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Valuing ecosystem services for improved national accounting: A pilot study from Madagascar

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ABSTRACT

The present paper proposes a micro-econometric methodology for the economic valuation of the impact of ecosystem services in selected economic sectors. In the context of natural capital and ecosystem accounting, we built a four steps valuation protocol. The methodology is applied to the valuation of freshwater in the Ankeniheny-Zahamena Forestry Corridor (CAZ), Madagascar – a country partner with the Wealth Accounting and the Valuation of Ecosystem Services (WAVES). Our results corroborate the intuition that understanding the value of water in its alternative uses is a key to fostering informed debate on water management and allocation in the CAZ area. More generally, this study provides a solid contribution towards a more effective way to elicit and record nature's ecosystem services contribution to the economy.

1. Introduction

Natural resources and ecosystem services flows account for over 20% of the wealth of world's nations, as estimated by their contribution to economic sectors such as tourism, food, and manufacturing (World Bank, 2011a). Acknowledging the contribution of nature's ecosystem services (ESs) to different economic sectors spurs us to attempt to quantify the magnitudes of such a contribution. This contribution, in fact, is currently invisible in the national account systems, despite its importance among different economic sectors. The proposed framework is based on the use of production functions, where ESs are interpreted as economic inputs (see Barbier (2007) and Dasgupta (2012)). In this context, ESs together with other technical inputs of production, such as labor and capital, are responsible for the determination of the overall supply of the final economic sector's output. By conceptually framing ESs as production inputs, we are not claiming that the only purpose of nature, and its ESs, is to be used to produce an economic output. We argue that just like labor and capital, the economic valuation of ESs can be estimated by investigating their marginal contribution to the production of selected (market) outputs.

The micro-economic valuation methodology has been chosen because computations are based on market transactions, and therefore based on the information reported in the system of national accounts. For these same reasons, the underlying ES economic value estimates are aligned with, and can be compared to, the national accounting data. According to Obst et al. (2013) an ecosystem valuation approach that is aligned with the national accounting principles *"aims to record the "output" generated by ecosystems, given current uses of ecosystem capital; thus, monetary values represent exchange values consistent with the principles of national accounting", (pag. 420).* We therefore propose to apply an economic valuation framework that is both able to estimate the value of ecosystem services and that respects the principles of national accounting. We test this framework in Madagascar, a core implementing partner of the World Bank-led global partnership WAVES – Wealth Accounting and the Valuation of Ecosystem Services.[1] Accounting for fresh water has been identified as a high priority by the National Government of Madagascar. In this context, we attempt to elicit the economic invisibility of fresh water in

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[1] WAVES aims to promote sustainable development by ensuring that natural resources are mainstreamed in national economic accounts and development planning. Consult www.www.wavespartnership.org for more details.

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the region by assessing its (marginal) contribution to key economic sectors that rely on water as a production input, including agriculture, mining, hydroelectricity production, and tourism sectors.

The paper is organized as follows. Section 2 sets the scene for valuing ecosystems for improved national accounting and presents the methodological apparatus. Section 3 discusses the field work and data collection in the CAZ area. Section 4 addresses the technical implementation of the proposed econometric-valuation approach in the study area. Section 5 shows the estimation results and discusses its informational value for policy makers. Section 6 concludes.

2. Measuring and accounting for ecosystem services: setting the scene and methodological apparatus

2.1. National natural capital and ecosystem services accounting

The seminal work of Pearce and Atkinson (1993) posits a practical linkage between sustainable development and a measure of national wealth that includes natural assets and their ecosystem services flows. If sustainable development is a matter of meeting the needs of the present without compromising the ability of future generations to meet their own needs, then it would be a question of maintaining wealth – as measured by savings rates adjusted to reflect depletion and environmental degradation. More recently, Arrow et al. (2012) proposed a natural wealth based theoretical approach to assess whether economic growth is compatible with sustainable development. The authors highlight the need for adequate measurements for estimating and recording natural capital and underlying ESs, as well as any additions and improvements. It has become increasingly evident that not only are natural resources an important share of national wealth, but the composition of natural wealth varies widely across developing countries and regions. This is particularly important when considering that widely used growth indicators such as Gross Domestic Product (GDP) do not take into account the depletion of natural resources (Lange, 2007a, 2007b; World Bank, 2011a). Therefore, recognizing the impact of natural capital and ecosystem services in national production, and the related economic value is the first, and foremost, step in the design and implementation of sustainable development policy. From this perspective, it is important to demonstrate formally the contribution of nature's goods and services to the economy.

An important step in this direction is represented by the recent adoption of the System of Environmental-Economic Accounting (SEEA) Central Framework – see (SEEA, 2012). This is first international statistical standard for environmental-economic accounting by the United Nations Statistical Commission, which places important nature benefits into the core of official statistics, within the constraints and boundaries of the International Standard System of National Accounts (UNSD, 2013). The SEEA Central Framework is complemented by the SEEA Experimental Ecosystems Accounts – designed as a state of the art systems approach in ecosystems accounting – as well as the SEEA Extensions and Applications, which will focus on how SEEA can be used to inform policy analysis.[2] There are, however, no agreed international standards on how to implement national ESs accounting. In fact, measurement of nature's ecosystem benefits for the purpose of their integration into a national accounting framework is a complex task, involving assumptions that have important implications for the measurement's estimates and interpretation of the value magnitudes. In this context, the paper attempts to address this gap, embracing an interdisciplinary economic valuation study that is characterized by the use of a micro-econometrics based methodology that links the valuation of ESs to national accounting. This methodology is presented and discussed in the following sub-section.

2.2. A micro-economic method for the valuation of ecosystem services

To our knowledge, many approaches have been proposed (see Barbier (2011) for a survey), but few were tested or operationalized.[3] For instance, Pattanayak and Kramer (2001) constructed a combined micro-econometrics-hydrological model to measure the contribution of upland forests to farm productivity downstream. Barbier (2000, 2007) and Green et al. (1994) used formal ecological models to compile a catalogue of the various services that are provided by wetlands. Duraiappah (2003) developed a range of dynamic optimization coupled socioeconomic-ecological models to capture a variety of ecosystem services including tidal fishing, water purification and biomass evolution. In our study, the proposed economic valuation analysis is articulated as follows. First, we interpret the selected ecosystem service, together with other economic factors, as an input for the production of a market good or service. Second, we model and estimate production functions taking into account the information collected on the selected economic factors and ESs. We want to estimate the marginal productivity of the input-ecosystem service. This indicator shows the effect on total production, i.e. total quantity of produced output, associated to the use of an additional unit of the selected ecosystem service. The indicator provides information about the (economic and technological) efficiency of the production process but does not convey information about its economic value, expressed in monetary terms. In this perspective, we need to compute the value of marginal productivity. Such monetary indicator is a measure of how much additional revenue varies with the use of an additional unit of the selected input-ecosystem service.[4] This monetary value is computed by multiplying the estimated marginal productivity times the output market price, as reported in the national account spreadsheets. The value of the marginal productivity of the selected ecosystem service bridges the technological characteristics of production to the economic revenues of production, where the ecosystem service plays a determinant role as an economic factor. Finally, we propose to scale up this value to the national level.

Formally, we can define a ‘production function’ as follows:

$$Q_t = f\,(L_t,\ K_t,\ ES_t,\ Z_t) \tag{1}$$

where Q_t is the output of selected market goods at time t, L_t is a vector of labour input (e.g. number of working hours); K_t is a vector of capital input (e.g. number of machines); ES_t denotes a vector of ES-input and; Z_t is a vector of other inputs. From a micro-economic perspective, water is here interpreted as a fundamental production input impacting the market based performance of key economic sectors in the study region under study. The marginal productivity of a production input is calculated as a partial derivative of the production function with respect to the selected input. In this context, the marginal productivity of the ES is calculated by Eq. (2):

$$MP_{ES} = \frac{\partial Q}{\partial ES} \tag{2}$$

Once the marginal productivity of the ES is estimated, one can compute the economic value of the marginal productivity of the selected ES. This economic value is defined by Eq. (3)

[2] Efforts to pilot such approaches are coordinated by the World Bank-led global partnership on Wealth Accounting and the Valuation of Ecosystem Services (WAVES), now it is second phase: WAVES+

[3] Barbier makes an attempt to adjust the net domestic product for the contribution of ecosystem services derived from mangroves in Thailand, see Barbier (2012, 2016). In the study, we do not attempt to adjust net domestic product but make visible the contribution of the selected ecosystem service to the reported domestic product.

[4] The value of the input marginal productivity can also be interpreted as an opportunity cost, that is the cost of a forgone unit of ES destined to an alternative allocation from the one currently considered.

$$\text{VMP}_{ES} = \underbrace{P_Q}_{\text{market price of the output/good or service}} \times \underbrace{\frac{\partial Q}{\partial ES}}_{\text{Marginal productivity of } ES} \quad (3)$$

where P_Q is the market price of the final output,[5] which is produced with the selected ES-input.

The final step aims at measuring the monetary value of the sector revenue generated by ESs. This is computed by multiplying the value of the marginal productivity of the selected ecosystem service by the total output sold in the selected market/sector. Sector output is reported in the system of national accounts and refers, for example, to the annual amount of tons that the mining sector produces in a country. At this stage, we are in a condition to make visible the contribution of the selected ecosystem to the economy. We label this contribution as *'ecosystem service induced sector revenue'*. This aggregated monetary magnitude is aligned with – and can be compared to – the information available in national accounts. In sum, the computed aggregated monetary value of the selected ecosystem service, and ultimately the comparison of this magnitude to the information provided by the national accounting system, here relies on the role that ESs play in the production of quantities of selected market goods and services. Table 1 provides a synthesis of our suggested methodological framework.

We propose to test this framework and empirically estimate production functions in the Ankeniheny-Zahamena Corridor (CAZ), Madagascar. We focus on the role of the Ankeniheny-Zahamena in the provision of fresh water for (1) mining, (2) agriculture, (3) tourism, and (4) hydro-electric energy production. Next section presents and describes the case study area as well as the application of the proposed valuation methodology.

3. Characterization of the case study

3.1. The case study area

The Ankeniheny-Zahamena Corridor (CAZ) is a newly-designated protected area in the eastern region of Madagascar, in the province of Toamasina. It includes the districts of Ambatondrazaka, Moramanga, Ampasimanolotra, and Toamasina Rural. The CAZ has a surface area of 381,000 ha, and its forests, wetlands, and rivers are home to over two thousand species of plants, many endemic to the region, as well as a great number of species of mammals (including many species of lemurs), amphibians and birds – see Portela et al. (2012) for more information. It also comprises a mosaic of land uses including agriculture, forest plantations, community-managed zones, and villages, as well as five government-managed national parks and reserves, including Zahamena National Park, Zahamena Reserve, Andasibe-Mantadia National Park, Mangerivola Reserve, and Analmazoatra Reserve – see Figs. 1 and 2.

CAZ is also home to nearly 350,000 people, mostly rural communities, who practice a mix of subsistence agriculture and cash crop production as a basis for their livelihoods. Key revenue sources in CAZ include rice, coffee, bananas, manioc, lychee, poultry, and charcoal. In this mosaic of land uses, deforestation – primarily as a result of *tavy* (i.e. slash and burn) agriculture – as well other unsustainable and illegal uses such as small scale illegal mining, illegal logging and hunting (USAID, 2007), threaten both the area's biodiversity and livelihoods of the communities that depend on the region's natural resources for their subsistence – for more information see also CI (2010), World Bank (2011b), and World Bank (2012). Main economic sectors in the region include agriculture, mining, tourism, and hydro-electric energy production – see Fig. 3. All these sectors are highly dependent on water for their production system.

3.2. Overview of the selected ecosystem service: freshwater

Madagascar is a country of relatively abundant renewable water resources,[6] which are distributed among five main drainage basins: the slopes of the Montagne d'Ambre (north), the Tsaratanana, the eastern slope, the western and north-west slopes, and the southern slope. However, due to large variations in climate (FAD, 2005), these water resources are unevenly distributed throughout the country. Water resources are abundant in the northern and central regions and become scarcer in the more drought-prone east and south (Health, 2010). The country's main rivers rise in the north-central highlands and flow west, south and east (FAD, 2005). Annual rainfall in the Ankeniheny-Zahamena Corridor (CAZ) is estimated to be in the range of 2,500–4,000 mm/year (USAID, 2007). The topography of CAZ is rugged and is characterized by steep slopes and narrow valleys that feed the eight major rivers whose headwaters are located in the corridor: the Faritany Toamasina, Simianona, Marimboha, Manatsatrana, Maningory, Onibe, Sahatavy, and Fanandrahana Ivondro (Miray, 2003). These rivers provide water directly to an estimated 350,000 residents within the corridor, as well as to residents of the provincial capital Toamasina via a network of dams and aquifers (Satoyama Initiative, 2012). In CAZ the main uses of fresh water resources are domestic, industrial and agricultural. Agriculture is responsible for 99.98% of the total freshwater withdrawals in the country – 14.31 km^3 of water per year – compared to 0.30 km^3 and 0.16 km^3 for municipal and industrial uses, respectively (FAO, 2012). Irrigation is largely gravity fed, and used primarily for micro irrigation (less than 200 ha) and family plots (less than 10 ha), which combined accounts for 73% of the irrigated land in the country. The majority of irrigation infrastructure is highly vulnerable to flooding and siltation, and often requires repair at the beginning of each season (UNDP, 2011a, 2011b).

3.3. Overview of sectors and economic data in the study area

In the CAZ area cobalt and nickel are extracted by the multinational firm Ambatovy, a large-tonnage, long-life nickel and cobalt mining enterprise. At a construction cost of approximately US$5.5 billion, Ambatovy is the largest-ever foreign investment in the country – and one of the biggest in sub-Saharan Africa and the Indian Ocean region. It will soon rank among the largest lateritic nickel mining entities in the world. Data for the mining sector analysis were gathered from different sources of information, including the company's website, documents, reports and experts meetings. Table 2 provides an overview of the selected variables for the mining sector in the CAZ area. These include:

- Output measures – quantity in tones of produced nickel, cobalt and ammonium sulphate per year, assuming a mine life span of 30 years;
- Input measures – labor measured in number or workers, machinery (measured in capital investment), water (measured in cubic meters), land (in hectares), raw materials (quantity of used tones of limestone, sulphur, and ammonia), energy (measured in kilowatt).

  In the CAZ area, like in most Madagascar, agriculture and farming are very important livelihood activities. Most local households in the region cultivate rice and manioc, as well as potatoes, corn, coffee, pepper, sugarcane and different fruit types (bananas, litchis, citrus, and pineapples). The rice cultivation in Madagascar

[5] When using market price information, one is not taking into account the presence of potential distortions, including externalities and market structures different from perfect competition. Market prices are compiled, and reported, in the national account systems. Market price is an important indicator of scarcity. In order to correctly deliver such scarcity-information, price is assumed to be formed in a perfect competitive market. In any market structure different from perfect competition, price is always inflated by a mark-up that captures the firm's market power.

[6] Long-term average annual precipitation is 1,513mm/yr. Total renewable water resources, (those that after exploitation will return to natural levels), are estimated at 337km^3/year – about 17,600m^3 per person (FAO, 2012).

Table 1
Summary of the methodological tool-box for ES economic valuation for national accounting.

Step 1	*Objective*	*Economics instrument*	*Operationalization*
	Assess the technological contribution of the selected ES in the production of the market good	Marginal productivity of the input: $MP_{ES}=\frac{\partial Q}{\partial ES}$	Empirical estimate of a Cobb-Douglas (or other types of economic production functions); Empirical information provided by experts; Empirical information derived by application of microeconomic theory
Step 2	*Objective* Assess the economic value the contribution of the selected ES in production of market good, measured in monetary terms	*Economics instrument* Value of the marginal productivity of the ES (VMP_{ES})=Marginal revenues of the good and service produced with the ES and defined in Eq.(2) as $\mathrm{VMP_{ES}}=\underbrace{P_Q}_{\text{market price of the output/good or service}}\times\underbrace{\frac{\partial Q}{\partial ES}}_{\textit{Marginal productivity of ES}}$	*Operationalization* Multiply output market prices times MP_{ES}.[a]
Step 3	*Objective* Record at the level of national accounting the monetary value of the economic sector(s) generated by the selected ES	*Economics instrument* Total ES-sector revenue=$VMP_{ES}\times total\ market\ sales$	*Operationalization* Multiply the selected output market sales times VMP_{ES}.
Step 4	National accounting Check the total revenues of the selected good and service in the national accounts. They should be registered in sectors balance sheets. National accounts as policy instruments to record and assess the economic value of ES and natural capital in national production		

[a] Caveat when using market output prices is that one may find difference between market price and shadow price (see Dasgupta (2012)).

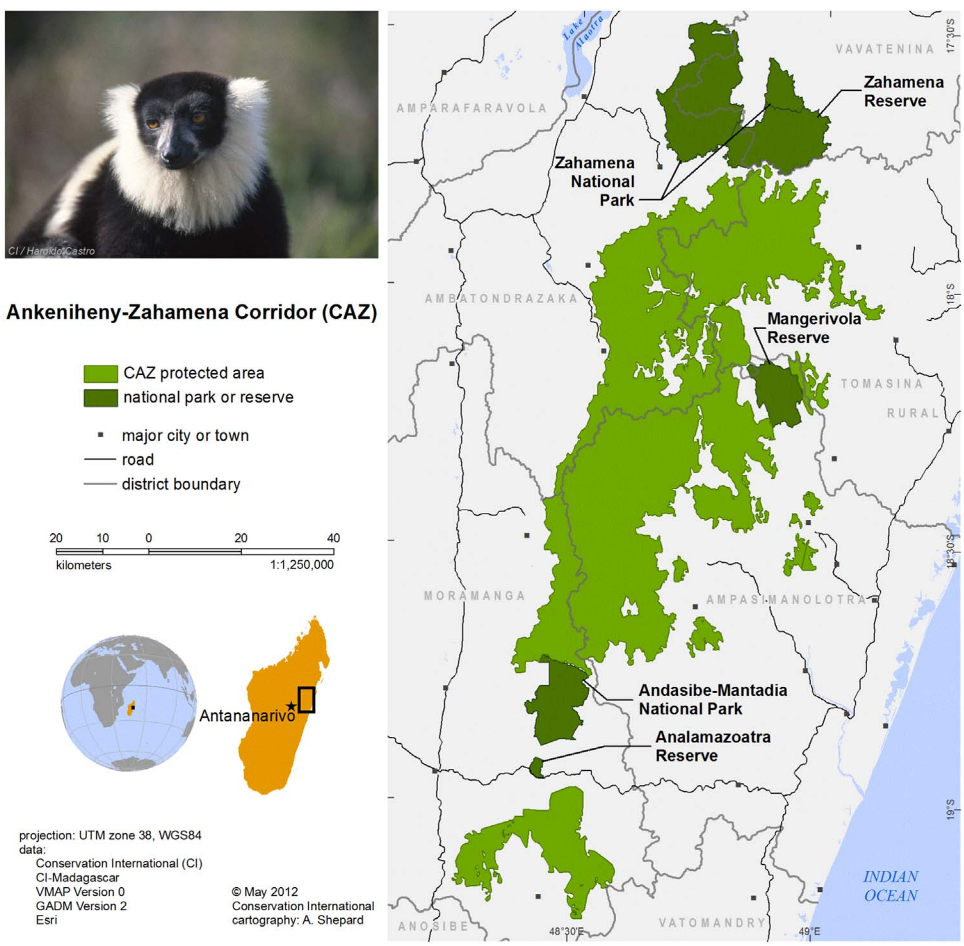

Fig. 1. Overview of the ankeniheny-zahamena corridor (caz).

(and in the CAZ area) follows two main techniques: (a) irrigation and (b) tavy. CAZ households practice both techniques on a 50:50 proportion. Rice cultivation in the CAZ region is primarily for household consumption and areas of cultivation is estimated to be largely insufficient in relation to the estimated population needs. In addition, in the CAZ area farming activities are mostly based on the management of the poultry-yards. The data behind this mapping were gathered from different sources of information, such as

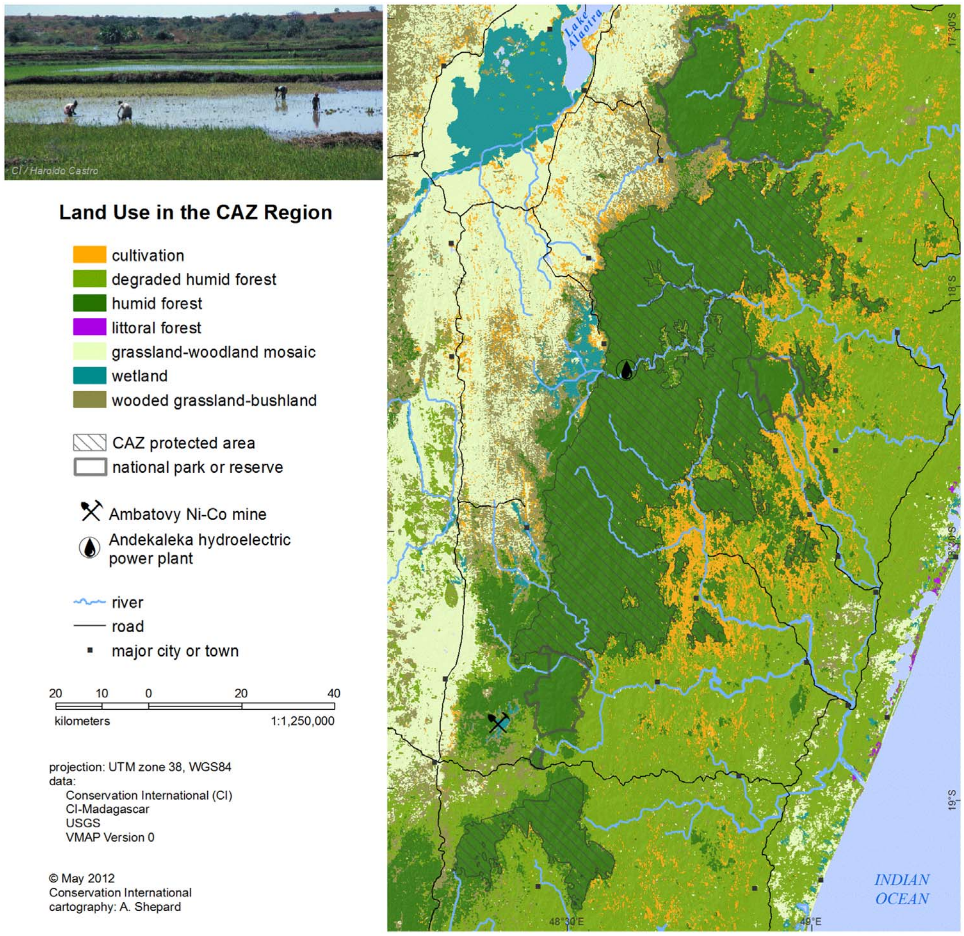

Fig. 2. Land use in the CAZ.

ministerial (Ministry for Agriculture, Farming and Fishery) surveys and census of the agricultural sectors and households, information from the National Statistical Bureau (INSTAT), national water company (Jirama), Rice Observatory, regional development plans, information from local authorities. Table 2 provides an overview of the selected variables for the agriculture sector in the CAZ area. These include:

- Output measures – quantity in tones of produced rice and manioc, number of households' farm animals in selected administrative areas within the CAZ in 2009;
- Input measures – labor measured in number or workers (farmers), number of a selection of most used handcraft utensils, water (measured in cubic meters), land (in hectares), type of machinery.

In the CAZ area the principal touristic attraction site is the Andasibe Park, where hindri lemurs and many autochthon flora and fauna species are protected. The touristic infrastructures are represented by 19 hotels of different categories for a total of 454 beds. Table 3 presents an overview of hotels supply in CAZ area.[7]

We combine this information with (1) the World Trade Organization (WTO) data, which provide an average value of the number of beds per room at a national level. WTO reports 1.63 beds per room Madagascar. We also used the Vakona forest lodge statistics, which reports an occupancy rate of 87.8%. We can infer that, on average, 142,677 beds were occupied during 2010. Furthermore, using average water consumption per dwelling per day (see UNDP (2011b)) we estimate that the total annual water demand per tourist ranges between 12,934 and 17,245 m^3, respectively for national and international tourists – see values in Table 4.

In the CAZ area, there is the Andekaleka hydroelectric power plant. In 2010 it produced about 25 millions kWh of electricity, conveyed to several country areas, including the capital Antananarivo. Our data was based on in-person interviews to Jirama[8] experts. According to these experts, the Andekaleka takes 0.5 m^3 of water to make 1000 kW h of electricity. This implies that Andekaleka, in the CAZ area will use about 12.5 million cubic meters of water for annual electricity production – see values in Table 5.

Against this background, we propose to test the economic valuation method discussed in detail in Section 2 and summarized in Table 1. This testing will be presented and discussed in detail in the next section.

4. Testing the proposed economic valuation methodology: the value of the marginal productivity

4.1. Mining sector and agriculture sectors

We have modelled and estimated the mining and agriculture production functions using different estimation methods and econo-

[7] Data used in the analysis were collected through a capillary field research performed by the World Bank and Conservation International consultant teams, in the period November-December 2011. For a more detailed description of context for analysis as well as mapping and biophysical assessment of additional ecosystem services, see Portela et al. (2012).

[8] Jirama is the Malagasy national energy company.

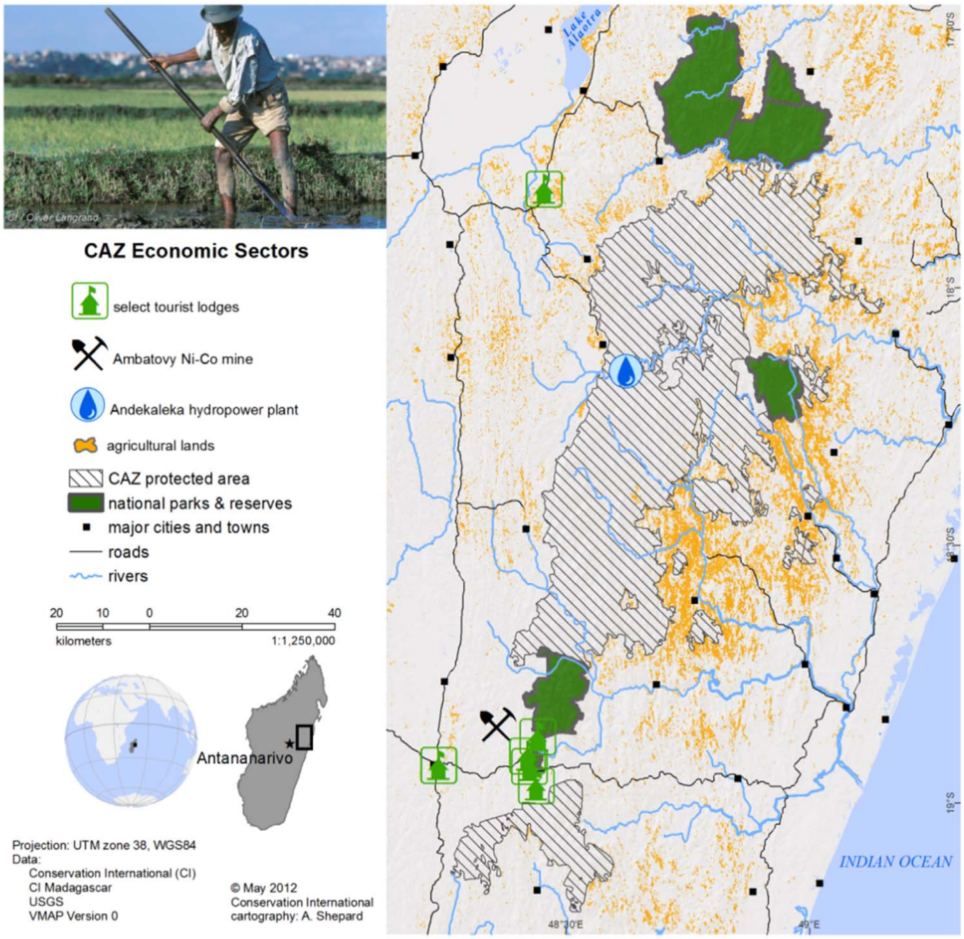

Fig. 3. CAZ economic sectors.

Table 2
Data and selected variables for empirical analysis of the Mining and Agriculture sectors in the CAZ area.
Source: (1) Ambatovy Sustainability Report (2010); Ambatovy Supporting Growth and Development In Madagascar (2010); Ernst & Young Extractive Industries (2010) and Transparency Initiative, EITI, Madagascar. (2) Enquéte Périodique auprés de Ménage, Ministerè de l'Etat, Charge l'Economie et de l'Industrie (2010); Recensement De l′Agriculture, Ministére de l′Agriculture de l'Elevage et de la Peche (2005); Observatoire du Riz; Rapport Final, Renforcement de la Disponibilité et de l'Accès aux Statistiques Rizicoles: une contribution à l'initiative d'urgence pour le Riz en Afrique Subsaharienne (2010); Centre National de Recherche Appliquée au Développement Rural Service de la Statistique Agricole; Conservation International Madagascar Regional Development Plans.

Economic sector variable	Description
Mining sector(1)	
Quantity/Output	Quantity of Cobalt and Nickel in tonnes produced per year.
Labour	Total number of white and blue collars employed per year.
Machinery	Machinery used in production, measured in capital investment per year.
Energy	Total amount of electricity (measured in Kw/h) used in production per year.
\`Land	Total amount of land devoted to mining, measured in hectares.
Water	Total amount of water measured in cubic meters used in production per year.
Agriculture sector(2)	
Quantity/Output	Quantity in tonnes of produced rice, manioc, number of households' farm animals in 12 selected administrative areas within the CAZ per year.
Labor	Number of farmers and/or breeders active in production per year.
Sickle	Number of sickles used in production per year.
Land	Total amount of land devoted to agriculture and/or farming per year, measured in hectares.
Water	Total amount of water measured in cubic meters used in production per year.

metric model specifications with the data made available to our team in Madagascar. Estimation of the production functions mostly has two implications: (1) testing with data if the theoretical formulation (the model) is a correct approximation of the economic and mathematical relationships (inputs and output) we want to describe, and (2) 'attaching' a monetary value to the model's explanatory variables, including the selected ecosystem service. The Cobb-Douglas production function specification has produced the most robust econometric estimates, showing a high goodness of fit as well as providing statistically significant parameter estimates.[9] We have, therefore,

[9] In addition, Cobb-Douglas production functions are quite tractable in empirical analysis. It is worth highlighting, that real world production relationships are often more complex than the Cobb-Douglas case and may involve a plethora of inputs exhibiting a variety of output and substitution relationships within a single function. Despite this, in the present study Cobb-Douglas production functions denoted a robust a solid theoretical and empirical framework to value the selected ecosystem service. For further information on the estimation of Cobb-Douglas production functions see Zellner (1966).

Table 3
Data on the tourism-receptive infrastructure in the CAZ area.
Source: Own elaboration (based on Moramamga Tourism Office and World Tourism Organization).

Hotel / Lodge	No. rooms	No. suites	No. bungalows	No. lodgings	Total no. beds
Vakona forest lodge	0	0	26	26	42
Bezanozano	11	3	16	30	49
Andasibe	0	0	12	12	20
Feon'ny ala	0	0	44	44	72
Site eulophiella	0	10	7	17	28
Zama meva	7	0	0	7	11
Espace diamant	17	13	0	30	49
Hazavana	10	0	0	10	16
Tsara	5	1	0	6	10
Les orchidees	7	0	0	7	11
Max'irene	26	0	0	26	42
Paradis du lac	0	9	0	9	15
Motel restaurant mialy	7	0	0	7	11
Rindra	9	0	4	13	21
Espace mirindra	12	0	4	16	26
Diamant vert	1	0	0	1	2
Manantena	2	0	0	2	3
Ny aina antanan-dava	2	0	0	2	3
Vohitsara	14	0	0	14	23
Total	130	36	113	279	454

adopted this econometric model specification and used the underlying parameter estimates for the economic valuation.

In the case of the mining sector our empirical model of the Cobb-Douglas production function becomes a couple of (separate) log-linear models, as described in Eqs. (4) and (5):

$$
\begin{aligned}
Log(quantity\ of\ cobalt)_t = {} & \alpha_c + \beta_{1,c} log(machinery)_t + \beta_{2,c} log(energy)_t \\
& + \beta_{3,c} log(work)_t + \beta_{4,c} log(land)_t \\
& + \beta_{5,c} log(water)_t + \beta_{6,c} log(land)_t \\
& + \beta_{7,c} log(primary material inputs)_t + u_{c,t}
\end{aligned}
\tag{4}
$$

$$
\begin{aligned}
Log(quantity\ of\ nickel)_t = {} & \alpha_n + \beta_{1,n} log(machinery)_t + \beta_{2,n} log(energy)_t \\
& + \beta_{3,n} log(work)_t + \beta_{4,n} log(land)_t \\
& + \beta_{5,n} log(water)_t + \beta_{6,n} log(land)_t \\
& + \beta_{7,n} log(primary material inputs)_t + u_{n,t}
\end{aligned}
\tag{5}
$$

where the dependent variables are the logarithms of total quantity of respectively cobalt and nickel in period t; and the explanatory variables are the logarithms of the selected production inputs, including water.

Table 6a and Table 6b present the econometric estimates, respectively for the nickel and cobalt production functions. Results confirm that the selected ecosystem service, water, is an important input in both production functions. The estimated coefficients show that water marginal productivity is not the same across the two mining segments. In particular, we can see that a 10% increase in the use of the ecosystem service (water) is associated to an increase of the 7% output of nickel and to an increase of 4.3% output of cobalt. In both cases, the estimated coefficients for the ES-water –input present diminishing returns for the mining production. In other words, there is a decrease in the marginal (per unit) output of the production (i.e. nickel and cobalt) with an increase of water input, all other inputs being held constant.

Table 4
Water consumption in the tourism-receptive sector in the CAZ area.
Source: Own elaboration and based on data from Vakona Forest Lodge, the UNDP report and World Tourism Organization data for Madagascar

Hotel and lodges located in the CAZ area	
Number of lodgings	279
Number of beds	454
Occupancy rate (over 360 days)	87.8%
Overnight stay (average number of days of a tourist)	4.6
Overnight stay (minimum and maximum number of days of a tourist)	4.0–5.4
Average water consumption per tourist (m^3 per day)	0.96–1.28
Lower and upper estimates of total annual water (m^3)	12,934–17,245

Table 5
Data on the Energy sector in the CAZ area.
Source: Jirama

Andekaleka hydropower generator	
Cubic meters of water used for producing 1.0 kW h of hydropower	0.5
Total cubic meters of water	12.5 millions
Total produced electricity (2010)	25 millions kW h

Table 6a
Cobb-Douglas estimates for the mining sector (nickel extraction, all variables in logs).

Nickel	Model 1
Work	−0.260*
Land	0.59***
Machinery	−0.66***
Energy	0.05*
Primary_ materials	0.06**
Water	0.70***
Constant	24.82***
R-squared	0.40

Nota: The model is estimated by the ordinary least squares estimation technique with
* 10% statistically significant.
** 5% statistically significant.
*** 1% statistically significant.

Table 6b
Cobb-Douglas estimates for the mining sector (cobalt extraction, all variables in logs).

Cobalt	Model 1
Work	0.49**
Land	0.10*
Machinery	0.15*
Energy	−0.48***
Primary materials	0.03**
Water	0.43**
Constant	8.91*
R-squared	0.28

Nota: The model is estimated by the ordinary least squares estimation technique with
* 10% statistically significant.
** 5% statistically significant.
*** 1% statistically significant.

Since the agricultural sector in the region is primarily for subsistence, we estimate a system of Cobb-Douglas production functions assuming that there are economies of scope between the activities of rice and manioc cultivation and the management of households' poultry-yard (*basse-cour*). We model production in the agricultural sector as a set of integrated productive activities, where a commonality

Table 7
Cobb-Douglas estimates for the agriculture sector (rice, manioc and farm animals, all variables in logs).

Production/Input variables	Coefficient estimate
Rice	
Water	0.92***
Sickle	0.03
Work	0.17*
Land	0.09**
Constant	1.61*
"R-squared"	0.98
(2) Manioc	
Water	0.82***
Sickle	0.04
Work	0.10*
Land	0.35**
Constant	2.14
"R-squared "	0.96
(3) Farm animals	
Water	0.93***
Work	0.01*
Constant	8.63***
"R-squared "	0.98

Nota: The model is estimated by the three least squares routine with
* 10% statistically significant.
** 5% statistically significant.
*** 1% statistically significant.

of inputs is used as described in Eqs. (6)–(8):

$$Log\,(quantity\ of\ rice)_t = \alpha_r + \beta_{2,r} log\,(work)_t + \beta_{3,r} log\,(land)_t + \beta_{4,r} log\,(water)_t + \beta_{5,r} log\,(sickle)_t + u_{r,t} \quad (6)$$

$$Log\,(quantity\ of\ manioc)_t = \alpha_m + \beta_{2,m} log\,(work)_t + \beta_{3,m} log\,(land)_t + \beta_{4,m} log\,(water)_t + \beta_{5,m} log\,(sickle)_t + u_{m,t} \quad (7)$$

$$Log\,(number\ of\ animals)_t = \alpha_a + \beta_{2,a} log\,(work)_t + \beta_{3,a} log\,(land)_t + \beta_{4,a} log\,(water)_t + \beta_{5,a} log\,(sickle)_t + u_{a,t} \quad (8)$$

where the dependent variables are the logarithms of total quantity of respectively rice, manioc and animals in period t; and the explanatory variables are the logarithms of the selected production inputs, including water.

Table 7 presents the econometric estimates for the agriculture sector. As before, estimation results confirm that the selected ecosystem service, water, is an important argument in both production functions. The estimated coefficients for the ecosystem water, however, show that water marginal productivity is not the same across the agricultural segments. In particular, we can see that a 10% increase in the use of the ecosystem service (water) is associated to an increase of 9.2% of the output of rice, to an increase of 8.3% of the output of manioc, and to an increase of 8.3% of the number of poultry. In all cases, the estimated coefficients inform that the ES-input-water presents diminishing returns in the selected markets.

4.2. Tourism and hydro-power energy sectors

As far as the tourism sector is concerned, we do not have enough information about the sector's technology for hotel management in the CAZ area in order to make make an econometric estimate of the marginal productivity of water. In order to be consistent with the selected analytical framework, we reason as follows. From a production function approach, we can assume that water is the only input affecting output, as in a typical short run economic analysis, keeping the other inputs fixed.[10] Alternatively, we can assume that the consumption of water, e.g. use of water in showers, baths and spa treatments, changes directly with the number of tourists. In this context, we shall be working with data made available by our team in Madagascar so to estimate the marginal productivity of water in this sector. In particular, we shall be focusing on information on the average use of water. According to our field work, we have 1.28 m^3 as the estimate of the average water consumption per tourist, as reported in Table 4. If we assume that water used in this sector presents constant marginal returns, then the average and marginal productivity are equal. In this context, the marginal productivity of water is 0.781 tourist/m^3.

In the absence of the primary value in the hydro-power energy sector, we make the use of expert's information, as obtained by personal interviews with Jirama engineers, as well international literature. A study of the U.S. Department of Energy, Office of Scientific and Technical Information (Campbell, 2010), reports that hydroelectric power can be generated by (a) water released by dams that are adjacent to small reservoirs; (b) water released by dams that are adjacent to large reservoirs. In the first scenario marginal returns to water are decreasing. In the second scenario they are constant. In fact, for dams that are adjacent to small reservoirs, water release would not be compensated for by inlets into the reservoir that would serve to maintain a constant level of water pressure as water is passed through the generators. As a result, water release over a fairly short period of time will reduce the head of the dam, thereby reducing the amount of power that can be generated per unit of water release. For larger reservoirs that receive inflows of water on a continual basis (or where daily releases have a small impact on reservoir levels), an assumption of constant returns to water releases appears to be more realistic. The Andekaleka hydroelectric plant is adjacent to small reservoirs, and we can realistically assume diminishing returns to the water releases. In the context of diminishing returns, the micro-economic theory shows that the value of the water marginal productivity is lower than the value of the average productivity, see Varian (2006). Therefore, we shall work with 0.4 kWh/m^3 as the estimate of the value of the marginal water productivity in hydropower generation. Taking into account the information provided by the experts, the Andekaleka makes, on average, the use of 0.5 m^3 of water to make 1.0 kWh of electricity. Second, this productivity figure is aligned with the range of figures for hydropower – see, for example, the recent study in Tanzania by Kadigi el al. (2008). Finally, this figure was also agreed by the Jirama engineers, who highlight the role of turbine discharge and evaporation. Therefore, we shall use this figure as the estimated value of the marginal productivity of water in the hydro-power energy sector located in the CAZ area.

At this stage we are in a position to calculate the monetary value of the marginal productivity across the four selected economic sectors. This issue will be addressed in the next section.

5. Monetary value of the sector generated by water in CAZ: final results and policy discussion

5.1. Valuation results

We can derive the monetary value of the marginal productivity of water across the selected sectors, by taking into account the estimates of the marginal productivity, as presented and discussed in Section 4 and summarized in the first column of Table 8. Another piece of information is represented by the market prices of each sector's output. We used nickel and cobalt market price, from the London Metal

[10] This is a realistic assumption since a hotel does not change its capacity, or the hotel manager does not directly change the number of rooms, in the short run, given the number of arrivals.

Table 8
Economic valuation of water in the selected economic sectors in the CAZ area (in USD 2012).

Economic sector	Marginal productivity (per m^3)	Market price (in USD)	Monetary value of marginal productivity (in USD)	Monetary value of the sector generated by water (in million USD)
Mining				
Cobalt[a]	0.43	27,500	11,825	66.22
Nickel[a]	0.70	15,440	10,808	648.48
Agriculture				
Rice[a]	0.92	510	469	44.45
Tourism				
International/ longer stay[b]	0.77	480	369	19.04
Electricity				
Industrial use[c]	0.40	14	5.6	0.14

[a] The output of the cobalt, nickel and rice is expressed in tons.
[b] The output of the tourism is expressed in terms of number of international tourists.
[c] The output of the electricity is expressed in terms of kW h.

Exchange, reported in 2012 British pounds, and then converted in 2012 US dollars. We use rice market price from the Observatory of rice, Ministry of Agriculture, reported in 2010 Aryary, and then converted in 2012 US dollars. In addition, we use the market price of a night in a luxury segment hotel, reported in 2011 Aryary, and then converted in 2012 US dollars. Finally, we adopt the electricity market price for industrial and residential use, from Jirama, reported in 2012 Aryary, and then converted in 2012 US dollars. Taking into account the information on both the estimates of the marginal productivity and the market prices, we are able to compute the monetary value of marginal productivity of water in the CAZ region. This information is summarized in the third column of Table 8.

As we can see, the estimates of the value of the marginal productivity of water, expressed in monetary terms, vary accordingly to the economic sector where the ecosystem service is employed. For example, freshwater presents the highest economic value when this ecosystem service is allocated in the mining sector. The values of water for the mining sector range from 10,808 to 11,825 USD/m^3. An additional cubic meter of water used for the production of cobalt is worth 11,825 USD, resulting from the underling increased value in the sales (and consequent revenues) of cobalt. Alternatively, we may read the results in terms of a forgone unit of water allocated to the production of cobalt. In this case, if an additional unit of water is not used to produce cobalt, i.e. is allocated to a different sector, or it is simply no longer available to the production of cobalt, this will be associated to an economic loss that amounts to 11,825 USD. For this reason we can also interpret these figures as opportunity costs.

The values of water for the mining sector are higher than those for irrigated rice, which ranges up to 469 USD/m^3. Combining these monetary values of water marginal productivity with the total annual production of each sector, we are able to scale-up the contribution of water across the different sectors. The last column of Table 8 summarizes this information. As we can see, the mining sector is the economic activity that presents the highest capability of the input water to produce economic value, expressed in monetary terms. In fact, the total contribution of water to the cobalt and nickel sector is, respectively, 66.22 and 648.48 million USD, annually. This corresponds, approximately, to 25 USD per capita, for the total population of Madagascar. Mining products are among the most important commodities that are exported from Madagascar, together with coffee, vanilla and petroleum products. For this reason, water plays a significant role in the exports of these two commodities, and underlying contribution to the Malagasy international trade.

The water contribution to the rice sector is estimated to be 44.45 million USD, annually. When compared to the mining sector this contribution is of a significant lower magnitude. Yet, rice supports livelihoods of about 1.4 million agrarian families in the country, with gross revenue of about 48 million USD. On the other hand, the contribution of water to the total Malagasy economy, measured in terms of its electricity sector, reveals to be smallest magnitude in the study, measured at 0.14 million USD annually. This signals an industrial landscape of economy that is characterized by the use of a wide range of production factors, but where electricity plays a relative minor role. Furthermore, from a household perspective electricity is only benefiting a small proportion of the population as only 4% of the rural areas, such as the CAZ region, has access to electricity.

Finally, we can see that the water contribution to the tourism sector is estimated at 19.04 million USD annually. This result is of particular relevance to the CAZ region. In fact, this economic sector is responsible for the creation of largest share of formal employment in the region.

5.2. Policy uptake

The valuation results play a significant role in terms of macroeconomic, industrial and nature conservation policy. Suppose, for instance, a scenario where freshwater becomes scarce in CAZ. What are the criteria that the policy maker should adopt, in the decision of how using water in alternative allocations? Ultimately, the reply to this question will depend on the profile, or objective function, of the policy maker. For example, how will behave a policy-maker whose industrial policy is oriented towards the support of the sectors generating the highest economic returns? In this scenario, the policy maker may support a re-allocation scheme that involves the transfer of water towards the mining sector, since this sector presents the highest monetary value of marginal productivity, which is estimated up to 648.48 million USD, annually. However, by doing this the decision maker is disregarding all other implications. For example, this policy scenario may involve large transfers of water from the sector generating the highest pro-poor returns, agriculture for this case.

Alternatively, how would policy-maker behave if (s)he supports an industrial policy that concentrates action on the sectors where the water productivity is higher? In this scenario, and in accordance to our value estimates, the policy maker will give preference to water reallocation decisions that involve transfers of water to the rice and tourism sectors. These are the sectors that present the highest marginal productivity, 0.92 and 0.77 respectively. Efficiency is here the key factor for water management. By doing this the decision maker is disregarding other implications, including the fact that water is not the single ecosystem contributing to the economy of the region. And again, this scenario does not take into account any income redistribution aspects.

In addition, the information contained in Table 8 can also be of support towards a nature conservation policy. For example, we can use this monetary information in cost-benefit-analysis of (public) investments on the natural assets that are responsible for the provision of freshwater, including forests. In fact, if you invest in conservation of forest land you are *inter alia* simultaneously investing in keeping the provision of a continued, regular flow of fresh water in the region.[11] In fact, from a cost-benefit-analysis this study highlights the importance of a policy-science based argument supporting the creation of the CAZ corridor, as the annual cost of policy inaction (i.e. no CAZ corridor) will be ranging up to 0.778 billion USD.[12] And this figure should be interpreted as a conservative value of cost of the policy inaction in the area. In fact, the present study, and underlying computations, does only focus at one single ecosystem service and only five selected

[11] The exact magnitude of this impact is an issue of study for natural scientists – see TEEB (2010) for some examples.
[12] This value corresponds to the aggregated value of water across the economic sectors under consideration, i.e. the sum of the last column of Table 8.

economic sectors.

Finally, this information makes now visible the contribution of water in the system of national accounts. It is of particular importance in the domain of sustainable finance, i.e. in netting financial funds and making available these financial resources to the implementation of actions that support sustainable land management practices. This is because the computed monetary values are indicators in line with the principles of national accounting. They also show the annual returns of an investment in a natural asset, such as forest area, that ultimately is responsible for the supply of the ecosystem service.[13] In particular, the computation of this economic indicator is of crucial importance in the implementation of climate finance, and underlying promotion of climate adaption actions, including the financial support to the conservation of forest areas. In fact, this argument is mostly welcome in the design of REDD+ finance instruments.[14] Moreover, the recent Paris Agreement re-invigorates the importance of climate finance, and the role in supporting ecosystem based adaption action to climate change. Therefore, this study clearly shows a significant contribution of water to the Malagasy economy and therefore supporting the investment in the natural assets that secure a continued, and regular flow of fresh water in the region.

The valuation methodology proposed in the study, however, does not shed light on the spatial distribution of the computed benefits. In this perspective, we need to supplement the information with a more detailed economic study that explores the use of spatial-econometric valuation tools and understand with rigour the distribution of costs and benefits. Such additional step should include *inter alia* the identification of the impacted communities; identification of the ‘winners’ and ‘losers’; and the identification of possible solutions to redistribution problems. For example, one could think of an accompanying mechanism that directs new funds to ecosystem services support activities in the communities that are identified as ‘losers’. In addition, this study is only addressing a limited number of economic sectors, as identified as key sectors in this pilot work and is only accounting for only one ecosystem service (freshwater supply) in the region. The discussion of trade-offs, economic values and investments programs generally involve the consideration of more than one ecosystem service. For this reason the discussion of the above policy does not consider trade-offs with other natural resources/ecosystem services, nor the full set of economic sectors that consume water, at the national level. Finally, from the technical view point it is also very important to note that our results are contingent on the observed market prices. In this context, one should highlight, for future research work, the focus on sector studies that understand price formation of selected goods and services. Dasgupta (2012), for instance, proposes an estimation method for environmental shadow prices. These are modelled as functions of both market prices and social value of the net externalities. Environmental shadow prices, then, are used for the subsequent estimations of the monetary value of the ecosystem under consideration.

Despite all the mentioned limitations, the study represents a solid piece of information in shedding light on the monetary value generated by water in different economic sectors in Madagascar. As the monetary metric is expressed in terms of price of the transaction, the estimated magnitudes are measured in accordance to the principles of the national accounts and can, therefore, be compared with other information that is available in the Malagasy national accounting system. Finally, the research contributes to the implementation of the SEEA-Experimental Ecosystem Accounts in Madagascar, which presents a pivotal information role in supporting the implementation of sustainable land and forest management practices.

[13] This argument does not mean that one should not invest in a natural asset where this indicator is not available. It means that once this indicator is present, we may have one additional argument to invest, a solid research-based policy advice argument to invest.

[14] The goals of this initiative are to reduce deforestation and enhance the capacity of the communities to manage natural resources, while protecting biodiversity and water resources important for downstream production. In Madagascar, the REDD+ initiative is already taking place on more than 425,000ha of rainforest, is one of the key elements that, in 2005, led to the designation of the CAZ as an official protected area. The CAZ REDD+ initiative is under the leadership of the Malagasy government and was the first REDD+ project to receive the support of the World Bank's BioCarbon Fund (Harvey et al., 2010).

6. Conclusions

The paper contributes to the ESs valuation literature by empirically testing an applied, micro-econometrics based methodological framework that assesses the economic productivity of water in market activities. The strengths of our proposed methodology refer to the strong economic theory foundations of the proposed exercise. In addition, our proposed methodology is in alignment with the SEEA approach. Therefore, the values of this exercise can be directly compared with the figures of national accounts and national sectorial balance sheets. But most fundamentally, the empirical findings helps us understanding the value of water in its alternative uses as key to fostering informed debate on water management. In particular, understanding the value of water is crucial in rural-based regions, where agriculture competes with other sectors and water re-allocation decisions need to be studied from the economic, ecological and social views points. In fact, water re-allocation actions that involve large transfers of water from the sector generating the highest pro-poor returns (agriculture for this case) to the sectors generating the highest economic returns (industrial for this case) will not produce the necessary policy-relevant consensus, and subsequent implementation of a sustainable development in line with the recently adopted SDGs. If we make an analogy to the English fairy tale “*The Story of Jack Spriggins and the Enchanted Bean*" (1734) – best known as “Jack tales” –, Jack has believed (and empirically experienced) that ecosystem services (the beans) can produce considerable value. As economists and econometricians, in this study we attempted to measure how much.

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