.40E+00	5.40E+00	5.40E+00	5.40E+00
	J/kcal	4.19E+03	4.19E+03	4.19E+03	4.19E+03	4.19E+03
0-30 CM						
organic matter content 0-30 cm	g/ha	2.28E+08	1.00E+08	6.20E+07	6.20E+07	7.60E+07
organic matter energy content 0-30cm / ha	J/ha	5.15E+12	2.26E+12	1.40E+12	1.40E+12	1.72E+12
organic matter energy content / surface	**J**	**8.46E+16**	**3.65E+16**	**4.14E+15**	**3.03E+15**	**4.41E+15**
EMERGY / ha**	**seJ / ha**	**3.81E+17**	**1.67E+17**	**1.04E+17**	**1.04E+17**	**1.27E+17**
EMERGY / surface**	**seJ**	**6.26E+21**	**2.70E+21**	**3.06E+20**	**2.24E+20**	**3.26E+20**
0-100 CM						
organic matter content 0-100 cm	g/ha	5.08E+08	1.92E+08	1.92E+08	1.00E+08	1.86E+08
organic matter energy content 0-100 cm / ha	J/ha	1.15E+13	4.34E+12	2.94E+12	2.26E+12	4.20E+12
organic matter energy content / surface	**J**	**1.88E+17**	**7.01E+16**	**8.68E+15**	**4.88E+15**	**1.08E+16**

Tabel 4. Organic matter energy / emergy content

Forestry cover – energy stock

The forestry mass represents the most important stock of exploitable energy. Broad-leaved forests represent the main energy reservoir in the Mara basin and include the following species: beech tree, oack tree, ash tree, birch tree and sycamore maple tree.

	units of measure	Corine Land Cover 2012		
		CLC 311	CLC 312	CLC 313
surface	ha	1.60E+04	8.92E+02	3.33E+03
estimated average volume	m^3/ha	2.17E+02	2.17E+02	2.17E+02
annula regrowth capacity	m^3/ha/yr	5.60E+00	4.55E+00	5.47E+00
average density (green wood)	g/m^3	1.14E+06	8.13E+05	9.76E+05
water content	%	8.71E+01	8.71E+01	8.71E+01
caloric density	kcal/g	4.50E+00	4.50E+00	4.50E+00
specific energy	J/g	1.88E+04	1.88E+04	1.88E+04
energy content	J	7.48E+16	2.96E+16	1.33E+16
UEV	seJ/J	4.11E+03	4.11E+03	4.11E+03
emergy	seJ	3.07E+20	1.21E+19	5.46E+19
emergy / ha	seJ	1.92E+16	1.36E+16	1.64E+16

Table 5. Emergy evaluation of forestry stocks

**CLC 311 – broad-leaved forests / CLC 312 – coniferous forests / CLC 313 – mixed forests

7. TERRITORIAL ORGANISATION OF MARA BASIN

This chapter highlights the relativeness of space as a transformed environment thoughout territorial relations. The centuries old process of human transformation have transformed the area into a space with distinctive features. The new content represents a form of energy conversion into build elements that define the **anthopic capital** and allow people to operate various social and economica activities. Qualitativelly speaking, the human capital has a high energy content and hold a *superior hierachical position* within the systems energy hierachy. The main form of human capital in the Mara river system is represented by the housing infrastructure.

Housing infrastructure – stock of energy

According to the methodological framework, the emergy content in buildings is expressed by multipying the value of the mass (grams) to the equivalent transformity (see table 6). Large amount of energy is stored as human capital on the Cosău valley, in one of the most populated settlements from the basin - Budești (5.29 E+20 seJ - 2011) și Călinești (5.79 E+20 seJ - 2011).

	2002				2011			
settlement	mass (g)	UEV sej / g	emergy seJ	seJ / ha	mass (g)	UEV sej / g	emergy seJ	seJ 2002-2011
Budești	1.84E+11	2.66E+09	4.89E+20	6.40E+19	1.99E+11	2.66E+09	5.29E+20	+0.40E+20
Sârbi	6.79E+10	2.66E+09	1.80E+20	6.52E+19	7.40E+10	2.66E+09	1.96E+20	+0.16E+20
Călinești	1.95E+11	2.66E+09	5.18E+20	6.40E+19	2.18E+11	2.66E+09	5.79E+20	+0.61E+20
Cornești	5.59E+10	2.66E+09	1.48E+20	6.40E+19	6.02E+10	2.66E+09	1.60E+20	+0.12E+20
Desești	6.41E+10	2.66E+09	1.70E+20	6.41E+19	6.96E+10	2.66E+09	1.85E+20	+0.15E+20
Hărnicești	3.92E+10	2.66E+09	1.04E+20	6.39E+19	4.31E+10	2.66E+09	1.14E+20	+0.10E+20
Mara	6.70E+10	2.66E+09	1.78E+20	6.41E+19	7.25E+10	2.66E+09	1.92E+20	+0.14E+20
Giulești	7.78E+10	2.66E+09	2.06E+20	6.40E+19	8.46E+10	2.66E+09	2.25E+20	+0.19E+20
Berbești	1.02E+11	2.66E+09	2.71E+20	6.38E+19	1.11E+11	2.66E+09	2.95E+20	+0.14E+20
Ferești	3.20E+10	2.66E+09	8.51E+19	6.40E+19	3.51E+10	2.66E+09	9.33E+19	+0.18E+19
Mănăstirea	1.01E+10	2.66E+09	2.69E+19	6.39E+19	1.08E+10	2.66E+09	2.81E+19	+0.12E+19
Ocna Şugatag	1.70E+11	2.66E+09	4.52E+20	6.46E+19	1.85E+11	2.66E+09	4.92E+20	+0.40E+20
Breb	4.72E+10	2.66E+09	1.25E+20	6.40E+19	5.13E+10	2.66E+09	1.36E+20	+0.11E+20
Hoteni	1.49E+10	2.66E+09	3.96E+19	6.39E+19	1.61E+10	2.66E+09	4.28E+19	+0.32E+19
Sat Şugatag	5.03E+10	2.66E+09	1.33E+20	6.37E+19	5.44E+10	2.66E+09	1.44E+20	+0.11E+20
Vadu Izei	4.31E+10	2.66E+09	1.14E+20	1.07E+20	4.31E+10	2.66E+09	1.14E+20	-
TOTAL			**3.20E+21**				**3.52E+21**	**+3.25E+20**

Table 6. Raw **emergy (seJ)** content in buildings

8. ENERGY FLOWS IN THE MARA BASIN

We define the flows of natural renewable resources as those types of energies available in unlimited quantities, even when actively used in natural or human made processess (Odum, 2001). From the perspective of territoriallity (territory as a humanised space), the more these types of resources are used efficiently, the bigger the emergy incorporated in the resulted products. Even if the renewables are not actively present in the local economy, the Mara Basin communities enjoy the work done by these indirectly, through the ecosystem services privided to them by nature.

Renewable energy flows

The natural renewable energy sources influencing the thermodinamic signature and balance of the Mara River system are represented by the solar energy, geothermal, wind and precipitaion energies, the latter being the main active element in territorial dinamics.

Geothermal energy potential

The constant heat flux towards the surface is measured in W/m2 and the average values in continental regions is estimated at around 0.06 W/m2. Unfortunately, globally speaking, the potential of geothermal energy exploitation is limited.

The average value of Mara Basin's geothermal heat flux at surface is situated around 0.09 W/m2/s (see table 1) / 5.7E+14 seJ/ha/yr (see figure 3) insufficient for a large scale and centralised exploitation as thermal energy.

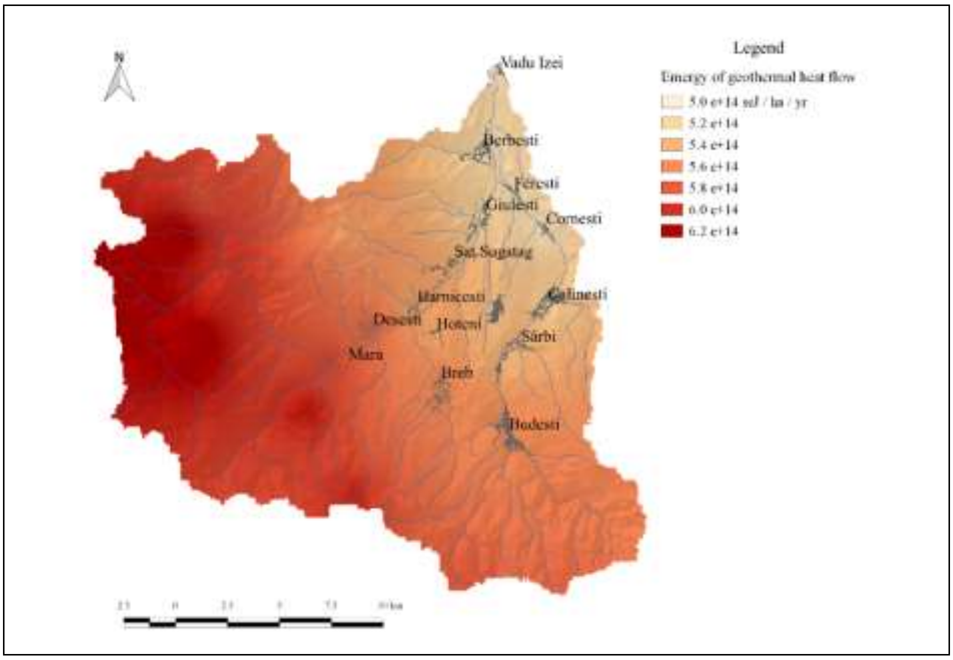


Fig 5. Spatial distribution of geothermal emergy flow at the surface of Mara watershed

Solar energy potential

In the Mara watershed, the direct solar radiation potential, taken into account in the evaluation of total solar energy flow at surface, is strongly influenced by relief's topography combined with surface ALBEDO and particular climatic conditions. In the process of estimating the yearly quantity of direct solar radiation at the watershed's surface, the Arc GIS 9.3 area solar radiation analysis tool was used, combining positional, elevation, direction and curvature atributes of the Mara basin's digital elevation model (30 arc second resolution), along side ALBEDO values derived from a LandCorine 2012 vector layer. The raw data were obtained in in kcal/m2.

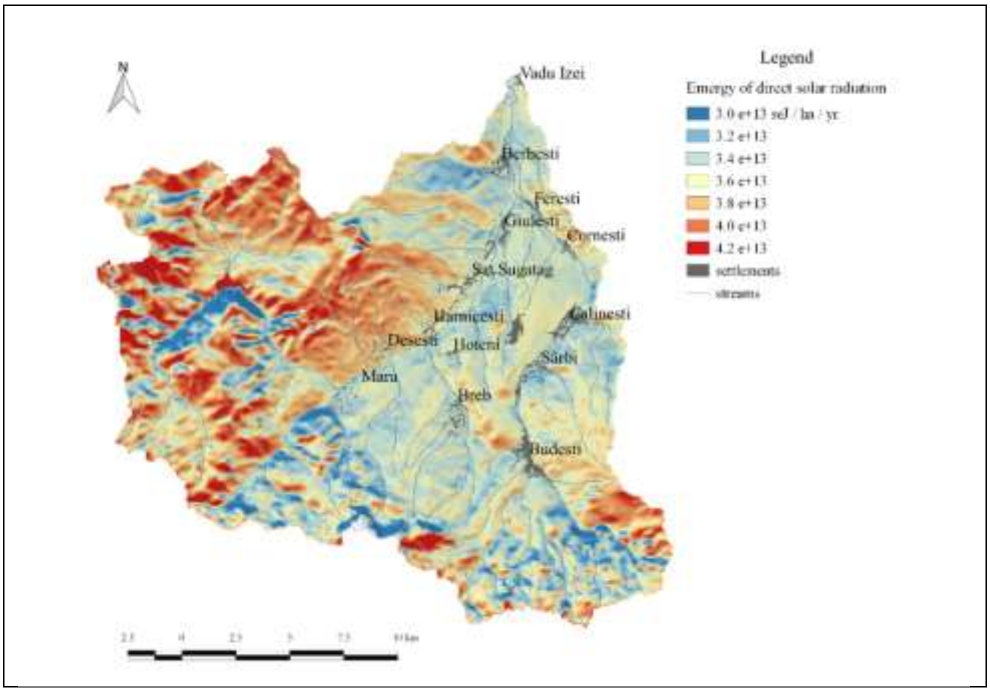


Fig 6. Spatial distribution of direct solar radiation's emergy content at the surface of Mara watershed

Wind energy potential

Even though wind represents a more concentrated form of energy in comparision with solar energy, an aspect reflected through a higher transformity coefficient, it is so spatially dispersed that it needs large and costly technological infrastructures to be captured and converted into useful, ready to use energy.

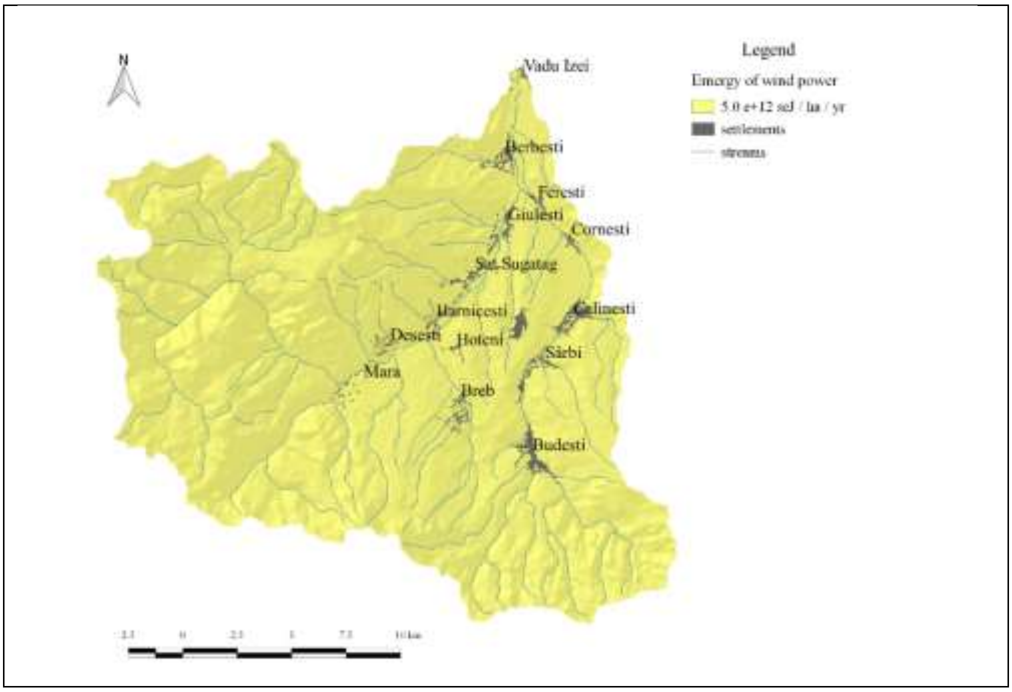


Fig 7. Spatial distribution of wind power's emergy content at the surface of Mara watershed

Rainfall energy potential

- the physical flow consisting in the actual rainfall geopotential as it falls on land and river geopotential as a the rain organises itself into streams once in contact with the topography;
- the chemical potential of rainfall (potential evapotranspiration) and rivers, used primarily by vegetation in the process of primary production and secondary by local atmospheric cycles;

Potential evapotranspiration (PET)

This potential can be quantified using a series of different algorithms, the most known and recommended being the Pennam-Montheith equation (Croitoru et al., 2013). However, another empirical algorithm offers similar results and has been used in estimating the potential evapotranspiration in the Mara watershed. The Turc equation (Mellino et al., 2014) gave satisfactory results in estimating the potential evapotranspiration in regions with average annual temperatures varring between 0 and 25 degrees Celsius (Kriiger et al., 2001, in Mellino et al., 2014). The calculus was made according to the following formula:

$$ETm = \ /1000 \quad // \quad ET(J) = ETm^{*}\ \rho * G$$

were

Etm – potential evapotranspiration (m)

P – average annual precipitation raster for the Mara watershed between 1950-2000 (m/m2)

L - 300 + 25T+0.05T, T – average annual temperature in the Mara watershed (7.60 C)

ρ – water density (1000000 g/m3)

G – Gibbs free energy (4.94 J/g)

The Mara watershed potential evapotranspiration has a value of around 429 mm/m2/yr / 1.35E+14 seJ/ha/yr and approximates the reference value obtained at Ocna Sugatag using the Pennam –Montheith formula (Croitoru el al., 2013), the value describing the watershed as having a moderate, intracarpathic character.

Rainfall and river geopotential

The precipitations fallen on land and resulted following the release of energy encapsulated in water vapours through condensation process in the lower atmosphere represents a new type of energy – geopotential energy.

Geopotential energy, either that we speak about rain drops mechanical action over soils and vegetation, or that we speak about rainfall channeling through a hierarchical flow network or glaciers, has the capacity of doing active geological work and represents in many of Earth's regions the prime landscape modeler. In the watershed organization process following rainfall on land, the geopotential energy derives from the friction between water and topography under the gravity. Surface and river drainage models the relief upstream, transporting and depositing sediments downstream.

Due to its complex genesis, precipitations have a high transformity compared with the other renewables. Therefore, the amount of emergy contained within it is the highest. For the Mara watershed, the rainfall geopotential has an yearly emergy revenue of around **6.8E+14 seJ/ha/yr** (see figure 6)**.** *In emergy terms, it registers the highest values among renewables and is considered to be the main driver of the system from this perspective.*

The geopotential energy of the basin's hydrological network, represented here by the river Mara, is calculated as a fraction from the total average annual amount of precipitations minus potential evapotranspiration.

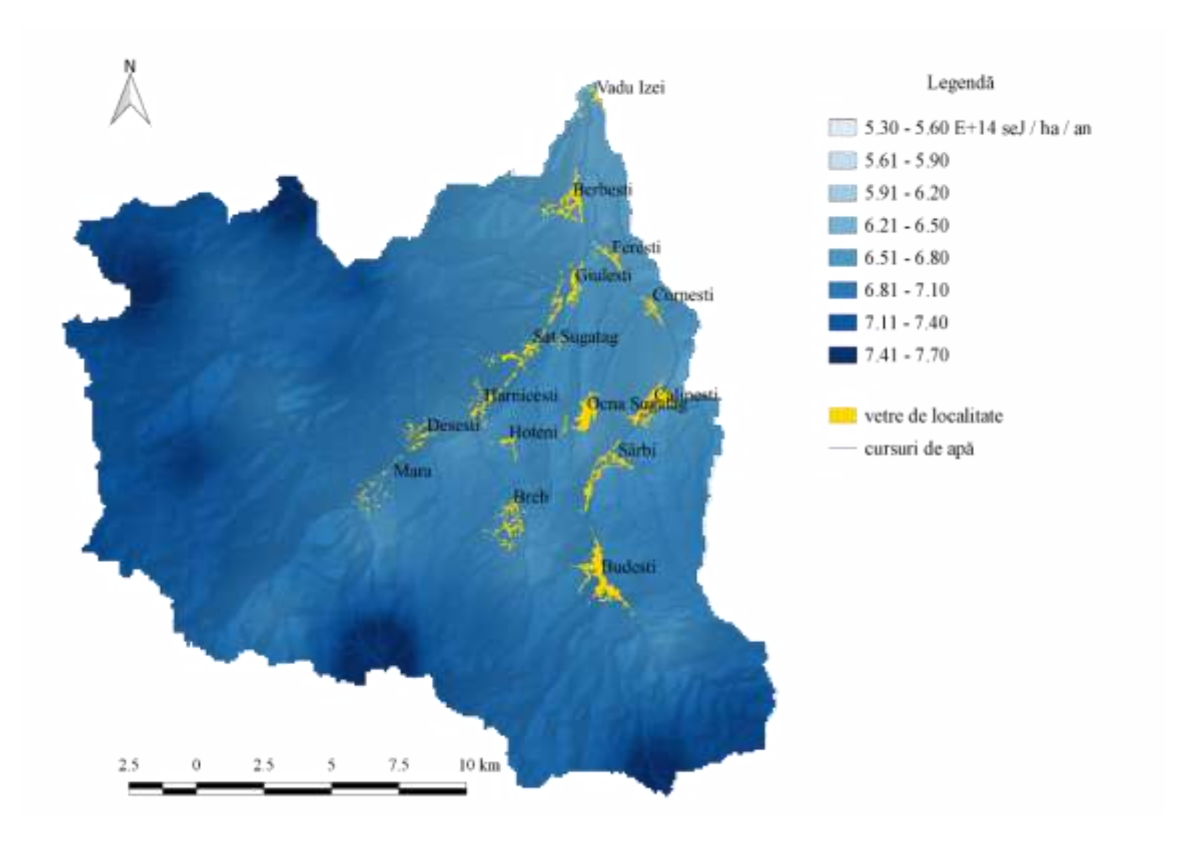


Fig. 8 Spatial distribution of rainfall's emergy content at the surface of Mara watershed

Emergy empower index

The emergy empower index represents the total amount of renewable emergy of the highest intensity that converges at the surface of the watershed and sustains the functionality of the Mara river system in the time frame of one year (see table 6). Measuring the quantity of renewable energy that flows through the system in a year and their aggregation within an empower index allows for the assessment of their intrinsic value and importance in the total emergy budget for the Mara watershed. It also allows for the identification of the most important energy flows that contribute the most in operating the system from a natural point of view.

The resulting visualization materials presented above emphasized the individual distribution and quality (through the order of magnitude) of renewable energy resources at the surface of Mara watershed. The visualization of empower index spatial distribution allows (see figure 7) for the identification of those areas were a higher concentration of emergy occurs. This means that, from an emergy perspective, the identified areas have a higher energy value and probably there one **can identify the most valuable forms of natural capital**.

The visualization material is presented as a Quantum GIS product and becomes:

- *information for better understanding the spatial distribution of renewable energies available within the watershed;*
- *an instrument partially useful in the decision making process regarding the conservation of local natural resources.*

According to the methodological framework, all forms of renewable energies are derived from the solar energy and become by-products. Therefore, the emergy empower index cannot be calculated by summing up all energies converging at the surface of the watershed, but by aggregating and extracting the highest value from them all for each surface unit – the hectare.

crt	item	units / yr	daw data	UEV sej/unit	UEV references	emergy seJ
1	solar energy	J/yr	1.47E+18	1.00E+00	Odum, 1996	1.47E+18
2	geothermal energy	J/yr	1.17E+15	2.00E+04	Brown & Ulgiati, 2010	2.34E+19
3	wind energy	J/yr	1.24E+14	1.58E+03	Brown & Ulgiati, 2013	1.96E+17
4	rainfall potential evapotranspiration	J/yr	8.70E+14	6.36E+03	Brown & Ulgiati, 2013	5.53E+18
5	rainfall geopotential	J/yr	1.61E+18	1.76E+04	Odum, 2000	2.84E+19
6	river chemical potential	J/yr	7.45E+14	1.80E+04	Brown & Ulgiati, 2013	1.34E+19
7	river geopotential	J/yr	1.48E+18	1.09E+04	Brown & Ulgiati, 2013	1.61E+19
	TOTAL (R)					**6.95E+19**

Table 7 Intensity of renewable emergy flows index in the Mara watershed

Rainfall and associated drainage represent the most important renewable energy source in the Mara watershed. From an emergy point of view, the quantification process leads to the identification of large differences in rainfall emergy quantity compared with the other types of energies.

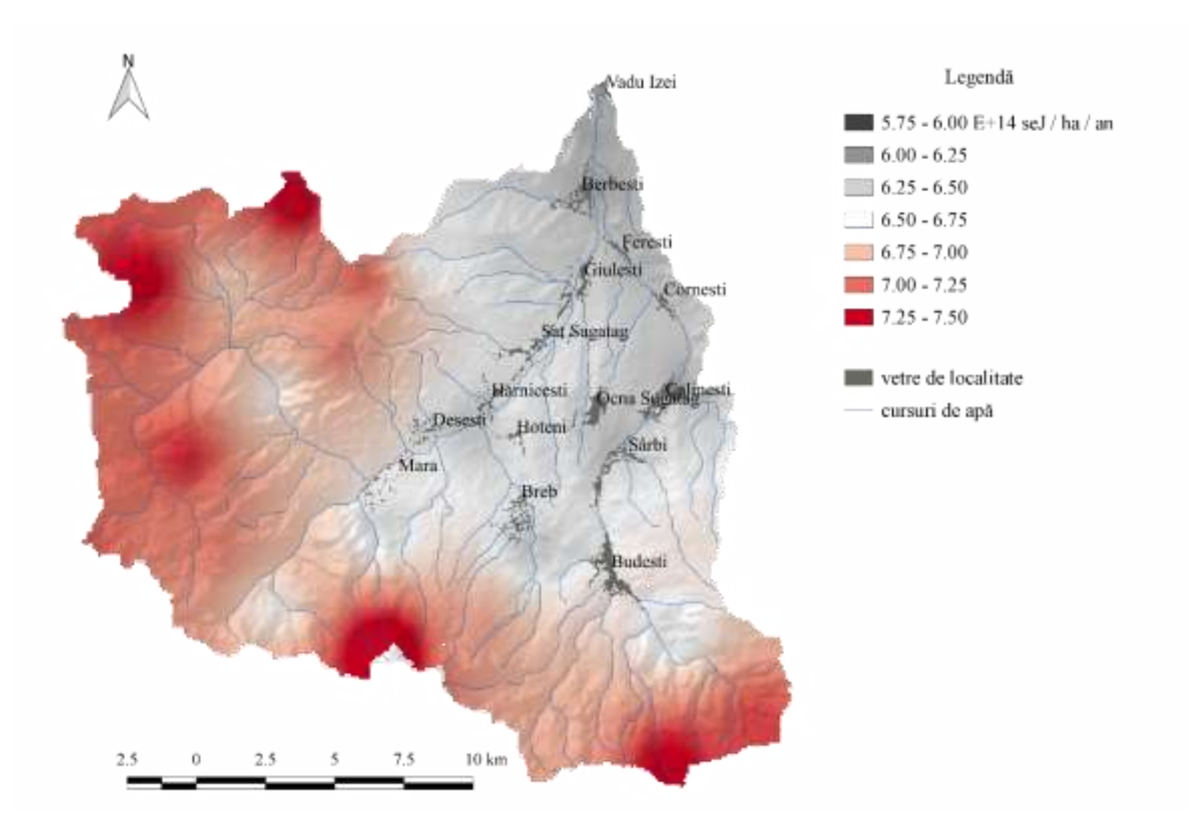


Figure 9. Emergy empower index at the surface of Mara watershed

Nonetheless this aspect can be visually observed through landscaping. Compared with the values registered in the depression the index decreases as we approach the habitable areas on the valley corridors.

Non-renewable energy flows

Energy resources are classified as non-renewables if the replenishing time exceed several decades. Carbon represents the main energy storage for non-renewable resources.

Estimating soil loss as non-renewable energy flow through USLE

The empirical equation takes into consideration five spatial variables – R, K, LS, C and P factors under the following formula:

$$A=R*K*LS*C$$

were

A – estimated quantity of potentially eroded soil (t/ha/yr)
R – Rainfall erosivity factor ((MJ mm) / ha/h/yr)
K – soil erosivity factor ((t ha) / ha MJ mm)
LS – slope length and steepness factor (degrees)
C – terrain management factor (0 – 1)

The calculus perfomed Quantum GIS via raster calculator emphasizes an annual amount of potentially eroded soil of up to 4.7 tones / ha / year, covering an area of approximately 481 hectares and totalizing approximately 2.200 tons annually.

From the emergy perspective, we used the above numbers in order to estimate an average value for the organic matter content that would be lost through erosion. Based on the average organic matter content for the Mara Basin soil categories and on the specificity of the economic profile, we estimated that around 152 tones organic matter are in danger of being lost annually. The emergy equivalent rises to 2.54E+17 seJ/yr and represents potential exported energy.

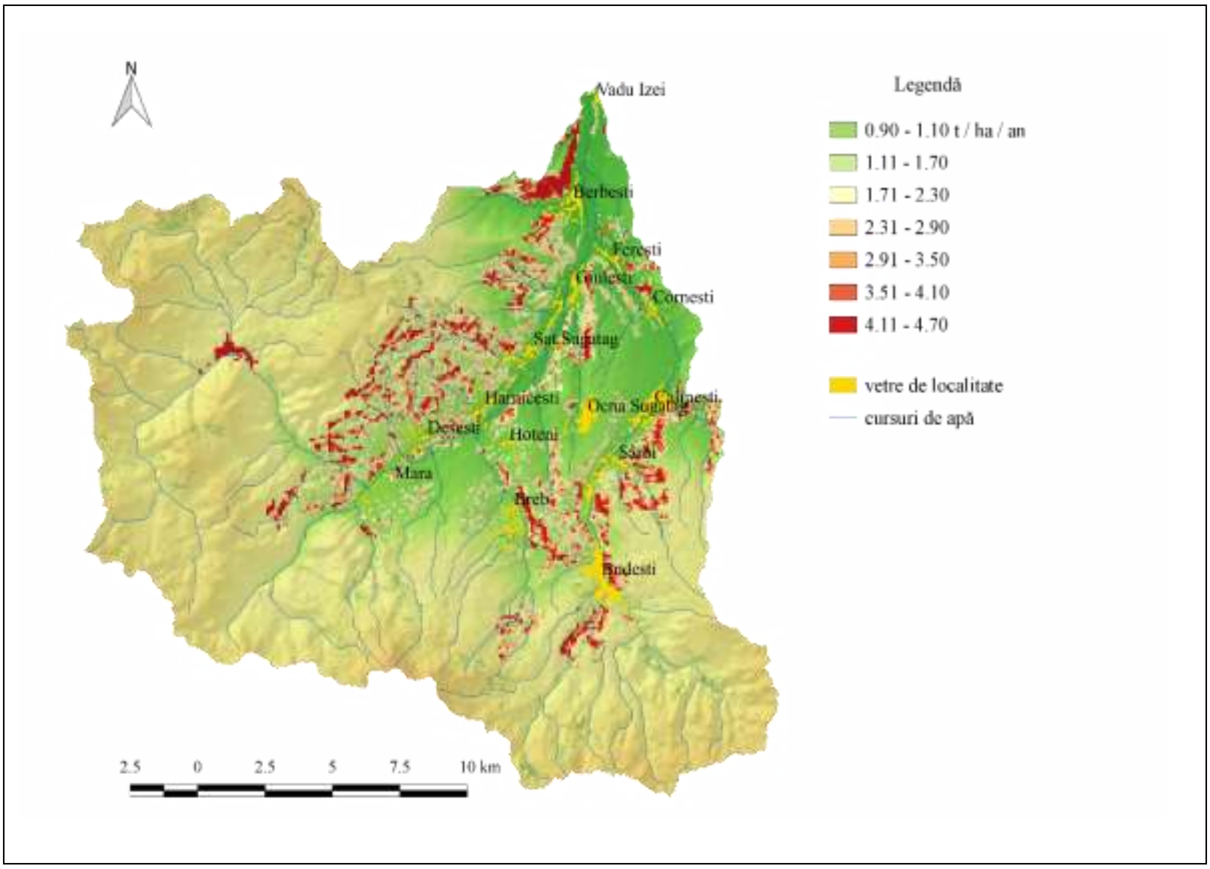


Fig. 10 Map of soils exposed to erosion and intensity of the process

Imported energy flows

The Mara river watershed is an open thermodynamic system, exchanging matter, energy and information with the neighboring territorial systems From the human perspective, the exchanges materialize through flows of specific goods, types of energies used in economy and society. The imported energy flows represent the feed-back from the economy and were categorized and calculated according to the system's structural model (see figure 1). Imported energy flow have a distinct feature. Visually, the distinctive element is represented by a flow connecting all imported categories to the associated services (extraction, processing and delivery) expressed in money values. If the emergy for those flows has been calculated based on transformities that incorporated the services in the first place, then the services will be ignored as to avoid a double counting.

	item	standard units	data / yr	energy standard units	energy J / yr	UEV** sejJ/ g	emergy seJ / yr
Imported flows (F)							
10	ELECTRICITY	kWh/yr	3.89E+07	J	1.40E+14	2.00E+05	2.80E+16
11	PROPANE GAS	g/yr	5.19E+08	J	2.54E+13	1.70E+05	4.31E+18
12	PETROL	g/yr	9.01E+08	J	3.89E+13	1.87E+05	7.27E+18
13	DIESEL OIL	g/yr	1.05E+09	J	4.48E+13	1.81E+05	8.11E+18
	DIESEL OIL agricultural machines	g/yr	1.25E+07	J	5.37E+11	1.81E+05	9.72E+16
14	CONSTRUCTION MATERIALS	g/yr	1.18E+10			2.66E+09	3.15E+19
15	VEHICLES	g/yr	7.32E+07			6.43E+09	4.71E+17
16	FOODS	g/yr	9.91E+09			2.54E+09	2.52E+19
	LIVESTOCK FEEDING	g/yr	4.17E+09			6.55E+05	2.73E+15
17	AGRICULTURAL FERTILISERS	g/yr	2.98E+07				
	(N) – 69.46%	g/ha/yr	3.01E+04			6.38E+09	1.32E+17
	(P) – 23.59%	g/ha/yr	1.02E+04			6.55E+09	4.61E+16
	(K)	g/ha/yr	3.01E+03			2.92E+09	6.05E+15
	SERVICES associated to imports	€/yr	4.25E+07				
	EMERGY TOTAL						1.07E+20

Table 8. Imported flow categories and their energy / mass / **emergy** equivalent

Construction materials represent one of the most important flows of imported energy in the Mara river system (3.15 E+19 seJ/yr), followed by foods (2.52 E+19 seJ/yr) and fossil fuels (1.63 E+19 seJ/yr) with a share of over 65%.

Exported energy flows

River discharge as the main form of exported energy from the Mara river watershed

River discharge means that waters that have performed geologic and chemical work inside the Mara river system will continue to perform in the upper hierarchical Iza river system. River Mara, the main water course in the territorial system discharges into the Iza river at Vadu Izei.

	item	Standard units	date / yr	Energy standard units	energy J / yr	UEV** seJ / J	emergy seJ / yr
Resurse de export (E)							
18	**HYDROLOGICAL DISCHARGE**	**g/yr**	**1.51E+14**	**J/yr**	**1.48E+15**	**1.89E+04**	**1.61E+19**

Table 9 Energy and emergy equivalent of river discharge

9. RESULTS AND DISCUSSIONS

This chapter presents the overall yearly emergy flows in the Mara river system and derived performance indicators that allow a full insight towards the system's state and functionality.

Annual emergy flow balance in the Mara river system

The total emergy flow expressed in solar emJoules (seJ) marks the energy value that supports the system in a year of reference. For the Mara river watershed, the emergy flow of **1.76E+20 seJ/year** can be regarded as a reference value describing the system's thermodynamic state. The number represents also a threshold value to be used further in order to quantitatively and qualitatively assess the variations and effects in the systems thermodynamic state based upon various evolution scenarios.

The table and map rendition emphasizes the following: the flow of renewable energy (6.95 E+19 seJ/yr) represents an important share and mark the thermodynamic signature of the entire system. The imported energy flow exceeds the contribution of natural resources becoming the main driving force of the system (1.07 E+20 seJ/yr).

crt	item	units/yr	data	UEV sej / unit	UEV references	**emergy seJ**
1	solar energy	J/yr	1.47E+18	1.00E+00	Odum, 1996	1.47E+18
2	geothermal energy	J/yr	1.17E+15	2.00E+04	Brown & Ulgiati, 2010	2.34E+19
3	wind energy	J/yr	1.24E+14	1.58E+03	Brown & Ulgiati, 2013	1.96E+17
4	rain chemical potential	J/yr	8.70E+11	6.36E+03	Brown & Ulgiati, 2013	5.53E+15
5	rain geopotential	J/yr	1.61E+15	1.76E+04	Odum, 2000	2.83E+19
6	river chemical potential	J/yr	7.45E+11	1.80E+04	Brown & Ulgiati, 2013	1.34E+16
7	river geopotential	J/yr	1.48E+15	1.09E+04	Brown & Ulgiati, 2013	1.61E+19
	TOTAL (R)					**6.95E+19**
8	organic matter	J/yr	3.43E+12	7.40E+04	Brown, 2001	2.57E+17
9	minerals	g/yr	1.33E+10	3.04E+09	Brown & Ulgiati, 2010	4.03E+19
	TOTAL (N)					**4.05E+19**
10	electricity	J/yr	1.40E+14	2.00E+05	Odum, 1996	2.80E+16
11	propane gas	J/yr	2.54E+13	1.70E+05	Brown & Ulgiati, 2010	4.31E+18
12	petrol	J/yr	3.89E+13	1.87E+05	Brown & Ulgiati, 2010	7.27E+18
13	diesel fuel	J/yr	4.48E+13	1.81E+05	Brown & Ulgiati, 2010	8.11E+18
14	construction materials	g/yr	1.18E+10	2.66E+09	Pulselli et al., 2007	3.15E+19
15	vehicles	g/yr	7.32E+07	6.43E+09	Mellino, 2014	4.71E+17
16	foods	g/yr	9.91E+09	2.54E+09	Mellino, 2014	2.52E+19
17	N	g/yr	2.07E+07	6.38E+09	Brown & Ulgiati, 2013	1.32E+17
	P	g/yr	7.04E+06	6.55E+09	Brown & Ulgiati, 2013	4.61E+16
	K	g/yr	2.07E+06	6.55E+09	Brown & Ulgiati, 2013	4.61E+16
	TOTAL (I)					**1.07E+20**
	TOTAL U (E+I)					**1.76E+20**
18	export – hydrologic discharge	J /yr	1.48E+15	1.19E+05	our estimate	**1.76E+20**
19	export – agricultural products	g/yr	3.93E+10	4.48E+09	our estimate	**1.76E+20**
20	export - alcohol	g/yr	2.68E+08	6.57E+11	our estimate	**1.76E+20**

Table 7. Annual emergy balance in the Mara river system

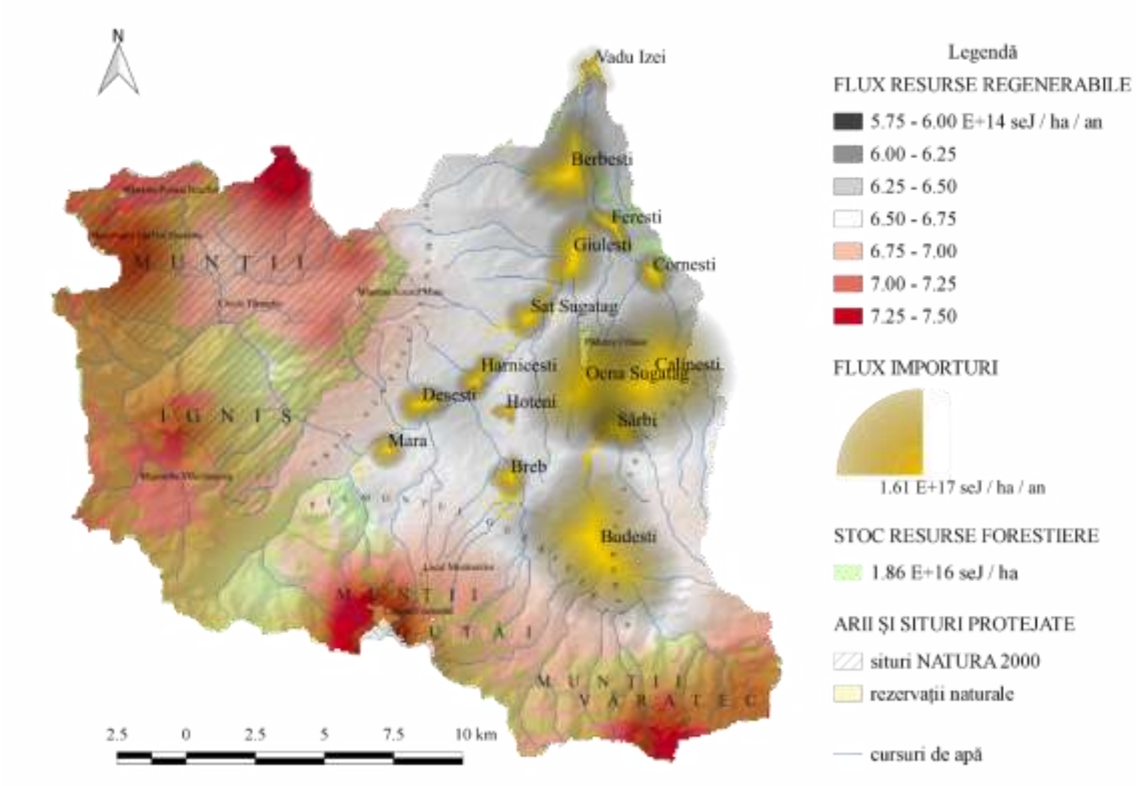


Fig. 11 Emergy synthesis of the main flows and stocks in the Mara river system

Performance indicators

Indicators are a necessity in any process of evaluation. In general, their typology is diverse and in correspondence with the established research objectives.

- *Emergy yield ratio EYR= (U/I)*

Calculated by dividing the total amount of emergy supporting the system (U) and the amount of imported energy (I), has the ability to measure the systems capacity to produce goods and services for export. For the Mara river system, the EYR has a value of **1.64** emphasizing the systems inability to efficiently convert imported resources through thenological processes in order to increase the quantity and value of the products generated for export. The imported resources are used exclusively for *internal consumption.*

- *Environmental loading ratio ELR = (N+I)/R*

The ELR indicator is sensible especially to the flows of non-renewable energy (N) from the system and compares the I and N flows against the R flows. For the mara river system the ELR is 1.54, a value characteristic for systems with a low population density and a agrarian economic profile.

- *Emergy sustainability index ESI = EYR/ELR*

On one hand, this indicator measures the system's levels of sustainability and degree of exploitation of locally available resources. On the other, it can be useful in assessing the systems degree of permeability. For the Mara river system the index is **1.06**, a threshold value that characterizes systems found in a transitional phase. Energetically, the Mara river system represents a **transitional system** found in a phase of transformation towards **consumer systems**.

- *Emergy density ESI = U / surface*

An intensity indicator, the emergy density measures the quantity of available emergy on a hectare in a year. The interpretation must bear extra attention since the index is dependend on the surface of the analysed system. Low index values are characteristic to natural areas and to areas with rural traits. The ESI in the Mara river system has a moderate value of approximately **4.29E+15 seJ/ha** (6.82E+11 / m^2)

- *Emergy per capita E/K = U / capita*

Environmentally speaking, the index emphasizes the natural wealth that inhabitants enjoy within the area of the watershed. In the Mara river system, approximately **1.19E+16 seJ** can be appropriated to every resident, a value that points out an ecological privilege. The local situation can be explained due to the low demographic pressure and also through the large surface size of the Mara river watershed.

Conclusions

The main findings of the study are:

- the annual emergy flow supporting the Mara river system has a value of **1.76E+20 seJ/year;**
- the annual emergy flow represents a general value that can describe the system thermodynamic state;
- from the spatial point of view, the renewable energy flows mark the thermodynamic signature of the Mara river system;
- from the quantitative point of view, the imported energy represents the most important energy flow in the Mara river system but the resources are processed for internal, household consumption;
- the Mara river system represents a **transitional system** (towards consumer systems) and has a **low intensity**;
- the internal economic processes inefficiently transform renewable and imported energies;
- the internal economic processes have a general low impact over the integrity of the environment;
- the internal economic processes generate a low added value to exported products and services (high transformity).

ADDEND 1

Algebraic formulas used in this paper to obtain the energy / emergy equivalence.
**the numeric data are expressed in *Scientific notation* – Microsoft Excel. The scientific format is used to express numbers that are too big to be written in decimal form. It replaces the numbers after the first two decimals with E+10^n (were E is the Exponent). The coding preserves the integrity of the number.

Renewable energy flows (R)

Solar emergy = [K · (1-a)] · 4184 J ·UEV = 1.47 E+18 seJ/yr

were

K	–	direct solar radiation raster (8.58 E+09 kcal/ha/yr) at the watershed surface (4.10E+04 ha)
a	–	surface albedo raster
UEV	–	1.00E+00 seJ/J

Geothermal emergy = HFU · T ·UEV = 2.34E+19 seJ/ayr

were

HFU	–	heat flux units (9.00E+02 W/ha/s) at the watershed surface (4.10E+04 ha)
T	–	seconds / yr (2.15E+07 seconds)
UEV	–	2.00E+00 seJ/J (Brown&Ulgiati, 2010)

Wind emergy = ρ · Cr ·(V_{geo}^3) · S · T · UEV = 2.04E+17 seJ/yr

were

V_{geo}	–	geostrophic wind (1.37 m/s)
Cr	–	dragg coefficient (0.003 %)
ρ	–	air density (1.3 kg)
T	–	seconds / yr (2.15E+07 seconds)
S	–	watershed surface (4.10E+04 ha)
UEV	–	1.53E+03 seJ/J (Brown&Ulgiati, 2013)

**the calculus didn't use QGIS raster calculator function

Rainfall emergy = [(P · 0.001) · $Alt_{(max-min)-min}$ ·ρ · g · UEV_1] – [(ET_m · ρ · G) · UEV_2]
= 2.84E+19 seJ/yr

were

P	–	rainfall raster (average multiannual amount of rainfall at the watershed surface (mm/yr) between 1950 - 2000)
$Alt_{(max-min)-min}$	–	498.7 m
ρ	–	water density (1000 g/l)
g	–	gravity (9.81 m/s)
ETm	–	potential evapotranspiration = $\frac{P}{\sqrt{0.9+P^2/L^2}}$ /1000 (Turc equation) L – 300+25T+0.05T, T – multiannual average temperature (7.6ºC)
G	–	Gibbs free energy (4.94 J/g)
UEV_1	–	1.76E+04 seJ/J (Odum, 2000)
UEV_2	–	6.36E+03 seJ/J (Brown&Ulgiati, 2013)

Emergy of river geopotential = Q · ρ · H · g · UEV = 1.61E+19 seJ/yr

were

Q	–	Mara river's average multiannual runoff rate at Vadu izei (1.51E+08 m^3/yr // 4.78 m/s)
ρ	–	water density (10^6 g/m^3)
H	–	average altitude at source (1000 m)
g	–	gravity (9.81 m/s)
UEV	–	1.09 E+04 seJ/J (Brown&Ulgiati, 2013)

Emergy of river chemical potential = Q · ρ · G · UEV = 1.34E+16 seJ/yr

were

Q	–	Mara river's average multiannual runoff rate at Vadu izei (1.51E+08 m^3/yr // 4.78 m/s)
ρ	–	water density (1000 g/l)
G	–	Gibbs free energy 4.94 J/g
UEV	–	1.80 E+04 seJ/J (Brown&Ulgiati, 2013)

Emergy empower index = (A>B and A>C and A>D)·A+(B>A and B>C and B>D)·B+(C>A and C>B and C>D)·C+(D>A and D>B and D>C)·D = 2.34E+19 seJ/yr

were

A – solar emergy raster

B – geothermal emergy raster

C – wind emergy raster

D – rainfall emergy raster

Non-renewable energy flows (N)

Emergy of organic matter content = [(A' · 10^6) · 6.86%] ·e · 4184 J · UEV = 2.54E+17 seJ/yr

were

A'	–	average quantity of potentially eroded soil (t/ha/yr) from surfaces with an estimated erosion rate ≥ 4.6 t/ha (S = 481 ha)
e	–	specific caloric energy (5.40 kcal/g)
UEV	–	7.40E+04 seJ/J (Brown, 2001)

Emergy of mineral resources = V · ρ · 10^6 ·UEV = 4.03E+19 seJ/yr

were

V	–	estimated extracted volume of quary rocks (andesite - 5.00E+03 m^3/yr)
ρ	–	average density of andesite (2.65E+05 g/m^3)
UEV	–	3.04E+09 seJ/g (Brown&Ulgiati, 2010)

Imported energy flows (I)

Electricity emergy = F_{elctr} ·3.6 ·10^6 · UEV = 2.80E+19 seJ/yr

were

F_{elctr}	–	electricity flow in the Mara basin (3.89E+07 kWh /yr)
UEV	–	2.00E+05 seJ/J (Odum, 1996)

Butane emergy = F_b · ρ · e · UEV = 4.31E+18 seJ/yr

unde

F_b	–	bitane flow in the Mara basin (5.19E+08 l/yr)
ρ	–	average butane density (5.40E+02 g/l)
e	–	specific energy (4.89E+04 J/g)
UEV	–	1.70E+05 seJ/J (Brown&Ulgiati, 2010)

Fuels - petrol emergy = F_{petrol} · ρ · e · UEV = 7.27E+18 seJ/yr

were

F_{petrol}	–	flow of petrol in the Mara basin (1.21E+06 l/yr)
ρ	–	petrol average density (7.45E+02 g/l)
e	–	specific energy (4.31E+04 J/g)
UEV	–	1.87E+05 seJ/J (Brown&Ulgiati, 2010)

Diesel fuel emergy = F_{diesel} · ρ · e · UEV = 8.11E+18 seJ/yr

were

F_{diesel}	–	diesel fuel flow in the Mara basin (1.25E+06 l/yr)
ρ	–	diesel fuel average density (8.37E+02 g/l)
e	–	specific energy (4.28E+04 J/g)
UEV	–	1.81E+05 seJ/J (Brown&Ulgiati, 2010)

Construction materials emergy = $V_{constr.\ mat.} \cdot \rho \cdot UEV$ = 3.15E+19 seJ/yr

were

$V_{.constr.mat.}$ – volume of imported construction materials in the Mara basin (2.94E+04 m^3/yr)

ρ – average density (4.02E+05 g/m^3)

UEV – 2.66E+09 seJ/J (Pulselli et al., 2007)

Vehicles emergy= $Nr._{auto} \cdot m \cdot UEV$ = 4.17E+17 seJ/yr

were

$Nr._{auto}$ – annually imported vehicles in the Mara basin (4.75E+01 unități/yr)

m – estimated mass (1.39E+06 g/unit)

UEV – 6.43E+09 seJ/J (Mellino, 2014)

Foods emergy = $(C_{food1} + C_{food2} + \ldots C_{food9}) \cdot UEV$ = 2.52E+19 seJ/yr

were

C_{food1} – meat and derived meat products (estimated quantity 5.38E+08 g/yr)

C_{food2} – fish and derived fish products (estimated quantity 5.61E+07 g/yr)

C_{food3} – vegetables and fruits (estimated quantity 1.55E+09 g/yr)

C_{food4} – milk and dairy products (estimated quantity 1.57E+09 g/yr)

C_{food5} – eggs (estimated quantity 2.71E+08 g/yr)

C_{food6} – cereals and cereal based products (estimated quantity de 5.35E+09 g/yr)

C_{food7} – beverages (estimated quantity 1.16E+05 g/yr)

C_{food8} – sugars (estimated quantity 3.67E+08 g/yr)

C_{food9} – vegetal fats (estimated quantity 2.04E+08 g/yr)

UEV – 2.54E+09 seJ/g (Mellino, 2014)

**the average quantities were estimated based on the annual average consumption pattern for basic foods and beverages per capita, at national level, in the year 2014 (*Statistical yearbook of Romania, 2014)*

Agricultural fertilizers emergy = $(N \cdot UEV_1) + (P \cdot UEV_2) + (K \cdot UEV_3)$ = 1.84E+17 seJ/yr

unde

N – nitrogen (2.07E+07 g/yr) – 69.46%

P – phosphorus (7.04E+06 g/yr) – 23.59%

K – potassium (7.04E+06 g/yr) – 6.95%

UEV_1 – 6.38E+09 seJ/g (Brown&Ulgiati, 2013)

UEV_2 – 6.55E+09 seJ/g (Brown&Ulgiati, 2013)

UEV_3 – 2.92E+09 seJ/g (Brown&Ulgiati, 2013)

Exported energy

Runoff emergy = $Q \cdot \rho \cdot H \cdot g \cdot UEV$ = 1.76E+20 seJ/yr

were

Q – Mara river's average multiannual runoff rate at Vadu Izei (1.51E+08 m^3/yr // 4.78 m/s)

ρ – water density (10^6 g/m^3)

H – average altitude at source (1000 m)

g – gravity (9.81 m/s)

UEV – 1.19 E+05 (our estimation – $U/(Q \cdot \rho \cdot H \cdot g)$)
U – total emergy flow - 1.76E+20 seJ/yr

Agricultural production emergy = $(C_{agr.prod.1} + C_{.agr.prod.2} + C_{.agr.prod.3} + C_{agr.prod.4}) \cdot UEV$ = 1.76E+20 seJ/yr

were

$C_{agr.pord.1}$ – potatoes (estimated quantity 1.01E+10 g/yr)

$C_{agr.prod.2}$ – fruits (estimated quantity 6.04E+09 g/yr)

$C_{agr.prod.3}$ – milk (estimated quantity 2.30E+10 g/yr)

$C_{agr.prod.4}$ – animal fats (estimated quantity 6.40E+07 g/yr)

UEV – 4.48E+09 seJ/g (our estimation – $U/(C_{agr.prod.\ 1} + C_{agr.prod.2} + C_{agr.prod.3} + C_{agr.prod4})$)
U – total emergy 1.76E+20 seJ/yr

Crafted spirits emergy = $C_{alc.} \cdot UEV$ = 1.76E+20 seJ/yr

were

$C_{alc.}$	–	crafted spirits (estimated quantity 2.68E+08 g/yr)
UEV	–	6.57E+11 seJ/g (our estimate – $U/C_{alc.}$)
		U – total emergy 1.76E+20 seJ/yr

Stock energy resources

Forestry emergy stocks = $(S_{CLC311} \cdot V \cdot \rho_1) + (S_{CLC312} \cdot V \cdot \rho_2) + (S_{CLC313} \cdot V \cdot \rho_3) \cdot e \cdot 4186\ J \cdot UEV$ = 3.74E+20 seJ

were

S_{CLC311}	–	broad-leaved forest surfaces in the year 2012 (1.60E+04 ha)
S_{CLC312}	–	coniferous forest surfaces in the year 2012 (8.92E+02 ha)
S_{CLC313}	–	mixted forest surfaces in the year 2012 (3.33E+03 ha)
V	–	average volume (2.17E+02 m^3/ha)
ρ_1	–	average density (1.16E+06 g/m^3)
ρ_2	–	average density (4.00E+05 g/m^3)
ρ_3	–	average density (9.76E+05 g/m^3)
e	–	caloric specific energy (4.5 kcal/g)
UEV	–	4.11E+03 seJ/J (Mellino, 2014)

Household emergy stocks = $(V_h \cdot \rho_h) \cdot N \cdot UEV$ = 3.52E+21 seJ

were

V_h	–	estimated average household volume (V=S (100m^2) · h (6m))
ρ_h	–	average density (401822 g/m^3), Pulselli et al., 2007)
N	–	number of households in the Mara basin (5473 households – 2011)
UEV	–	2.66E+09 seJ/g (Pulselli, 2007)