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SPATIAL ASSESSMENT OF RENEWABLE ENERGY FLOWS IN THE AGRARIAN MARA RIVER WATERSHED (MARAMUREȘ LAND, ROMANIA) AS A POTENTIAL TOOL FOR LOCAL AND REGIONAL RESOURCE MANAGEMENT POLICIES

Silviu BUMBAK*
Babeş-Bolyai University, Faculty of Geography, 5-7 Clinicilor Street, 400006, Cluj-Napoca, Romania, e-mail: silviubmk@gmail.com

Abstract: Watersheds have been described often as one of the most intelligible forms of natural hierarchical organization and as appropriate holistic spaces for a sustainable water and natural resource management at local and regional scales. In a time when resource scarcity has become a major preoccupation and concepts like auto-sufficiency, resource optimization or sustainability in general are guiding principles in the development process of territorial planning policies and strategies, both for urban and rural environments, we propose an integrated approach that imagines watershed spaces as hierarchical energy systems, quantifying its renewable energy flows by encompassing the premises of Emergy methodology and GIS. The purpose of the study is to identify and describe the spatial distribution of available renewable energies in the Mara River System, especially identifying areas of high energy concentration, an assessment usable as a tool for a more effective territorial planning and management.

Key words: watershed, energy systems, renewable energy flows, Emergy analysis, GIS

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INTRODUCTION

Watersheds – natural units for territorial management

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, especially 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

* Corresponding author

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.

Watersheds – energy systems

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.

Natural renewable energy flows in the Mara Watershed

Technically speaking, an energy flow is defined as the energy transfer rate per surface unit / per time, as a measure of intensity and its capacity of doing work. In the departments of Earth Sciences, the geological processes of orogenesis, associated vulcanism and earthquakes or the formation of mineral ores and fossil fuels reservoirs can be explained through the radioactive properties of internal energy from the core of the Earth, while at the surface, the action of energies responsible with erosion or building biological stocks are the result of solar energy's transformation throughout climatic and biological processes. Solar energy, the primordial form of energy, can be stored in various forms. For example, either as geopotential energy of rainwater and rivers, either as chemical energy stored in water vapour within the atmosphere or as energy stored by biological organisms. All these types of energies capable of doing geological and biological work at a global scale are called renewable energy resources, the quantity available today having no impact whatsoever on the quantity available tomorrow. The *major forms of renewable energy resources available in intracontinental areas are: solar energy, geothermal energy, wind energy and rainfall energy* and as disparate as they are in terms of origin, materialisation and scientific quantification, it is possible to agregate them all using a single unit of measure – the solar Joule.

METHODS

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, 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 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.

Following the range of energy tranformations withing a network, the emergy necesary for the activation of a superior process will carry the emergetic signature (information) of all past procesess. This in itself speaks about energy quality and is stated by another specific notion – transformity.

Solar transformity (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.

MARA RIVER SYSTEM – SPATIALIZATION, DESCRIPTION AND DIAGRAMMING

From a systemic point of view, the strict delineation process of a geographycal space for analysis purposes with respect to neighbouring systems represents a dull procedure, mainly due to the open system's permeability, especially in the spaces of interference and also due to the imposibility of segregating exchanges between them based on rigourous and strict limits. Take for example the differences between authors in establishing the vertical limits of what is considered the object of study for Geography (Mac, 1996, 2000; Petrea, 1998, 2005; Roşu, 1987). The task becomes even more difficult when one analyses a morphologically varied space, humanized through rural establishments without a urban infrastructure that could lent it a unitary and convergent character.

Spatial delineation

The delineation process of Mara River system is facilitated in particular by the decision to impose system limits based on the morpho-hydrographical criteria. The watersheds as systems are one of the few primary natural organisation patterns that present a coherent, functional and intelligible structure and allow the imposing of clear limits, at least in two-dimensional space. 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 Maramureş Land, a well known tourism brand (Ilieş et al., 2015), found today in two countries, Romania and Ukraine (Figure 1). The river Mara at its origins drains a typical tectono-structural caldeira in the south-east of Igniş Plateau, delineating itself from the Săpânţa Basin in the area of Pleşca Mare Peak throughout an interfluve characterised by petrographic prominences and structural saddles. The watershed limit descends to the depressionary sector and follows to the north-east the piedmontan broad ridge that separates the Mara from the Şugău watershed.

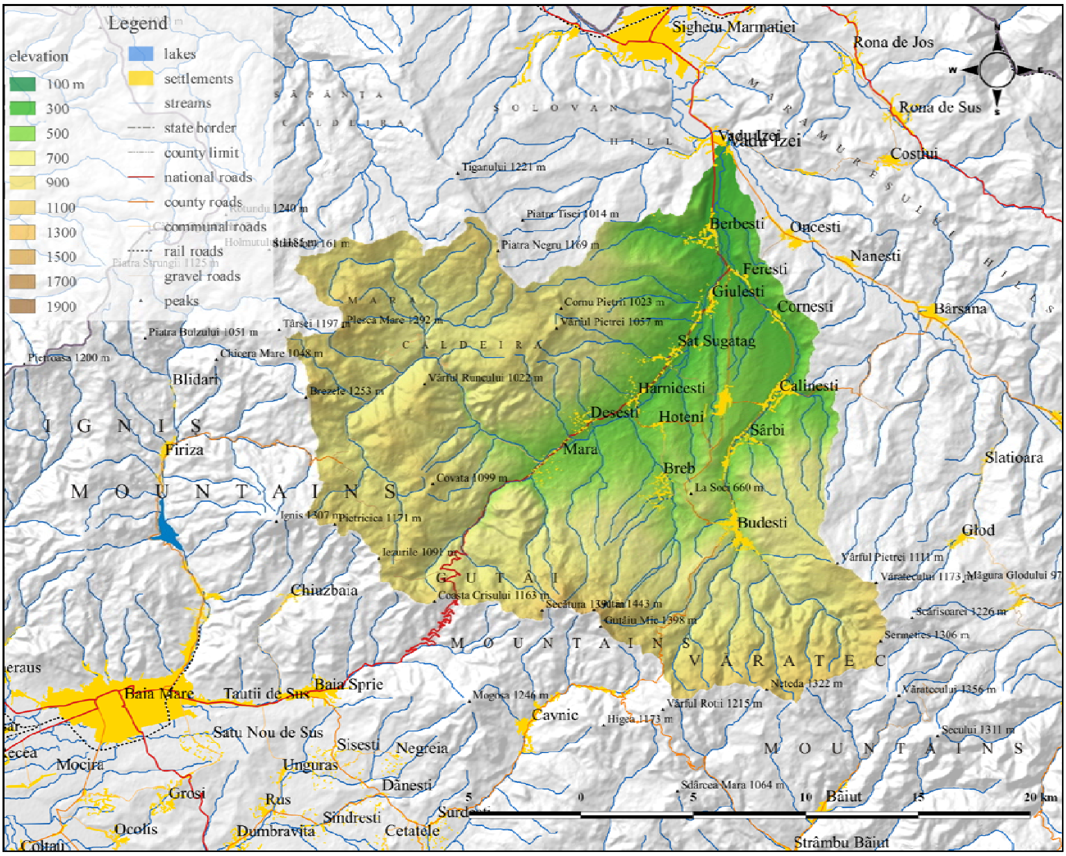

Figure 1. The Mara Watershed – a geographic and spatial reference

The upper Iza-Mara terraces outline the crossing from the confluence zone in the perimeter of Vadu Izei village to the area of Văratec Piedmont and mountain range. The watershed limits crosses the peaks of Călineşti Hills, in our opinion a monoclinic sedimentary structure. The Călineşti-Văratec range flanks the entire eastern limit with Iza Basin on the following alignment: Coman's Peak (495 m) – Pietrii Peak (1111 m) –

Sermetieș Peak (1306 m). The southern part of the Mara basin is separrated by Lăpuș and Cavnic watersheds through the Văratec and Gutâi main range, with altitudes between 1300-1400 meters. Gutâi and Văratec ranges constitute the elements of higher altitude in the Mara watershed. A large spatial unfold is characteristic to the limit between Mara and Săsar watersheds on the south-western and western side, on the same interfluvial petrographic and structural series typical for the Ignis Plateau: Secatura Peak (1391 m) – Gutâi Pass (987 m) – Iezurile Peak (1091 m), Pietricica Peak (1171 m) – Brezele Peak (1253 m) – Pleșca Mare Peak (1292 m).

Diagramming the Mara watershed as a thermodynamic system

The delineation processes is followed by a inventory procedure resulting in a system diagram that portraits the defining characteristics of the system in terms of essential energy fluxes and equivalent stocks, processess, production and infrastructure subsystems (Figure 2). The resulting diagram incorporates two-dimensional graphic design elements specifically used in drawing up energy systems (Odum, 1996 p. 73) and describes at first, in a qualitative manner and in a graphycal bi-dimmensional form the energy flow network of the system alongside with the restrictions imposed by the laws of thermodynamics. If the energy flows are represented through arrows oriented from left to right, suggesting the irreversibility of the process, the restrictions are symbolised by arrows drawn to the bottom side of the diagram. The degraded heat resulted with each process is oriented out of the system into a thermal sink. The first law of thermodynamics is respected by balancing all energy influx to the outflux. The heat generated by the multiple forms of work being done inside storage units are also represented by arrows toward the heat sink. In the process of establishing the main energetic components inside the Mara river system, defining morpho-hydrographic, climatic and socio-economical features of the watershed were taken into consideration. Here are some on the main attributes of the watershed that influenced the drawing procedure. 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 vulcanic 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.

Soils, products of synthesis considerred as non-renewable resources are another major control variable taken into consideration and represented on the diagram as stocks of energy. The entire anthopic suprastructure comprising a network of 15 rural settlements organised 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 along side the road network and mechanical features such as vehicles and agro-forestry machinery.The landcover (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 emphasised 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 stade water flow and adjuster of the main energy input - the annual rainfall that falls on land.

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. The article concentrates solely on these types of resources.

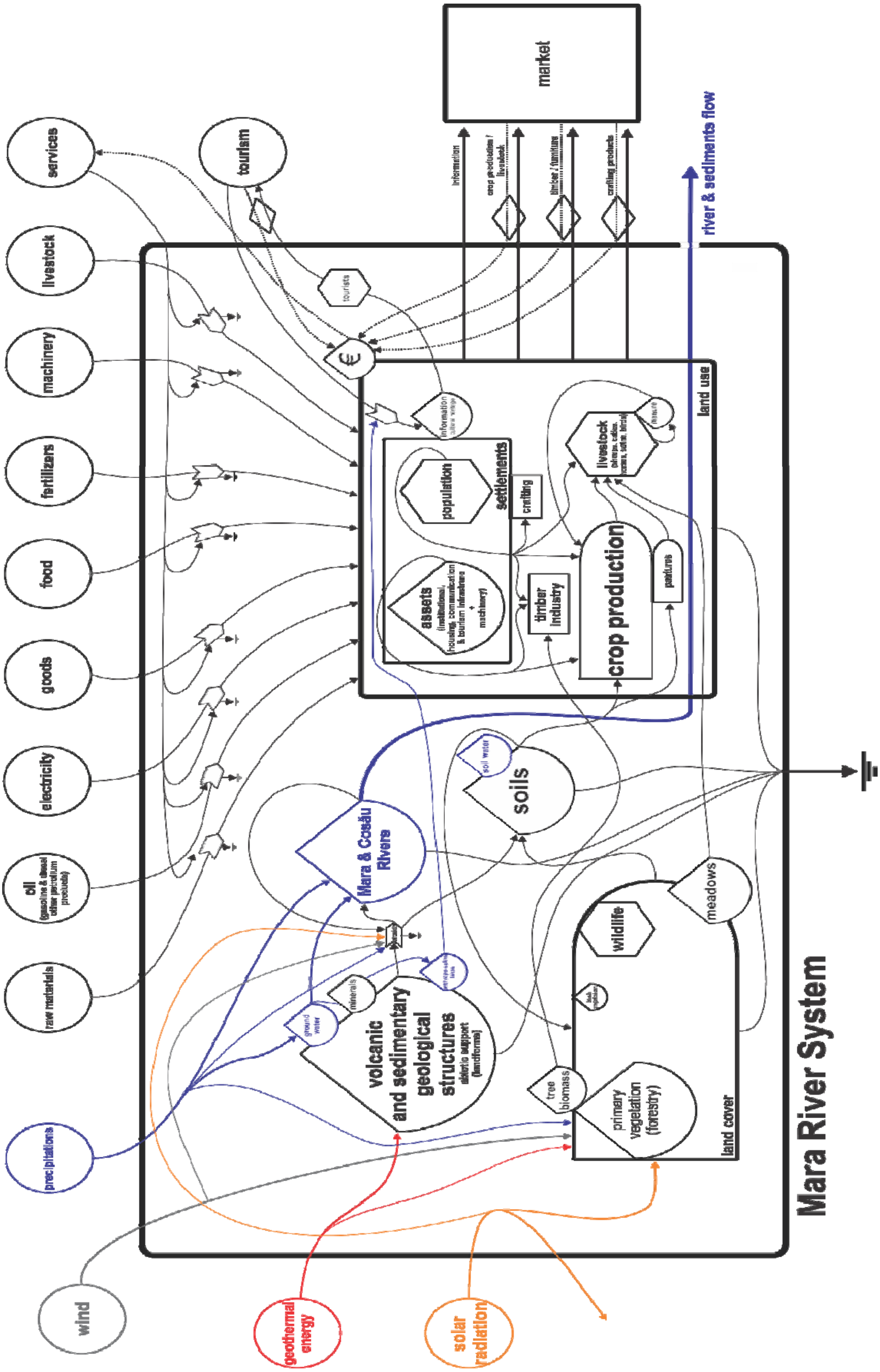

Figure 2. Mara Watershed as a system

RESULTS AND DISCUSSIONS

Because of the fact that any type of useful energy for humanity has at it's origin a natural renewable or non-renewable energy source, 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 procesess (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.

Geothermal energy potential

Considered as a renewable energy source, the geothermal energy is understood not just as the heat coming from within the Earth's core, but as a fraction of that heat used to generate useful work for society (Dickson&Fanelli, 2004 in Norden et al., 2011). The temperature grows with depth based on a geothermal gradient. Near surface, in the areas unaffected by vulcanism or tectonic activity, the geothermal gradient has a constant of about 2.5 degrees Celsius / 100 meters. Local and regional variations of this parameter can be registered based on discrepanties regarding the thermal conductivity of rocks in the area. The geothermal energy can lose this status due to heavy exploitation in areas were the thermal potential in based on remnant heat provided by extinct vulcanism. In Island, a country known for its active vulcanoes and were geothermal energy is considered at home, the potential is exploited only in areas were measurements indicate a geothermal gradient of over 4 degrees Celsius / 100 meters. The constant heat flux towards the surface is measured in W/m^2 and the average values in continental regions is estimated at around 0.06 W/m^2. 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 $W/m^2/s$ (Table 1) / 5.7E+14 seJ/ha/yr (Figure 3) insufficient for a large scale and centralised exploitation as thermal energy.

item	units	raw data	energy units	energy J / yr	UEV** sej / J	emergy seJ / yr
GEOTHERMAL ENERGY			J/an	1.17E+15	2.00E+04	2.34E+19
geothermal heat flux	W/m^2	9.00E-02	$J/m^2/an$	2.85E+06	-	-
	W/ha	9.00E+02	J/ha/an	2.85E+10	-	-
watershed surface	m^2	4.10E+08	-	-	-	-

Table 1. Emergy of geothermal heat flux **UEV 2.00E+04 sej/J (source: Brown&Ulgiati, 2010)

For the Mara watershed, the geothermal potential was quantified using relevant data regarding the surface geothermal heat flux identified on http://harti.igr.ro/geofizica-v1/ visualization platform. Data expressed in mW/m^2 was gathered for a number of 30 points covering the entire basin and having distinct geographical coordinates. The point values were introduces in Quantum GIS 2.6.1 through a vector layer superimposed on the digital model. The values were interpolated using GDAL Interpolation function, followed by a series of algebric operations in Raster Calculator in order to express this potential in energy and emergy values after the formula:

1. [geothermal heat flux (W/ha)*time(seconds/year)*surface(ha)]*UEV(sej/J)** (Odum, 1996)

The Igniș Plateau, formed of basaltic rocks, registers higher values compared with the rest of the basin and the numbers can be explained through the thermal properties of these rocks, known to be good heat conductors (1.87-2.26 W/(m K), Eppelbaum et al., 2014). From an economical point of view, the Mara watershed is situated in a area with higher values of this potential with respect to the rest of the country, mainly because of its remnant Neogene vulcanic activity. According to the proposed clasiffication of geothermal resourcses by Norden (Norden et al., 2011), which takes into account the reservoir temperatures among others, the basin is enclosed in an area characterised by an energy class of low enthalphy, the temperatures being situated under 150 degrees Celsius.

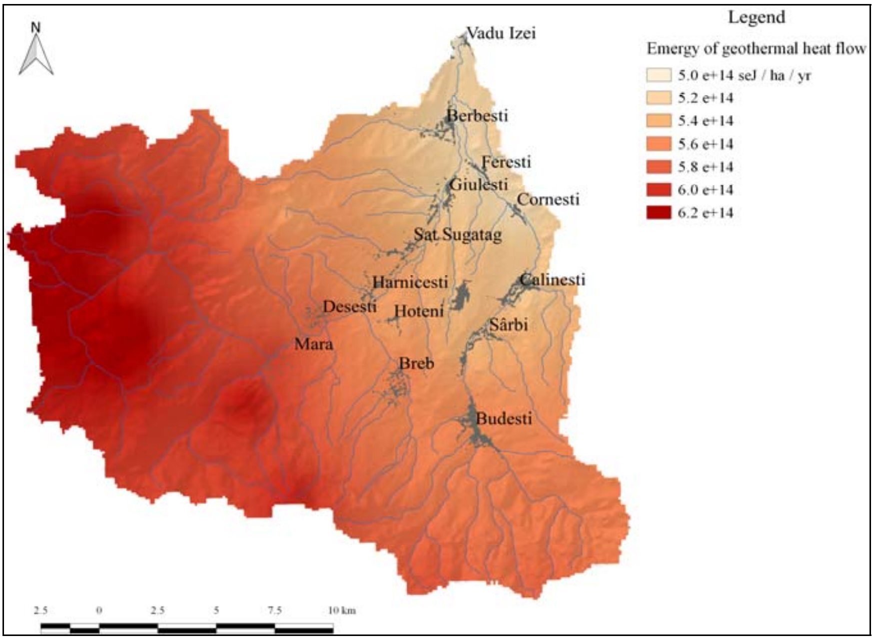

Figure 3. Spatial distribution of geothermal emergy flow at the surface of Mara watershed

This means that preferably, the geothermal potential in the Mara watershed can be exploited through a decentralised system based on individual, low-depth geothermal instalations used as heat providers for households. *High performance instalations installed in the most geothermally attractive areas, can be used for electric power generation, an aspect that would reduce the preassure on rivers as producers of clean electricity and on reducing dependence on outside electricity flow towards the system.*

Solar energy potential

The solar energy represents a diluted form of energy, especially if we make reference at the historical time frame. This type of energy is at the core of every energy transformations within a system and is the main denominator in the proposed methodology. Quantitatively, for the Mara watershed, the solar energy represents the third source of energy after geothermal energy and the energy of rainfall.

Practically, solar energy is efficient when used actively by plants through photosyntesis and pasively by humans. The simple building orientation on a proper cardinal direction and the community can benefit at no extra expense from passive heating of walls. At a larger spatial and temporal scale, the solar energy is performing geologic work, modelling the landscape directly or indirectly (Odum, 2001).

The biosphere represents the most efficient solar energy user, activating through photosyntesis it's biomass production capacity via a series of bio-chemical reactions that transform solar energy into storages of organic matter. The larger the storage time interval, the larger the energy / emergy content. A self-evident example is provided when the caloric energy of secular forests are compared with the same type of energy contained in forestry plantations. Compared with geothermal energy, solar energy isn't always available. It has a cicardian rithm due to Earth's rotation, aspect that deviates from the classical definition of renewable resources availability. Due to Earth's geoidal shape, this potential cannot be exploited at all latitudes. Also, the distribution of solar energy at surface is strongly influenced by topographic curvature and direction.

At a national level, Romania is a category B country (http://www.cnecc.org.cn/uploadfile/Solar%20Energy%20in%20Romania.pdf) attractive for potential photovoltaic investments, especially in the southern and south-eastern Oltenia and Dobrogea regions.

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 emergy values were obtained in kcal/m², furtherly estimating the quantity per hectare in terms of Joules and emJoules using the following algebric algorithm:

2. [direct solar radiation at surface (kcal/ha/yr)*surface (ha)*4184 (J)]*UEV(sej/J) (Odum, 1996)

The basin's solar potential is situated around the values of 8.58E+05 kcal/m²/yr (Table 2)/ 3.6E+13 sej/ha/yr (Figure 4).

item	units	raw data	energy units	energy J/yr	UEV**sej/J	emergy seJ/yr
SOLAR ENERGY			J/yr	1.47E+18	1.00E+00	1.47E+18
direct solar radiation	Kcal/m²/yr	8.58E+05	J/m²/yr	3.59E+09	-	-
	Kcal/ha/yr	8.58E+09	J/ha/yr	3.59E+13	-	-
watershed surface	m²	4.10E+08	-	-	-	-

Table 2. Emergy of direct solar radiation **UEV 1.00E+00 sej/J (source: Odum, 1996)

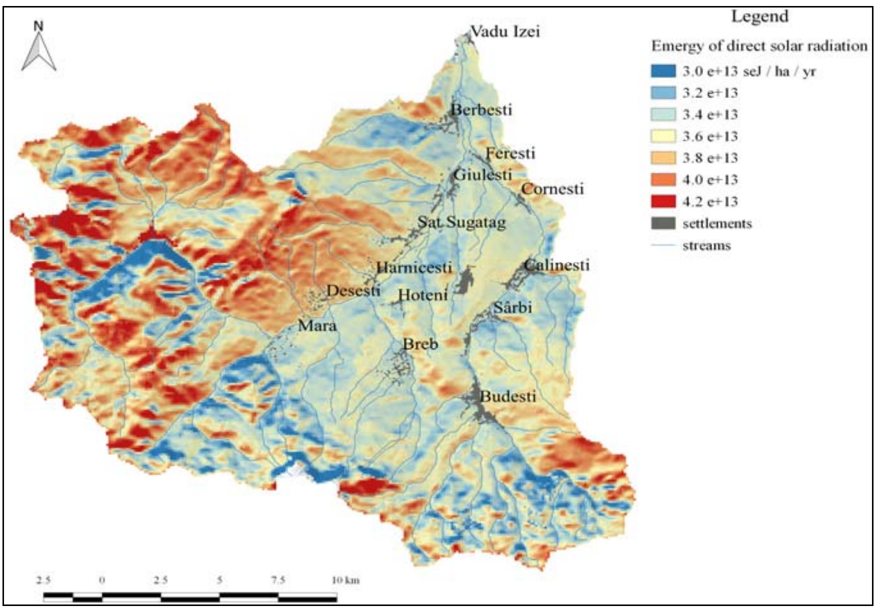

Figure 4. Spatial distribution of direct solar radiation's emergy content at the surface of Mara watershed

In a very pragmatic way, and avoiding implementing high cost technological systems, the passive use of local solar potential represents a cushy modality for Mara Basin's communities to harness this potential. The household's maintenance costs can be substantially reduced by applying discrete building design features capable of increasing the storage capacity of solar power during winter daylight, releasing it during night time. The same principle can be applyed for building summer cooling.

Wind energy potential

Albeit without a major role in local economy, wind energy indirectly participates to it by co-generating atmospheric systems, energising the evapotranspiration process or polenisation. The contribution in the process of rock weathering, a crucial step in soil formation is also significant. The local population uses this resource passively as for example in drying hay stacks and linen or drying up wood material in a pre-processing stage. In the quantitative evaluation process of this potential in the Mara watershed, the raster calculator capabilities of Quantum GIS were enabled in order to process and represent spatially, in terms of emergy values, the wind speed at surface and the geostrophic wind speed, values gathered from relevant bibliography. The calculation were done based on the following algebric formula and considering the fact that, due to the spatial dimension of the Mara Basin, the wind represents a uniformly distributed parameter:

3. [air density(g/m^3)*dragg coefficient(%)*geostrophic wind(m/s)^3*surface(ha)*s/yr]* UEV(sej/J) (Odum, 1996)

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.

item	units	raw data	energy units	energy J/yr	UEV**sej/J	emergy seJ/yr
WIND ENERGY			J/yr	1.24E+14	1.58E+03	2.04E+17
air density	kg/m^3	1.30E+00	-	-	-	-
geostrophic wind at 1000 m/15°C	m/s	1.37E+00	-	-	-	-
velocity absorbed	m/s	1.70E-01	-	-	-	-
dragg coefficient	%	3.00E-03	-	-	-	-
watershed surface	m^2	4.10E+08	-	-	-	-
seconds/yr	s	3.15E+07	-	-	-	-

Table 3. Emergy of wind power **UEV 1.58E+03 sej/J (source: Brown & Ulgiati, 2013)

Low speed winds have low energy potential. Wind speed yearly variability is another factor that burdens the harnessing process. In the Mara watershed, the wind registers the lowest renewable energy potential, with an estimated emergy value of around **5.0E+12 seJ/ha/yr** (Figure 5). The community is being able to harness it passively, throughout building design features meant at easing building ventilation.

Rainfall Energy Potential

Solar energy is the propellant of nature's water circuit in general and of rainfall in particular. Atmospheric precipitations are the major supplier of fresh water stocks, fluid or solid around the world. The contribution of rainfall's energy budget can be separated into two separate flows:

- 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.

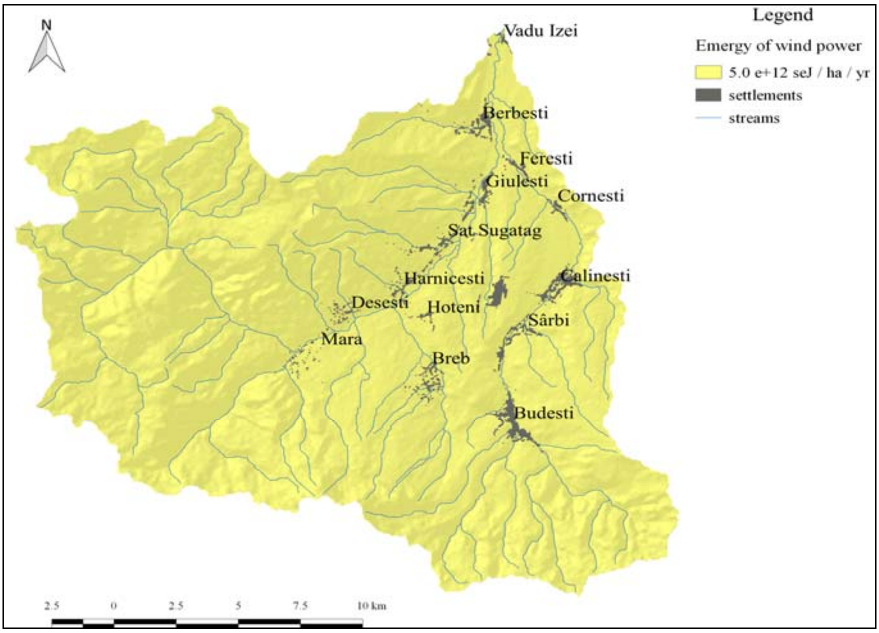

Figure 5. Spatial distribution of wind power's emergy content at the surface of Mara watershed

Potential evapotranspiration (PET)

In its circuit, water carries its chemical potential related to the purity of sea water from which it originates through the combined action of solar and wind energy that evaporated and transpored it. Potential evapotranspiration represents the amount of water that can be evaporated and transpired from a certain area if there were sufficient water available and it must be multyplied by the surface coefficient. In this way, it can be compared with the average annual precipitation for the same area. The simple term of evapotranspiration means that the calculus was made for a reference point, such as a climate station. The potential evapotranspiration is a complex parameter, often determined using a series of important climatic variables – temperature, wind speed, atmospheric humidity etc. and controls the energy exchanges between the active surface and atmosphere (Croitoru et al., 2013)

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 (Turc, 1961, 1963 in 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:

4. $ET_m = \frac{P}{\sqrt{0.9 + P^2/L^2}} / 1000$ (Turc, 1961, 1963, Mellino et al., 2014)

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 (7.6° C)

5. $ET(J) = ETm^{*} \rho * G$ (Odum, 1996)

were:
ET(J) – rate of potential evapotranspiration expressed in Joule
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 (Table 4) and approximates the reference value obtained in the Maramureş Depression using the Pennam –Montheith formula (Croitoru el al., 2013), the value describing the watershed as having a moderate, intracarpathic character.

item	units	raw data	energy units	energy J / yr	UEV** sej / J	emergy seJ / yr
POTENTIAL EVAPOTRANSPIRATION	m/yr	1.76E+07	J/yr	8.70E+14	6.36E+03	5.53E+18
	m/m²/yr	4.29E-01	J/m²/yr	2.12E+06	-	-
	m/ha/ayr	4.29E+03	J/ha/yr	2.12E+10	-	1.35E+14
annual average precipitation in the Mara watershed (1950-000)	m/yr	3.26E+08	-	-	-	-
water density	g/m³	1.00E+06	-	-	-	-
gibbs free energy	J/g	4.94E+00	-	-	-	-

Table 4. Emergy of potential evapotranspiration **UEV 6.36+03 sej/J (Brown & Ulgiati, 2013)
(Source: precipitation data – WorldClim-Global Climate Data portal)

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+17 seJ/ha/yr (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. Here are the algotihm under which the values were obtained:

6. rainfall geopotential = [average annual rainfall(m/ha/yr)*surface(m)*mean elevation of watershed(m)*water density(g/m³)*gravity(m/s²)]*UEV(sej/J) (Odum, 1996)
7. river geopotential = [run-off(m³/yr)*water density(g/m³)*height at entry(m)* gravity (m/s²)]*UEV(sej/J) (Odum, 1996)
8. river chemical potential = [run-off(m3/yr)*water density(g/m3)* Gibbs free energy (J/g)]*UEV(sej/J) (Odum, 1996)

The relatively constant flow of water for the Mara river and its high emergy content (approximately 5.10E+14 seJ/s / 1.61E+22 seJ/yr) (Table 5) together with the low sedimentary transportation budget transform the stream into an attractive opportunity for micro hydropower plants, an exploitation design fashionable in recent years in all mountain landscapes across the country.

Upon designing a micro hydropower plant, the river's geopotential is reduces and the geological and biological work diverted into producing cheap electrical power. Such as rain itself, the rivers possess a high transformity coefficient due to their colossal geologic effort in modelling the relief. Estimating the emergy contained within the rivers means estimating how much geologic effort the rivers do in a year.

item	units	raw data	energy units	energy J / yr	UEV** sej / J	emergy seJ / yr
RAINFALL GEOPOTENTIAL	m/yr	1.76E+07	J/yr	1.61E+18	1.76E+04	2.83E+22
	m/m²/yr	7.96E-01	J/m²/an	2.37E+09	-	-
	m/ha/yr	7.96 E+03	J/ha/yr	2.37E+13	-	-
annual average rainfall (1950-2000)	m/yr	3.26E+08	-	-	-	-
watershed's average altitude	m	4.99E+00	-	-	-	-
water density	g/m³	1.00E+06	-	-	-	-
gravity	m/s²	9.81E+00	-	-	-	-
RIVER GEOPOTENTIAL	m³/yr	1.51E+08	J/yr	1.48E+18	1.09E+04	1.61E+22
Q Mara river at Vadu Izei	m³/s	4.78E+00	-	-	-	-
average height at source	m	1.00E+03	-	-	-	-
water density	g/m³	1.00E+06	-	-	-	-
gravity	m/s²	9.81E+00	-	-	-	-
River Chemical Potential	m³/yr	1.51E+08	J/yr	7.45E+14	1.80E+04	1.34E+19
water density	g/m³	1.00E+06	-	-	-	-
Gibbs free energy	J/g	4.94E+00	-	-	-	-

Table 5. Emergy of rainfall and river geopotential / emergy of river chemical potential
**UEV 6.36+03 sej/J (Brown & Ulgiati, 2013)

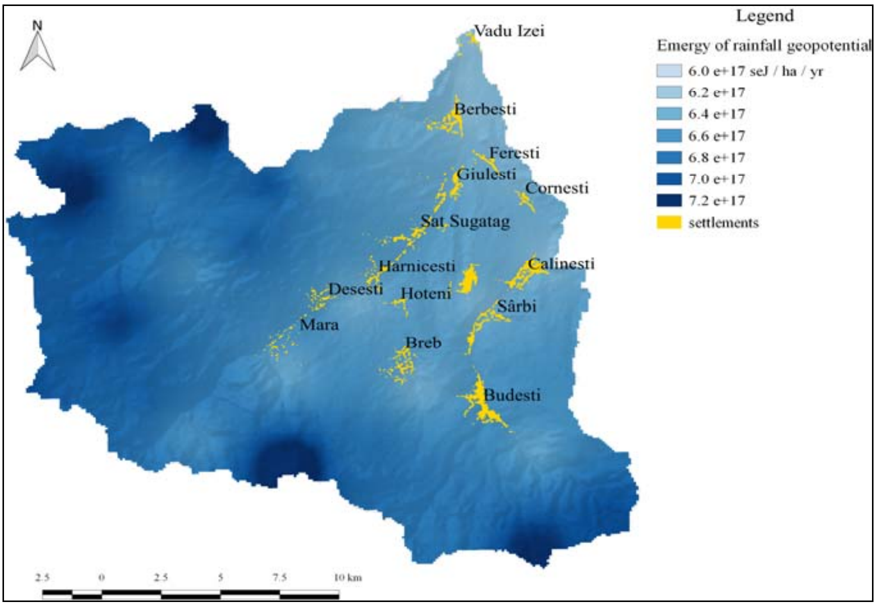

Figure 6. Spatial distribution of rainfall's emergy content at the surface of Mara watershed

Emergy empower index of renewable energy flows

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 (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 (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.

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	2.83E+22
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+22
	TOTAL (R)	-	-	-	-	**2.79E+22**

Table 6. Intensity of renewable emergy flows index in the Mara watershed

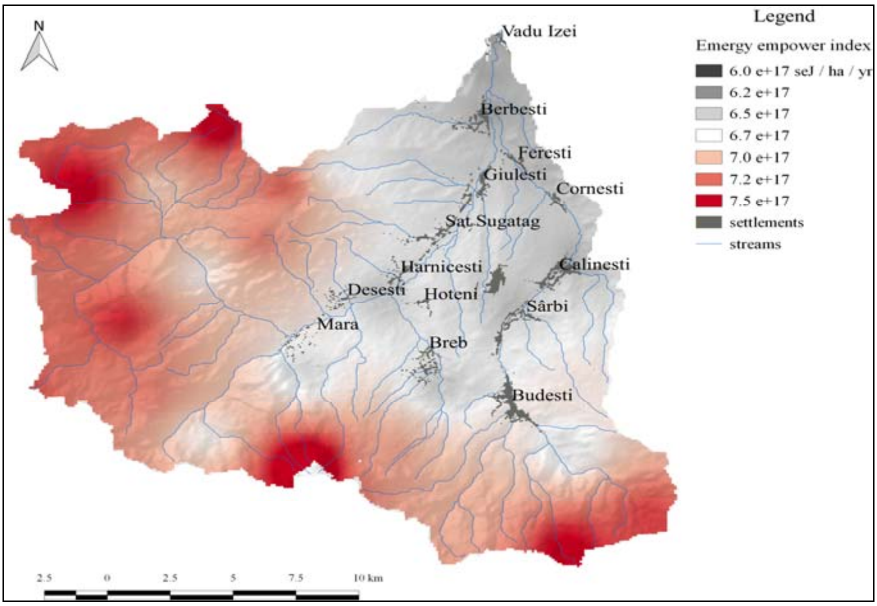

Figure 7. Emergy empower index at the surface of Mara watershed

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.

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. Nontheless 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.

CONCLUSIONS

Speaking about flows in general and about energy flows in particular, inoculates the idea of an interaction phenomenology, materialized as an exchange of matter, energy and information, both natural and anthropic that has a modelling capacity over the spaces it occurs. In geographic space, the flows indicate a superior form of organization of different entities bonded by causal relations.

In this paper, the description and quantification of the main renewable energy flows in the Mara watershed using the premises of Emergy methodology aid in portraying the most important renewable energy resources in the basin, their hierarchical position and their heterogenous spatial distribution within the territory. The resulted visualization materials become information that can assist the decision making processes regarding useful local resource allowance and conservation.

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