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An emergy approach for the assessment of sustainability of small marinas

*C. Paoli**, *P. Vassallo*, *M. Fabiano*

Department for the Study of Territory and its Resources, University of Genova, Corso Europa 26, 16132 Genova, Italy

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ABSTRACT

The construction and the activity of a marina could imply some detrimental effects on the coastal and marine environment. Actually, small marinas activities and the increase in tourism pressure linked with their presence have many interactions with the surrounding environment. Because of the tight links among economic interests, environmental protection and development policies an integrated approach to sustainability is compulsory. In order to give adequate answers to various demands arising from different stakeholders (i.e. marinas managers, policy makers, private owners and users), emergy analysis seems to be an appropriate approach. Emergy is a methodology able to consider both environmental and economic aspects in terms of energy previously used up (directly or indirectly) to make a product. The approach has been applied to two marinas, both located on the western Ligurian coast (Italy, North-western Mediterranean). Both structures emerged as attended by guests exploiting a huge quantity of electricity and fuels, making energy saving a critical issue. The adaptability of the analysis allows further comparison with other key sectors in the same geographical area and with marinas characterized by different natural conditions but it also allows detection the relevance of different management practices and highlighting of changes due to variations in external constraints.

1. Introduction

Recreational boating is a thriving economic sector in Italy offering a large number of development opportunities. Presently, Italy occupies second place in the Mediterranean in terms of number of pleasure boats per inhabitant and recreational boating represents an important economical and occupational resource.

Although the country is facing a continuous growth in term of berths (with an increase greater than 20% from 1999 to 2005), boating activities (and all facilities or structures related to their maintenance) imply negative impacts on coastal and marine areas that cannot be neglected.

Drawbacks related to recreational boating, comprising (among the others) wastes and wastewaters discharge, building processes and resources exploitation, can really affect negatively the coastal system and must be taken into account in order to join a sound environmental management of our coastal zones.

In the national background, Region Liguria plays a pivotal role, being the one with the greatest number of berths in the whole country (UCINA, 2006).

The Ligurian coast is characterized by a dense concentration of marinas (42 marinas located all along the 150 miles littoral), often separated by very narrow distances. Nonetheless, these structures are not sufficient to satisfy boating

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* *Corresponding author*. Tel.: +390103538069; fax: +390103538140.
E-mail address: chiara.paoli@unige.it (C. Paoli).

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tourists' demand. This latter condition can be partly ascribed to a very lack of berths but, most of all, to a general inadequacy of Ligurian marinas in satisfying user's requests. Consequently an increase in the number of berths (the Territorial Co-ordination Plan of the Coast of Ligurian Region foresees the construction of 10,000 further berths) cannot represent an exhaustive answer to this problem. This augmentation must actually be coupled with new management techniques making marinas more efficient without neglecting environmental aspects.

In this context the need for multidisciplinary tools for the analysis of marinas becomes clear, most of all in accordance with principles of sustainable development and integrated coastal zone management which foresee a coastal management "integrated in content and precautionary in ambit" (UNCED, 1992).

From this perspective, integration must be interpreted in its broadest meaning as integration between environment and economic development, government and community, public and sectional interests, science and management but also among sectors and among nations. This work arises from this background and it aims at applying a tool able both to assess the sustainability level of marinas with a holistic approach and to address institution, policy decision maker, managers and private owners toward a more sustainable environmental management of marinas. Toward this purpose the main goals of this analysis are the evaluation of marina impacts in terms of economic and natural resources exploitation, the application of indicators able to track changes and improvements and the suggestion of alternative management techniques addressed to improve efficiency level. This purpose proves to be even more justified considering that this work has been developed in the context of Life P.H.A.R.O.S. project (Playgrounds, Harbours and Research of Sustainability-LIFE 04 ENV/IT/000437). This project involved the Ligurian Region as leader partner, University of Genoa and other 20 other partners among which are four Ligurian marinas. The main target of the project was to test the adoption of EMAS (Eco-Management and Audit Scheme http://ec.europa.eu/environment/emas/registration/sites_en.htm) registration in tourist facilities (such as Golf courses and marinas) and to improve the sustainability level of these structures.

In order to achieve these goals, an appropriate tool, considered suited to answer these complex demands, has been identified in advance. Emergy analysis, a thermodynamic-based methodology introduced in '80s by Howard Odum (1983), provides a series of useful and easily accessible indices that can be used to address marina management.

Emergy has been already applied by scholars and authors to a number of human-driven activities also being included as the basis in the procedure for ISO 14001 and EMAS certification of an Italian Province (Ridolfi et al., 2006). With regard to the coastal zone, several coastal issues have been tackled using emergy methodology (Brown et al., 1991; Odum and Arding, 1991; Ton et al., 1998; Qin et al., 2000; Odum, 2001; Zuo et al., 2004; Tilley and Brown, 2006; Vassallo et al., 2007) but so far this method has not been applied to the evaluation of tourist marina activities.

In this context this paper represents a preliminary effort on the path to realise a bottom-up design. Our overall aim is to analyse activities related to coastal zone with an integrated approach in order to lead different stakeholders (fishermen, marinas managers, beach managers, etc.) to an environmentally sound management of their activities.

2. Materials and methods

Emergy analysis is a thermodynamic-based methodology defined through the concepts of solar emergy and solar transformity.

Solar emergy is identified by the quantity of solar energy required, directly or not, to provide a given flow or storage of energy or matter (Odum, 1996). Emergy is expressed in solar emergy Joule (sej).

Transformity measures the input of emergy per unit output and is calculated as the ratio of the emergy needed to produce a flow or a storage to the actual energy of that flow or storage (Ulgiati and Brown, 2002). The transformity is expressed in solar emergy Joules per Joule of output flow (sej/J) although for certain products or flows easily quantifiable in units of mass (or money) a conversion value (named specific emergy) expressed in sej/g (or sej/€) can be used.

The emergy accounting is based upon the assumption that energy flowing through hierarchical patterns in systems mirrors a universal law. This statement was claimed by Odum (1996) as a fifth law of thermodynamics. In these hierarchies of energy or matter, units placed higher up in the hierarchy are assumed to have higher influence on the system's function than units lower down (Grönlund et al., 2004).

This difference of influence is made clear by multiplying the energy or matter value by its proper transformity. The higher the transformity value value of a certain flow, the higher the hierarchical level it occupies.

Emergy accounting is organized as a top-down approach (Ulgiati and Brown, 2002) leading to the conversion of all inputs to the system into their emergy content.

The methodology's first step consists in the drawing of a system diagram.

This chart must be complete and representative of the case study; then it requires the contribution of experts in different disciplines sharing knowledge (Odum, 1996). Energy system language suggested by Odum (1971a, b) has to be adopted in order to organize relationships between main components of a system, to depict the ecosystem environmental basis and its connection to the larger economy (Tilley and Swank, 2003; Cavalett et al., 2006) and also to make the diagram comparable to similar ones.

The energy systems language (Odum and Odum, 2000) is actually a universal and standardized language able to provide a holistic view of the system and specify main forcing functions, internal components, process interactions and exported products (Tilley and Swank, 2003).

Diagramming process proceeds following some precise steps. Principal phases include the definition of temporal and spatial boundaries and the inventory of all the forcing factors and internal units. Such procedure leads to the sketching of preliminary and complex diagrams of the system. Differ-

Table 1 – Emergy indicators calculation formulae

Name	Abbreviation	Formula
Total emergy	U	$R+N+F$
Percentage renewable	Φ_R	R/U
Environmental loading ratio	ELR	$(U-R)/R$
Emergy investment ratio	EIR	$F/(N+R)$
Emergy yield ratio	EYR	U/F
Emergy/user	EpU	U/users number
Emergy density	ED	U/total surface

ent components are then aggregated filtering out unessential parameters and combining others.

Tables of the actual flows are constructed from the diagrams. Different units for each flow are multiplied by appropriated transformities (or specific emergy) to convert them to solar emergy. Comparisons between flows of different materials and energies are possible once expressed in emergy units. Emergy evaluation offers the undeniable advantage of considering all the resources involved in sustaining a system, including those of natural origin normally not accounted for in traditional analytical approaches because they are perceived to be offered free of charge by the surrounding environment (Ridolfi et al., 2005). The resources used up in the system, expressed as solar energy equivalents (Odum, 1996), represent the U flux (Table 1) and are conventionally grouped into three types. This classification is based on resources origin and replacement rate: F group comprises resources imported from outside the system, while L group refers to those of local origin. This latter category can be split in R and N, respectively local renewable and local not renewable. The greater the F sources, the more the system proves not to be self-sufficient, while a huge expense in term of N inputs mirrors a strong dependency upon resources that cannot be replaced at the current exploitation rate. Several emergy-based indicators can be calculated relating these various resources types to assess a process performance. These tools are able to give synthetic information regarding a more complex phenomenon within a wider sense; they work to make a trend or a process that is not immediately clear more visible and simplify information that is often relative to multiple factors enabling investigators to communicate and compare results (Pulselli et al., 2007).

Formulae for the calculation of emergy indicators used in this work are shown in Table 1.

Among the existing emergy-based indicators, Φ_R (Table 1) represents a first measure of system sustainability: the lower the fraction of renewable emergy used, the higher the pressure on the environment. In the long run, only processes with high values of this index are sustainable (Brown and Ulgiati, 1997).

ELR is given by the ratio of non-renewable resources (both local and imported) to renewable ones (Pulselli et al., 2008). It is critical to the evaluation of environmental services and indicates an excess investment of not renewable compared to locally renewable emergy (Ulgiati and Brown, 1998).

EIR is given by the ratio of purchased inputs (F) to local resources (L), both renewable and non-renewable (Pulselli et al., 2008). It provides an evaluation if the process is a good user of the emergy that is invested, in comparison with alternatives (Brown and Ulgiati, 1997). ELR and EIR converge if N sources have zero value.

EYR is an indicator of the yield compared with inputs other than local inputs and gives a measure of the ability of the process to exploit local resources accounting for the difference between local and imported. EYR indicates the efficiency of the system using purchased inputs (Ortega et al., 2005).

Emergy per capita is the ratio between the total emergy fuelling the system divided by the population. It is an indicator of individual contribution to the sustainability or unsustainability of the system (Ridolfi et al., 2005). In our case we made this index fit by computing an "Emergy per user" value. Emergy per user (EpU) is calculated dividing total emergy by the total number of person visiting marinas for nautical or recreational purposes, namely users.

ED is given by the ratio of total emergy to the area of the system and is a measure of the spatial concentration of emergy within a given territory. When this value is high, it means that territorial limitations hamper the future economic growth of the system. However, this does not preclude further development of the system that would be possible if there were a more efficient use of resources and available space (Ridolfi et al., 2005).

Finally, transformity values obtained for the studied processes can further provide major information. Actually transformity can be considered both a quality indicator, according to Lotka-Odum's maximum power principle (Odum, 1988; Odum and Pinkerton, 1995) and an efficiency indicator because a lower transformity needed to obtain similar products means a lower (and better) exploitation of resources during the process. Thus, we could refer to emergy as a sustainability indicator because it allows evaluating the quantity and quality (in terms of renewability) of resources employed in a process (Vassallo et al., 2006).

2.1. *Study area*

The emergy analysis has been applied in two small marinas chosen among those participating in the P.H.A.R.O.S. project: Marina degli Aregai (named M1 hereinafter), located in the small municipality of Santo Stefano al Mare, and Portosole (named M2 hereinafter), located in the town of Sanremo (Fig. 1).

The two study sites are located in the western part of the Ligurian Region and in the Province of Imperia. Both marinas are set in a periurban context, easily accessible to the public and characterized by a very strong anthropic influence.

Some basic statistics for a preliminary comparison among the two small pleasure boats harbours are reported in Table 2.

M1 has been constructed recently (its opening dates back to the early nineties) while M2 was completed in the seventies. Both structures are medium-sized, occupying an average surface (land and marine area) of about 250,000 m^2 (Table 2), with less then a thousand berths each.

Even if services and facilities offered by the two marinas are not exactly the same (Table 2), the two structures are managed in a very similar way.

Both marinas were awarded the blue flag in 2006 (http://www.feeitalia.org/). Berths are principally held by private owners who have bought the mooring and solely pay for services and resources exploitation (electricity, water, fuels, etc.).

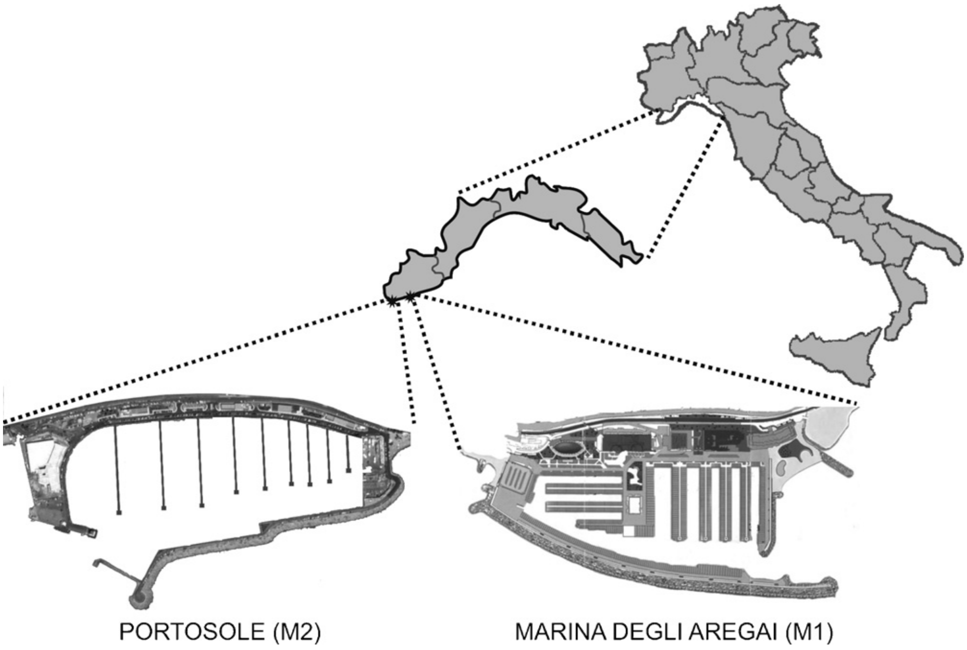


Fig. 1 – Location of the marinas.

The remaining part of berths (Table 2) is open and available for seasonal or transient boats paying a time fee to be allowed to stay in the marina.

2.2. *Emergy accounting*

Fig. 2 shows "the marina system" diagram that includes system components and fluxes considered most relevant by taking the advice of experts, academics, and students advice and by considering a typical activity on a yearly base.

The driving sources, represented as circles outside the main system window, are placed along system boundaries with decreasing renewability clockwise (Fig. 2).

Pathways may indicate casual interactions, show material cycles, or carry information but always with some energy (Vassallo et al., 2006).

R is shown on the left-hand side of the diagram while *F* inputs such as fuels, electricity, goods are placed on the upper side. Outputs, yields and market exchanges Y (system outputs) are located on the right-hand side of the diagram.

An emergy table is obtained by the calculation of the fluxes represented in the diagram. Annual quantities of *R*, *N* and *F* flows are classified and listed in first two columns. The next columns show transformity and emergy value corresponding to each input together with the adopted renewability factors. Actually *F* flows are basically considered not renewable even though a partial renewability has been assigned to each mate-

Table 2 – Marina description and characterisation

		M1	M2
Year of construction		1992	1977
Total surface (m^2)		268294	263860
Water area (m^2)		123000	167500
Number of berths		989	803
Boats length (m)		Max 26	Max 90
Berths for transient boats	Number	73	38
	Percentage	~7%	~5%
Number of wharves		7	9
Opening season		All year round	All year round
Facilities and services	Boating activities	Fuels, water (showers and berths) and electricity supplying	Fuels, water (showers and berths) and electricity supplying
	Commercial activities	Laundry, bar, restaurants, boat and motor repair, bathing establishment, shopping arcade (3 restaurants, bar and shops), parking	Laundry, bar, restaurants, boat and motor repair, shops, parking
	Residence	~200 one or two roomed flats among which only 6% for marina guests	

Table 3 – Marina emergy calculation table (Calculations, parameters and references for Table 3 are given in Table A.1, Appendix A)

Item			Quantity/year		U.M.	Transformity or Specific emergy (sej/u.m.)	Reference	Emergy (sej)		Type	Renewability factor
			M1	M2				M1	M2		
1	Wind energy		1.12E+13	1.10E+13	J	2.45E+03	a	2.74E+16	2.70E+16	R	1.00
2	Tide energy		1.01E+07	1.38E+07	J	7.39E+04	a	7.50E+11	1.02E+12	R	1.00
3	Geothermal heat		2.54E+11	2.50E+11	J	1.49E+04	b	3.78E+15	3.72E+15	R	1.00
4	Electricity	Boating	4.79E+12	1.39E+13	J	1.70E+05	c	8.14E+17	2.36E+18	F	0.09
		Commercial	1.03E+12	2.49E+12	J	1.70E+05	c	1.75E+17	4.24E+17	F	0.09
		Residence	1.83E+11	/	J	1.70E+05	c	3.11E+16	/	F	0.09
		TOT	6.00E+12	1.64E+13	J	1.70E+05		1.02E+18	2.79E+18	F	0.09
5	Fuels										
5a	Methane	Boating	1.35E+11	/	J	4.80E+04	d	6.47E+15	/	F	0.00
5b		Commercial	1.32E+11	/	J	4.80E+04	d	6.33E+15	/	F	0.00
		TOT	2.67E+11	/	J	4.80E+04		1.28E+16	/	F	0.00
5c	Gasoline	Boating	9.80E+12	2.09E+13	J	6.60E+04	e,f	6.47E+17	1.38E+18	F	0.00
5d	Lubricating oil	Boating	1.44E+05	/	J	6.60E+04	g	9.50E+09	/	F	0.00
5e	Diesel	Boating	7.26E+12	1.55E+13	J	6.60E+04	e,f	4.79E+17	1.02E+18	F	0.00
5f	LPG	Boating	/	3.67E+11		6.60E+04	e,f	/	2.42E+16	F	0.00
6	Water	Boating	1.78E+10	7.29E+10	g	7.64E+06	h	1.36E+17	5.57E+17	F	0.77
		Commercial	8.45E+09	8.32E+09	g	7.64E+06	h	6.46E+16	6.36E+16	F	0.77
		Residence	2.43E+08	/	g	7.64E+06	h	1.86E+15	/	F	0.77
		TOT	2.65E+10	8.12E+10	g	7.64E+06		2.02E+17	6.21E+17	F	0.77
7	Human labour	Boating	2.54E+10	2.54E+10	J	7.38E+06	d	1.87E+17	1.87E+17	F	0.60
		Commercial	9.52E+10	1.28E+11	J	7.38E+06	d	7.03E+17	9.42E+17	F	0.60
		TOT	1.21E+11	1.53E+11	J	7.38E+06		8.90E+17	1.13E+18	F	0.60
8	Structures		4.77E+05	4.27E+05	€	2.22E+12	i	1.06E+18	9.48E+17	F	0.00
	Total emergy							4.31E+18	7.94E+18		

[a] Odum et al., 2000.
[b] Ulgiati and Brown, 2002.
[c] Bastianoni et al., 2005.
[d] Odum, 1992.
[e] Rydberg and Haden, 2006.
[f] Haden, 2003.
[g] Bastianoni et al., 2001a, b.
[h] Vassallo et al., 2006.
[i] Bastianoni, 2002.

rial or service taken in account. This approach is considered an evolution in emergy methodology, representing a step forward in describing, with greater fidelity, the sustainability of complex systems (Ortega et al., 2005).

Several renewability fraction values have been suggested in previous studies (Ulgiati et al., 1994; Bastianoni et al., 2001a, b; Ortega et al., 2002; Ortega and Polidoro, 2002; Panzieri et al., 2002; Ortega et al., 2005; Vassallo et al., 2006; Cavalett et al., 2006) and have been found in literature.

Renewability fraction for electricity has been evaluated starting from data related to: (1) electric energy balance in Italy (http://www.terna.it, ENEA, 2007); (2) renewable percentage index previously reckoned for different electricity production processes (Ulgiati and Brown, 2001); and (3) calculations performed by authors. In particular, we computed transformity and renewable percentage for photovoltaic electricity. This calculation leads to the evaluation of the renewability value of Italian electricity production (see Table 3, item 4).

3. Results and discussion

3.1. Marinas' assessment and comparison

An emergy accounting table (Table 3) has been obtained for both marinas. Forcing factors have been listed and split among different main marinas activities (Table 2 see item Facilities and Services).

Both systems are fed by a huge quantity of emergy coming from abroad while renewable resources contribute to a lesser extent to the global emergy budget. The contribution of natural renewable resources can be principally ascribed to wind energy (items 1, 2 and 3 in Table 3). Among partially renewable resources, the greatest contribution is related to human labour both in M1 and M2.

Comparison between renewable and non-renewable values leads to the calculation of several indices. These indicators allow us to trace a general overview of both structures and to make comparisons among the two marinas (Fig. 3).

Indices analysis shows scarce efficiency of both systems as proved by EYR. Values of this index are close to the unit (M1 = 1.23; M2 = 1.22) demonstrating a scarce ability of the two marinas to provide net emergy outside the system. This trend is coupled with ELR and EIR ratios. Values of these indices are equal due to the absence of *N* flows, as shown in Table 3, second-last column. ELR and EIR figure up at 4.35 in M1 and 4.54 in M2, demonstrating that both systems exert a relevant pressure on the surrounding environment and strongly depend on external resources supply. Probably the forthcoming adoption of EMAS registration will lead to an improvement of this condition and to a more environmentally sound management of marinas.

The comparison between the two systems shows a slightly better sustainability level in M1 than in M2 (Fig. 3) due to a lower impact exerted on the environment, a gently better efficiency and a greater exploitation of natural resources.

Nevertheless, in M1 a greater quantity of emergy (EpU in Fig. 3) is necessary in order to answer the need of a single user, even if total emergy and ED are lower than in M2.

This condition shows a worse allocation of resources among users in M1 and suggests a modification in marina management addressed to a better exploitation of resources (e.g. implementing awareness and knowledge about resources saving, encouraging longer stays of transient boats). In order to investigate this phenomenon a scenario suggesting an increase in the number of boats staying for a single day or transient ("transient boats" hereinafter) has been realised ("visitors scenario" hereinafter).

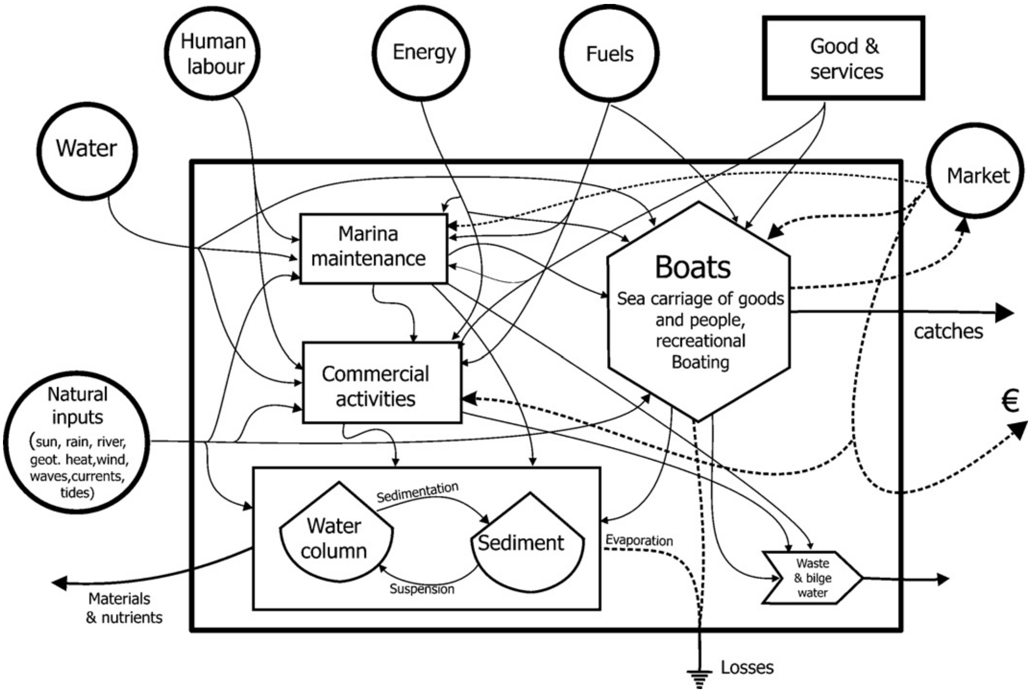


Fig. 2 – Emergy system diagram for the evaluation of marinas activities.

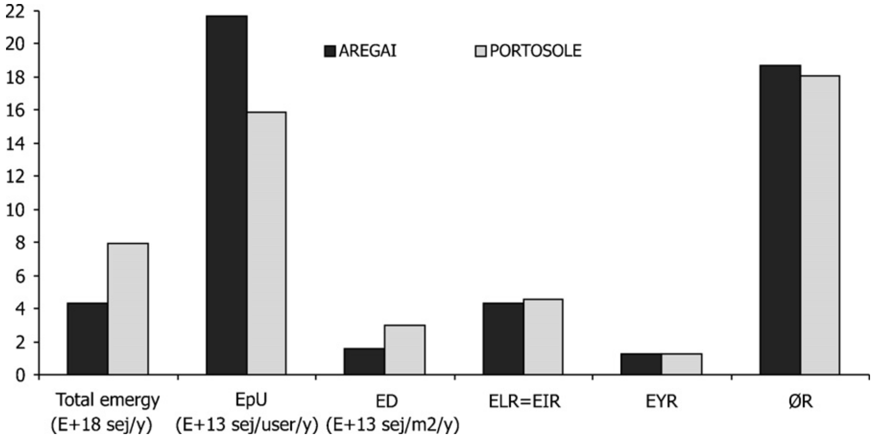


Fig. 3 – Emergy and indicators values in M1 and M2.

3.2. *Visitors scenario*

As previously described, in both marinas, most of the berths are permanently occupied by users who bought their berth once for all. Even though both marinas are similarly managed, a little difference among the two case studies can be detected considering the number of transient boats. In fact, even if in M1 the 7% of exiting dockings are available for transient boats, in M2 this percentage counts only for the 5%. Nonetheless, the number of transient boats yearly accommodated in M2 is more than 4 times greater than M1. In the proposed scenario the number of boats visiting M1 has been supposed to be equal to that of boats visiting M2 in order to deepen the sustainability level issue.

This scenario does not foresee a modification in structures and buildings currently composing M2 and it has been formulated solely considering an appropriate increase in resources consumption directly related with nautical users accommodation (namely fuels, electricity and water).

The suggested increase in the number of boats visiting M1 would imply an occupancy rate equal to less than 10% of total transient boats yearly potential accommodation and less than 40% of summer accommodation. This increase causes a worsening of M1 sustainability level as shown by indices values (Fig. 4).

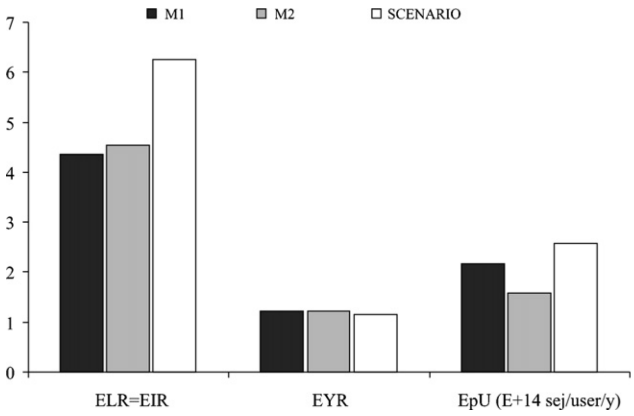


Fig. 4 – Visitor scenario comparison.

These evaluations let us infer that differences between M1 and M2 (previously described in the paragraph dealing with marinas assessment, Fig. 3) is, as a matter of fact, due to a lower M1 attending in comparison with M2. This statement confirms the previous evaluation about resources allocation efficiency in M1. The higher ED value shown in M2 seems to rebut this evaluation. This latter condition can be ascribed to the high attendance of the marina compared with the smaller occupied surface of M1. This analysis does not reject the previous statements about the low level of sustainability of both marinas; thus a deeper insight in marina activities is worthy of attention in order to suggest some management techniques and to characterise critical compartments.

3.3. *Single activities emergy balance*

The emergy needed to maintain different components of the system (Table 2) has been counted distinguishing emergy contribution for the maintenance of different activities (boating and commercial) from emergy of materials needed for construction of the boating structures (wharves, piers) and buildings (Fig. 5). Emergy used up to build structures does not significantly affect total emergy budget. This condition seems to be due to the fact that emergy of structures must be evaluated considering their entire lifetime, varying from 20 to 70 years (Ajit Shenoi and Wellicome, 1993; Mockett and Simm, 2002). This evaluation suggested ascribing to each activity its proper ratio of construction materials (e.g. wharves have been ascribed to boating activities while buildings for catering or shopping have been assigned to commercial activities). Thus, emergy indices for different compartments, considering both construction and maintenance emergy, have been calculated (Fig. 6). Boating activities, whose maintenance counted for more than 50% of total requested emergy (Fig. 5), affect heavily the sustainability level of both marinas as mirrored by indices values (Fig. 6). In fact, boating activities (black colour in Fig. 6) display efficiency (EYR) and Φ_R values lower than those referring to the whole system (white colour in Fig. 6) in both marinas. Moreover, the impact exerted on the surrounding environment as well as the dependence from external not renewable resources and the effort per user (respectively expressed by the ELR, EIR and EpU indices) result to be more severe.

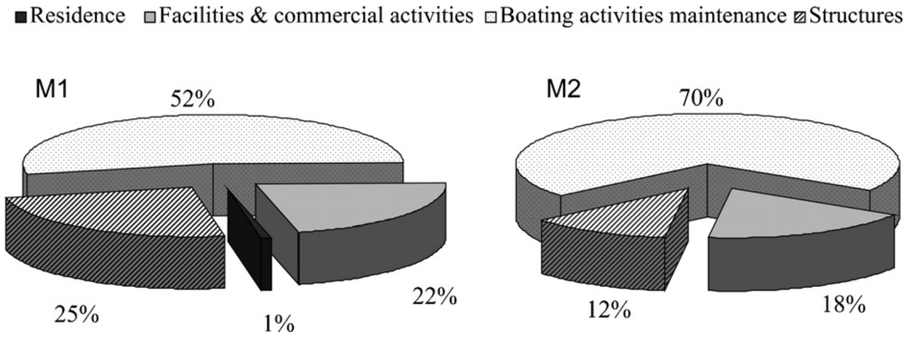


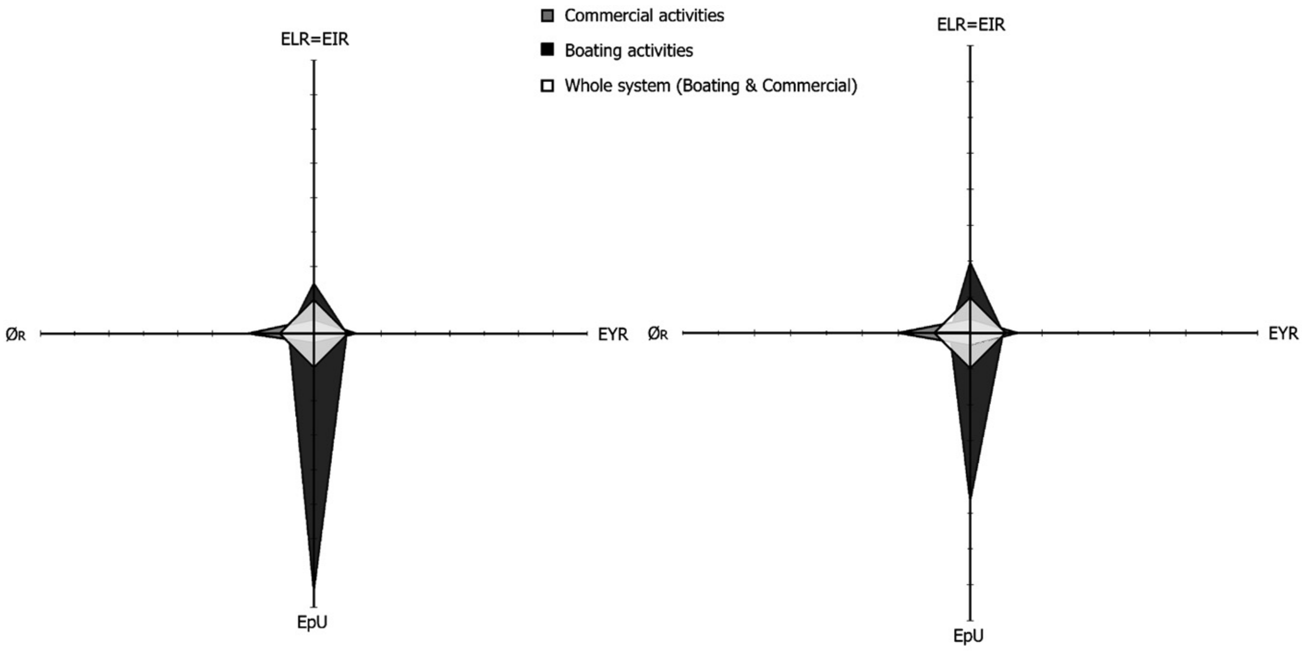
Fig. 5 – Emergy contributions due to activities maintenance and structures.

On the contrary, commercial activities show a relevant exploitation of renewable resources that positively affects indices (light gray colour in Fig. 6). This condition is principally due to the great contribution of human labour considered as mostly renewable according to references (Ortega et al., 2005). In fact, a great deal of human labour is exploited in order to assure guest accommodation and supply of amenities (restaurants, shops, etc.).

As previously stated, recreational boating represents the activity that most negatively affects the level of sustainability. That is, this compartment of the system has been analysed in detail. The analysis has been achieved considering only flows (namely fuels, electricity, water and human labour) that could be easily modified by marinas managers by the adoption of environmentally sound practices. This choice has been performed also considering the negligible contribution due to structures in the total emergy budget. The remarkable contribution of boating activities is principally ascribable to the use of a huge quantity of electricity and fuels (Fig. 7).

In fact, in both marinas electricity is not only used to light piers and other structures but also to feed conditioning plants in winter and summer. Moreover, fuels are plentifully used to produce hot water and as carburant for boats.

In order to formulate suggestions to tackle this issue, a scenario proposing the adoption of solar panels has been assessed (energy scenario hereinafter).



	M1				M2			
	ELR=EIR	EYR	EpU (E+13 sej/user)	ØR	ELR=EIR	EYR	EpU (E+13 sej/user)	ØR
▩	1.65	1.61	7.73	37.77	1.89	1.53	4.39	34.55
■	8.60	1.12	100.86	10.42	6.63	1.15	119.31	13.10
□	4.35	1.23	21.71	18.69	4.54	1.22	15.88	18.05

Fig. 6 – Emergy indices calculated for maintenance and structures related to different marina compartments.

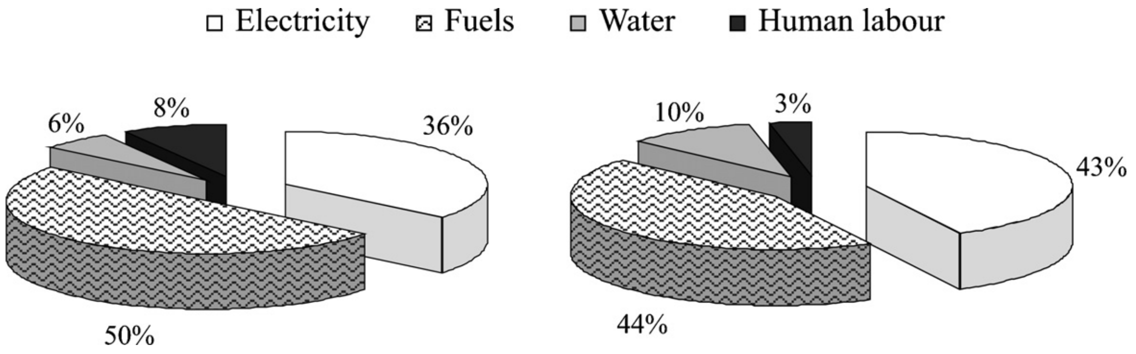


Fig. 7 – Boating activities emergy budget characterisation.

3.4. *Energy scenarios*

In particular, two different scenarios for M1 have been planned: the first proposes the setting up of a thermal solar installation for the production of hot water while the second suggests the adoption of a photovoltaic solar plant for the production of electricity (technical data are listed in Table 4).

The scenarios have been realised supposing the same spatial occupation for both plants (136 m^2 each one, equal to about 0.3% of the M1 land surface). The designs have been realised considering that the installation of such a plant would lead, in the thermal case, to the complete self-sufficiency of the marina.

The two project proposals have been compared to characterise the more efficient solution to be applied. For this purpose, four main outputs have been obtained and considered in order to investigate the efficiency of proposed solutions: (1) saved energy: the quantity of Joules saved by using every single plant; (2) emergy expense: the emergy spent to set up each plant (thermal solar or photovoltaic); (3) saved emergy: the quantity of emergy saved by replacing methane or electricity with solar power; and (4) profited emergy: obtained balancing the emergy expense due to plant installation and saved emergy. Emergy expense had similar results for both suggested plants (Fig. 8).

Photovoltaic plants revealed a greater efficiency as shown in Fig. 8. Even if a larger amount of energy can be saved (Fig. 8) by the installation of a solar thermal plant, the emergy saved results is roughly two times lower (considering both total and net emergy, see Fig. 8). Nonetheless, the use of the proposed thermal solar plant would lead to the complete self-sufficiency of the marina, completely replacing the exploitation of fuels for hot water production. Contrariwise the adoption of the photovoltaic solution would fulfill only an amount equal to the 1.60% of total marina requirements, suggesting that energy saving techniques are still desirable (e.g. turn building conditioning from electric power to natural gas power, thermal insulation increase of buildings, public lighting rationalisation such as energy saving bulbs or timers, customers awareness increase).

Table 4 – Solar plants technical data

	Solar plant	Photovoltaic plant
Solar module	C8 Jacques Giordano Ind.	585 F BP Solar
Module surface (m^2)	2.1	0.63
Module weight (kg)	35	7.5
Number of modules	65	215
Plant total surface (m^2)	~136	~136
Energy production (KWh)	4.94E+04	2.13E+04

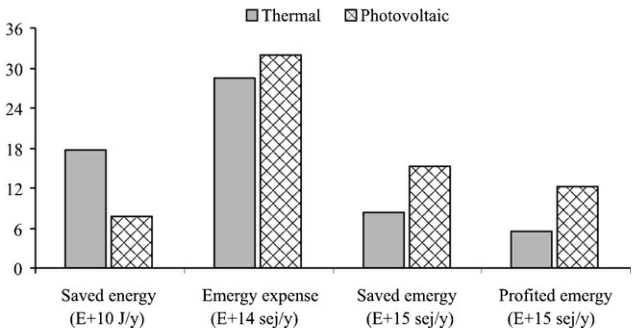


Fig. 8 – Energy scenarios comparison.

4. Conclusions

The Ligurian Region is economically based on tourist activities whose development must be sustainably pursued aiming at gaining an environmental sound management and at answering to multi-stakeholders questions.

Emergy revealed itself a valid tool to assess and evaluate marina management and sustainability level because it highlights critical components of the management system.

Since emergy analysis has been applied to two marinas, both located in the North-western part of Ligurian Region, this calculation allowed assessment of the scarce environmental sustainability status of analysed case studies.

In both cases boating activities, whose maintenance counted for more than 50% of total requested emergy, was revealed to heavily affect the sustainability level as mirrored by indices values. On the contrary, commercial activities showed a relevant exploitation of renewable resources that positively affects indices due to the great contribution of manpower.

Moreover, both structures emerged as attended by guests exploiting huge quantities of energy whose presence makes energy resources consumption (electricity and fuels) a critical issue.

Accordingly, the adoption of energy saving techniques seems to be clearly compulsory. Calculations previously developed (visitor scenario, Section 3.2) proved longer stays of transient boats would lead to an increase in efficiency level.

Obviously this condition should be coupled with the implementation of users' awareness and knowledge about resources (energy and water) saving.

Moreover, advantages deriving from the adoption of two plants for production of heat and electricity directly from solar power have been checked. Two different technologies, thermal and photovoltaic, have been evaluated. The photovoltaic technique proved to be more efficient and advisable.

These evaluations should be taken into account during planning stages of new structures and modernisation of existing ones.

From a general viewpoint, indices can be precious in the context of environmental management systems (EMS) implementation as foreseen by ISO 14001 certification and EMAS registration. EMS, in fact, expects the attainment of improvement targets. Emergy indicators, thanks to their ability to temporarily and spatially monitor the analysed system, can represent the proper tool to reach EMS goals or verify their achievement.

Finally, further studies will be performed to investigate other key sectors of the Ligurian coastal economy with the aim of suggesting alternative management techniques (able to support a wholesome, balanced resources exploitation) and to locate marina analysis in a wider and integrated viewpoint. In this context ED and EpU values could be useful for the emergy assessment of other marinas characterized by similar natural conditions and management strategy. For this purpose, even though these indices cannot be considered either as a transformity or a specific emergy, they can be used to evaluate marina impact. Actually these indicators cannot only be used in the broader context of coastal zone analysis, in order to obtain a comprehensive view of multiple anthropic activities developed here, but also can aim at comparing different marinas to detect the relevance of alternative management practices and to highlight changes due to the variations in external constraints.

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Appendix A

See appendix Table A.1.

Table A.1 – Calculations, parameters and references for Table 3

Item	Formula	Coefficient value		Reference
Wind energy (Odum, 1999)	Density × drag coefficient × (geostrophic wind velocity)^3 × area × (seconds/year)	Density	1.3 kg/m^3	Campbell et al., 2005
		Drag coefficient	3.00E−03	Garratt, 1977
		Geostrophic wind	5.2 m/s	Campbell et al., 2005
Tide energy (Ulgiati et al., 1994)	Shelf × 0.5 × (tides/year) × (mean tidal range)^2 × (density of seawater) × gravity	Density of seawater	1.03E+03 kg/m^3	Ulgiati et al., 1994
Geothermal heat (Ulgiati and Brown, 2002)	Area × (annual heat flux/m^2)	Annual heat flux/m^2	30 mW/m^2	Cataldi et al., 1995
Electricity	Total annual charges × (€/kWh)(J/kWh)	€/kWh	0.21 €/kWh	http://www.enel.it
Fuels				
Methane	Annual volume consumption × heat power/m^3	Heat power	3.43E+07 J/m^3	http://pcfarina.eng.unipr.it
Gasoline	Annual weight consumption × heat power/kg × J/kcal	Heat power	7.50E+03 kcal/kg	http://pcfarina.eng.unipr.it
Lubricating oil	Annual volume consumption × heat power/l	Heat power	40 MJ/l	http://www.ipcc-nggip.iges.or.jp/
Diesel	Annual weight consumption × heat power/kg	Heat power	4.27E+07 J/kg	http://pcfarina.eng.unipr.it
LPG	Annual weight consumption × heat power/Kg × J/kcal	Heat power	1.10E+04 kcal/kg	http://pcfarina.eng.unipr.it
Water	Total annual consumption in g	/	/	/
Human labour (Odum, 1996)	(Total annual hours of work) × body metabolism per hour × J/Kcal	Body metabolism per hour	312.5 kcal/h of work	Odum, 1996
Structures	(Original cost)/lifetime	Lifetime	From 20 and 70 years	Ajit Shenoi and Wellicome, 1993; Mockett and Simm, 2002

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