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An assessment of the metabolic profile implied by agricultural change in two rural communities in the North of Argentina

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Abstract The soy expansion model in Argentina generates structural changes in traditional lifestyles, which can be associated with different biophysical and socioeconomic impacts. To explore this issue, we apply an innovative method for integrated assessment—the multi-scale integrated analysis of societal and ecosystem metabolism framework—to characterize two communities in the Chaco Region, Province of Formosa, North of Argentina. These communities have recently experienced the expansion of soy production, altering their economic activity, energy consumption patterns, land use and human time allocation. The integrated characterization presented in the paper illustrates the differences (biophysical, socioeconomic and historical) between the two communities that can be associated with different responses. The analysis of the factors behind these differences has important policy implications for the sustainable development of local communities in the area.

Keywords Societal metabolism · Soy expansion · Chaco · Biophysical accounting · Rural development · Multi-scale integrated analysis · Land-time budget analysis

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1 Introduction

Agriculture is a very important sector for Argentina, accounting for around 10 % of GDP and approximately 60 % of exports (CIA 2009; FAO 2010). The sector has been undergoing major changes over the last decades related to the expansion of soy.

The model of soy expansion currently present in Argentina and Brazil implies boosting consumption of different inputs such as machinery, oil, fertilizers and transgenic seeds (Pengue 2005; Arizpe et al. 2011). Associated changes in land use imply impacts in sociocultural lifestyles and biodiversity and pose a threat to food and energy sovereignty (Altieri 2009). The boom is reflected by the fact that the area under soy cultivation in Argentina has increased from 6.9 million hectares (Mha) in the 1990s to 19.7 million ha in 2012 (Goldsmith et al. 2004; IADB-Garten Rothkopf 2007; Mathews and Goldsztein 2009; Tomei and Upham 2009). This expansion of arable land has meant that since the introduction of genetically modified soy in 1996, the country has tripled soy production, with an average of 40 million tons of grain in 2008. This was also achieved by increasing yields, from 2,105 kg per hectare in 1996 to 2,826 kg in 2008 (Negri 2008). Expansion of agricultural area for soy has meant larger deforestation and habitat loss during the last century (MSyA and UNEP 2004; Zak et al. 2008). Argentina and Brazil produce approximately 90 percent of world soy supplies (Mathews and Goldsztein 2009).

The production of soybeans became completely transgenic in Argentina in 2008. This fast expansion in GM soy resulted in several (positive and negative) impacts such as increasing yields, reduction in farm jobs, increasing monetary flows associated with crop production, increasing pressure on traditional “marginal” and non-colonized areas, forest clearings, biodiversity losses, carbon releases from both soil and biomass stocks, loss of traditional, mixed agricultural systems and a decline in agricultural diversity, among others (Qaim and Traxler 2005; Morello et al. 2006; Monti 2008a, b; Zak et al. 2008; Tomei and Upham 2009; Pengue 2009b).

The expansion of soy is supported by government inaction that assumes that large-scale soy mono-crops can be sustainable (García-López and Arizpe 2010). At the moment, however, there is no large-scale national policy or plan for guaranteeing the long-term sustainability of agriculture within which the expansion of soy may be regulated. In this situation, markets are determining the direction of agricultural development pushing for intensification and exports, which have increased the sector’s vulnerability to fluctuations in external markets (Tomei and Upham 2009).

At the regional scale, the main areas under transformation in the country are the Pampas and the Chaco region in the North of Argentina (Pengue 2009a). Recent processes of rapid deforestation have been described in the Chaco forest in Bolivia, Paraguay and Argentina (Grau et al. 2005; Boletta et al. 2006; Zak et al. 2008; Gasparri and Grau 2009). Waterway Paraná Paraguay promotes agricultural expansion due to irrigation potential and facilitates the expansion of the soy model to the north of the country (Pengue 2009a). Currently, an agricultural pressure exists in the Chaco region where our case studies are located. There is a high demand for new land for soy production that implies a major change in production systems. This change is characterized by technology to intensify production and the adoption of new economic, productive, financial and cultural models that are not characteristic of this region (Pengue 2005). This expansion has led to a rise in the number of conflicts in the North of Argentina, mainly in poor communities, and due to limited access to land by peasants (EPRASOL 2008). It has also contributed to deforestation, displacement of peasants and farmers, increased demands on water, soil degradation and pollution.

The aim of this article is to characterize and analyze the land-time budget analysis of two rural communities, described at the local scale within the context of soy expansion to new areas in north Argentina. The quantitative information is obtained by applying the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) framework. The resulting integrated characterization is used to individuate relevant changes experienced by the two communities because of the soy expansion and to study the differences between the two communities due to their distinct responses.

In this work, we build on Gomiero and Giampietro's work, along with land-time budget analysis (Pastore et al. 1999; Gomiero and Giampietro 2001; Giampietro 2003; Grünbühel et al. 2003; Grünbühel and Schandl 2005), and compare the societal metabolism of two rural communities in the north of Argentina, with the main objective of providing sound information that will allow the comparison of various attributes relevant for the sustainability of the models of development. That is, the resulting integrated analysis makes it possible to explore the farming household's interaction with natural resources in order to identify economic and ecological constraints and development opportunities. With this study, we want to better understand the ongoing process of soy expansion in the region and its repercussions in traditional farming practices and standard of living.

The structure of the rest of the paper is as follows. Section 2 presents the theoretical framework, followed by Sect. 3 with data and methods, and Sect. 3.3 area of study. Then, the main results are shown in Sect. 4. Section 5 presents a discussion and also offers some concluding remarks.

2 Theoretical framework

2.1 The conceptual basis of the MuSIASEM

Studying sustainability entails the challenge of how to properly perceive and represent a process that requires the simultaneous adoption of different dimensions and scales of analysis (Giampietro 2003). For this reason, sustainability analysis requires the integrated use of non-equivalent descriptive domains and non-reducible models that have to be periodically updated and substituted (Giampietro et al. 2006a, b, c). Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) is a tool that fulfills the two challenges.

A key theoretical concept of the MuSIASEM approach is the incorporation of the flow-fund model proposed by Georgescu-Roegen (1971, 1975) for representing, in biophysical terms, the socioeconomic process of production and consumption of goods and services. The flow-fund model makes it possible to carry out quantitative analysis of complex systems organized across different hierarchical levels and scales. In fact, following Giampietro et al. (2011), we can say that, according to the chosen representation of the process, flow coordinates are elements that enter but do not exit the production process (e.g., an input used in production)—in the time horizon of the analysis—or, conversely, elements that exit without having entered the process (e.g., a new product). Flow coordinates refer to matter and energy in situ, controlled matter and energy and dissipated matter and energy. Fund coordinates (capital, labor and Ricardian land) are agents that—in the chosen time horizon of the analysis—enter and exit the process, transforming input flows into output flows. Put in another way, the identity of the fund elements remains the same during the analysis. Fund elements require a given overhead for their own maintenance and reproduction and do entail a constraint on the rate of their associated flows. That is, we can define a range of values for the pace of conversion of the flows they control.

In this paper, we focus on two fund elements:

1. Land—this makes it possible to study the interface between colonized land (land uses whose characteristics depend on human agency) and non-colonized land (land covers whose characteristics depend on the identity of local ecosystems) and
2. Human time—this makes it possible to study structural (demographic) and functional (socioeconomic) changes in the allocation of human activity within the communities.

We also consider two main flow elements:

1. Monetary flows—this makes it possible to interface the biophysical analysis with economic analysis.
2. Biomass flows—this makes it possible to interface the biophysical analysis with both economic and agronomic analysis.

It should be noted that in this paper we do not include other biophysical flows (energy, water and other key materials—e.g., soil erosion, cement for construction) in the characterization of the metabolic pattern, since at the chosen level of analysis—the community level—they do not result relevant for the purpose of our analysis.

2.2 The multi-scale view

By implementing the flow-fund model, within the MuSIASEM approach, it becomes possible to develop a quantitative accounting of flows across different hierarchical levels and scales (Giampietro and Mayumi 2000; Pastore et al. 1999; Gomiero and Giampietro 2001; Giampietro 2003; Giampietro et al. 2011). In particular, when dealing with the analysis of farming systems, we can define "metabolic units" [autopoietic systems capable of reproducing themselves when operating in favorable boundary conditions—Giampietro et al. 2011] at different hierarchical levels: households, communities and municipalities. In this paper, we have chosen the community as focal level—which is level n in the figure applied to our case study. The characteristics of the community are affected by upper-level constraints (the characteristics of the municipality to which the community belongs—level $n + 1$), and its behavior is the result of the initial conditions determined at the lower level. In particular, the characteristics of a community are determined by the household typologies (defined at the level n-1 and the profile of distribution of instances of these typologies within the community.

Because of this choice of focal hierarchical level, this paper focuses on the main differences in the pattern of land uses and the pattern of human activity, expressed at the community level, between the two communities analyzed, La Primavera (*Potae Napocna Navogoh*) and Tacaaglé. In a forthcoming paper, we provide the same type of analysis carried out at the level of lower-level components (i.e., households) of those communities.

3 Methods, data and study area

The research was carried out in four phases: (i) an extensive literature review on social, economic, environmental and political aspects associated with soy cultivations at the regional and global scale; (ii) tailoring MuSIASEM to the local reality; (iii) fieldwork for gathering data (between September 2008 and March 2009, and again September 2012); and (iv) data integration and analysis by applying the MuSIASEM approach. The two communities are located at the east of Formosa's province in the North of Argentina.

In Fig. 1, we can identify the different activities involved in the methods and data gathering.

3.1 Methods

As a part of MuSIASEM framework, the land-time budget analysis considers categories to characterize the fund elements land and human time. In the case of land use, we started with a study of land use changes made by the Ministry of Forests (Naumann and Madariaga 2003) with data from fieldwork activity (2008–2009). We use the categories presented in Giampietro (2003):

$$\mathrm{TAL} = \mathrm{LU_{NC}} + \mathrm{LU_{SC}} + \mathrm{LU_{COL}}$$
$$\mathrm{NCL} = \text{National Park, RAMSAR sites (wetlands) and water bodies}$$
$$\mathrm{COL} = \mathrm{LU_{agr}} + \mathrm{LU_{liv}} + \mathrm{LU_{infr}} + \text{others}$$
$$\mathrm{LU_{SC}} = \text{LU semicolonized}$$

where TAL stands for total available land (or availability), which includes both colonized and non-colonized, and it conforms the land budget for the system analyzed. NCL stands for non-colonized land. COL stands for colonized land and comprises the various categories of land uses under direct control of humans—e.g., colonized land for agriculture (agr), livestock (liv), infrastructure (infr) and others. $\mathrm{LU_{SC}}$ stands for semi-colonized land. Examples are land for hunting or gathering. $\mathrm{LU_{agr}}$ can also be split in two subcategories: subsistence agriculture and industrial agriculture that is focused on expansion of soybean or cotton cultivation. $\mathrm{LU_{infr}}$ is mainly land use for the dwelling and includes the constructed area as well as the surrounding area for keeping poultry and pigs.

Regarding human time use, we build on previous work to select the set of categories relevant for our study (Giampietro 2003; Pastore et al. 1999). Total human activity (THA) is the total human time a society has available for conducting all the activities and is measured in hours. It equals population times 8,760 h. THA can be split into different subcategories according to the specific activity:

- Time for physiological activities (physiological overhead) $\mathrm{HA_{PO}}$, referring to the accumulated number of hours for sleeping, eating and personal care.
- Time spent on unpaid work ($\mathrm{HA_{UW}}$), including the number of hours used in maintaining the household, such as cooking, cleaning, going to the store and childcare.
- Time allocated to paid work activities ($\mathrm{HA_{PW}}$), i.e., the number of hours that are related to the market.
- Time for mobility and transportation ($\mathrm{HA_{TR}}$).
- Time for leisure and recreation activities ($\mathrm{HA_{LE}}$).

Therefore

$$\mathrm{THA} = \mathrm{HA_{PO}} + \mathrm{HA_{UW}} + \mathrm{HA_{PW}} + \mathrm{HA_{TR}} + \mathrm{HA_{LE}}$$

The land-time budget analysis (LTB) integrates the previous analyzes of time and land aggregating the information at a given hierarchical level: either the land-time budget of a household (at the level $n - 1$) or the land-time budget of the community (at the level n).

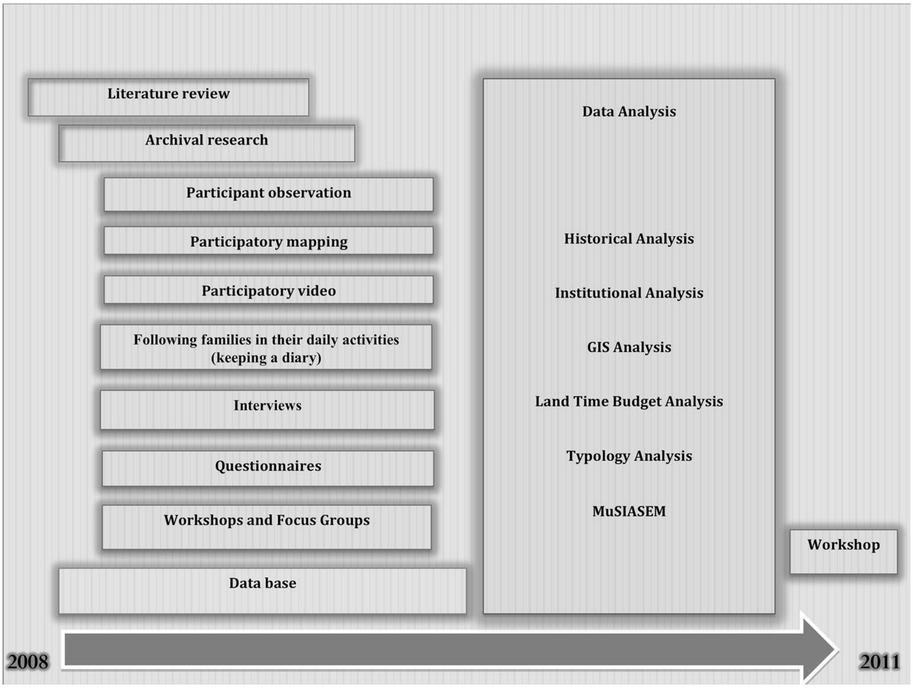

Fig. 1 Methodological diagram

The analysis of land-time budget can be integrated with an analysis of flows—e.g., monetary and food flows—providing useful information for sustainability analysis.

The dendrogram of human activity (Fig. 5) starts with total human activity (THA). This initial amount of human activity is then divided into "physiological overhead" (POHA) and "human activity disposable fraction" (HADF); the society allocates a certain fraction to its own reproduction. This fraction includes leisure, education, social life and events. This fraction of human activity belongs to the category leisure and education (L&E), which should be considered as a sort of "societal overhead" on labor time as this amount of hours of human activity is not directly used to perform economically productive activities. The remaining of HADF is included in the category "work time" (HAWork) which is allocated to a number of economic and household activities: off-farm work (agricultural companies or industries outside the community), cash cropping (harvesting for profits), subsistence farming (agriculture, livestock, hunting and gathering) and household chores (all household activities not related to food production).

The dendrogram of allocations of hectares of colonized land starts with total available land (TAL) in the box on the upper right side. In our accounting system, the TAL of the community is defined by the administrative boundaries of the system. Of the total amount of land that can be used by the community (the total budget), there is a first fraction that is not used productively by the society. This non-colonized land (NCL) can also be considered as the ecological overhead of available land. This label suggests that a portion of available land should be preserved from human exploitation, because of some sort of social agreement, justified either by the need of conservation, religion taboos, or by the cultural traditions. The remaining land is included in the category of "colonized land" (COL), which refers to all land used productively by the society. This category is further subdivided into land not in agricultural production (LNAP) and agricultural land (LIP). Forests provide firewood, construction material, food and marketable products. Agricultural land (LIP = land in production) comprises fields, pasture, fallow land and gardens. Within agricultural land, it is possible to distinguish between land for commercial production (LIP$) and subsistence land (LIPsub). The proportion of the land in the category LIP$ can be further allocated to different categories of land use (and concurrent categories of human activities): for cash crops, productive land used to cover taxes and productive land used to cover technical inputs (self-produced inputs, such as seeds, or purchased inputs, such as fertilizer, tools and machinery). This category makes it possible to individuate a final division in Fig. 5 between land that produces net disposable cash (L-NDC) and land that is producing monetary flows needed to pay taxes and inputs (L-pay inputs).

At this point, this quantitative information makes it possible to calculate for selected categories both (i) density of flows per hectare of specific categories of land uses (e.g., food per hectare, added value per hectare) and (ii) intensity of flows per hour in specific categories of human activity (e.g., food per hour of labor, or added value per hour of labor). These values can be used for comparison and to generate benchmarks, making it possible to assess the performance of rural communities, in relation to different criteria.

3.2 Data collection

The socioeconomic, cultural, territorial and agricultural data come from the databases of the Ministry of Finance, Ministry of Agriculture, National Institute of Statistics and the Province of Formosa. Existing maps were complemented with participatory mapping for the area under study. Due to the lack of information at the local level, questionnaires and in-depth interviews were used to complement the available data when needed. The software used to compile and analyze information was Excel 2003 for data organization, SPSS for statistical analysis and ArcView 9.2 and Google Earth for GIS analysis. The number of questionnaires applied is 26, out of 71 households in Tacaaglé, and 43 out of 446 households in La Primavera. The questionnaires[1] were completed in the presence of the interviewer. The in-depth interviews were the same number as questionnaires and lasted about 3 h each.

The fieldwork had two principal goals: (i) identification of the case studies, better definition of the sample as well as identification of both the main conflicts and needs of the communities (ii) data gathering in relation to the different dimensions of analysis (economic activity, land use, time use, etc.).

To fulfill these two goals, an integrated set of research activities was carried out in 6 months, with the first author living in the two communities. These activities can be described using different labels: (a) action research (Bryman 1989), (b) participant observation (Rusell 2009; Bryman 1989), (c) participatory mapping to identify the different land uses associated with the perceptions and narratives of the locals (NOAA 2009; FIDA 2009), (d) time use analysis, following families in their daily activities keeping records in diaries and (e) in-depth interviews, semi-structured interviews and structured interviews (Bryman 2008).

[1] The questionnaire applied can be found in supplementary documents.

3.3 Area of study

Case study research entails the detailed examination of one or a small number of "cases." Since our unit of analysis is the community level, we considered two rural communities that share similar problems, such as the expansion of soy cultivation, and similar ecological conditions. A key difference however is the history and culture of the population. Tacaaglé, which is located in the Pilaga Department in the Formosa Province, is populated mostly by non-indigenous people immigrated mainly from Argentina and Paraguay, whereas La Primavera "Potae Napocna Navogoh" located in Pilcomayo Department has an indigenous[2] population, called *Qom,* although their popular name is Toba. Both communities are located in the Formosa Province in Argentina, and each of them has a surface area of approximately 5,500 hectares.

The Tacaaglé's community is composed of two rural communities ("25 de Mayo" and Carpinteria) comprising 71 households. La Primavera "Potae Napocna Navogoh" has *Qom* population and consists of 446 households.

Two different cultural backgrounds are reflected also in the demographic evolution of the two communities under analysis. Whereas La Primavera, home to a *Qom* indigenous group, who used to be nomadic just 100 years ago, shows no fast population growth and consequent crowding, reflecting an adaptation to the limited declared aboriginal reserve area, Tacaaglé, settled by Paraguayan-Argentinean migrants who were mostly engaged in agriculture and livestock, shows rapid demographic growth.

Rural development in the province of Formosa, where the study cases are located, has been based in the past on cultivation of cotton, which was very important in the 1970s, but has since been replaced, by other crops and livestock. Another historically important activity is livestock, which takes advantage of the natural pastures of the region. From a demographic perspective, the province has been inhabited by different indigenous groups that found refuge in this "bleak" land after the *desert war (that took place in 1880)*. It was not until 1920 that Paraguay and Argentina began to systematically colonize this area. Indigenous and *criollos*[3] do not mix neither in social nor in financial terms.

Figure 2 shows the location of the two case studies.

Demographic data were collected distinguishing five age groups (<5; 6–11; 12–17; 18–65; >65) and gender (male/female). Existing official population data came from the National Census of Population and Housing in Argentina (INDEC 2001). The census only offered figures at the municipal level, combining rural and urban population corresponding to the municipalities of Misión Tacaaglé (2,034 inhabitants in total, including the two rural communities "25 de Mayo" and Carpintería) and Laguna Blanca (6,508 inhabitants, including also the indigenous community La Primavera).

Since the census did not give information at the community level, we had to estimate population. In the case of La Primavera, we followed Iñigo (2008) who estimated 800 families and 3,800 people—based on interviews carried out in 2005. Recent studies increase this number up to the range between 4,600 and 5,000 people. In the case of Tacaaglé, for the communities of Carpintería and 25 de Mayo, data from the Peasants Movement in Formosa (MOCAFOR) survey and the Social Agricultural Program indicated a population size between 255 and 284 people (interview data). Table 1 resumes the main indicators of the population and land in both communities.

[2] Argentina does not officially use the term 'indigenous', but rather 'aboriginal' population. We use the term indigenous, which is more frequent in Latin America.

[3] The indigenous called criollos to the inhabitants that colonized their land.

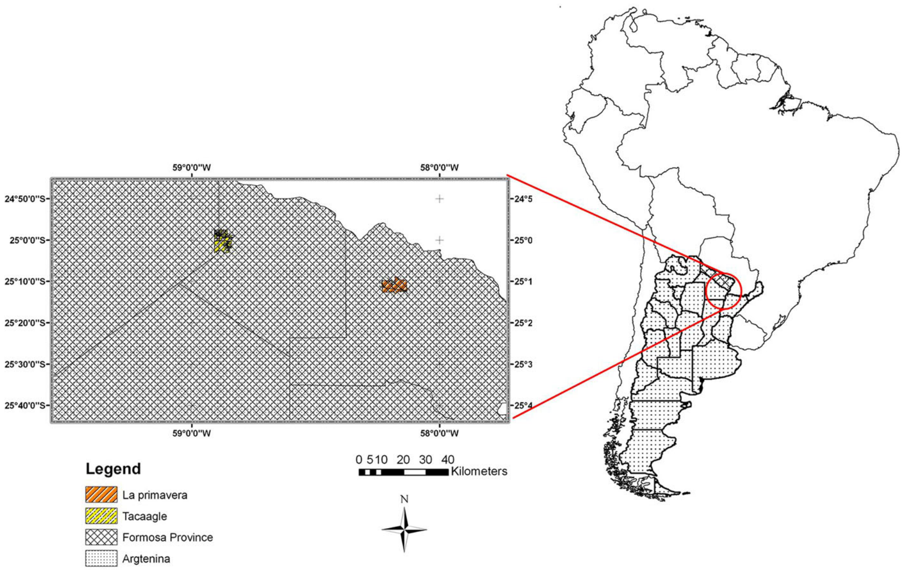

Fig. 2 Map of the study area

Table 1 Characterization of the communities in terms of population, land and density

Communities	No. inhabitants	No. household	Total land (Ha)	Density (pop/100 Ha)
La Primavera	3,122	446	5,186	60
Tacaagle	284	71	5,576	5

Source Own elaboration. Household Survey, 2009

The main economic activities of the Province of Formosa are related to food production and processing industries. The main crops are cotton, soybeans, wheat, rice, sunflower, sorghum, corn and avocado. They also grow fruits, such as citrus, bananas, mangos and pineapple. Forestry is also of major economic importance, with the main species under exploitation being red and white quebracho, lapachos guayaibí, algarrobo, guaranine, urunday and rosewood. Apart from that, other relevant economic activities are livestock and beekeeping, from which organic honey is produced. Finally, some oil extraction occurs in the west of the province (Ministerio del Interior 2011).

The two case studies are found between the Glens Forest Chaco and the Lower Rio Paraguay. As an example of their ecological value, National Park Rio Pilcomayo (sharing land with La primavera community) hosts 49 species of mammals, 353 species of birds, 28 species of amphibians, 35 species of reptiles and 38 species of fish (Morello and Rodriguez 2009).

4 Results

In this section, we first present the profile of allocation of the fund element land (budget of colonized land across different compartments) and the profile of allocation of the fund element human activity (budget of human activity across different compartments) of the two communities. The different land-time budgets found in the two communities are used to analyze the density (flows per hectare) and the intensity (flows per hour) of monetary and biophysical flows.

4.1 The pattern of land use at the community level

The characterization of the fund element "land use" in the two communities is carried out using three main categories: (i) colonized land—land under human control in which the density and intensity of biomass flows is determined by human agency (high-external input agriculture); (ii) non-colonized land—land covers outside human control in which the density of biomass flows is determined by ecological processes; and (iii) semi-colonized land—land in which human activity does not alter the value of natural processes of production of biomass, based on natural recycling of nutrients (low-external input agriculture). Still human agency prevents, in these categories of land use, the expression of the typology of land cover that would be expected in the area without human interference—e.g., use of natural pasture for seasonal feeding livestock. This category of land is characterized for having more biodiversity than colonized land. Non-colonized land also includes areas of rivers and lakes and the forest, even if used for hunting or gathering. Table 2 summarizes land use distribution.

The profile of distribution of land uses in Tacaaglé's community is shown in Table 2. In this view, we can individuate a small amount of non-colonized land corresponding to the river "Riacho porteño" and the riparian vegetation.

A more articulated analysis can be obtained by adding additional categories of land uses defined within the category of colonized land. Using the definition of colonized land given above, we can define these categories according to the main activity performed there, either related to agriculture or related to livestock.

We begin with total available land (TAL), which is split into colonized land (COL)—the vast majority—and non-colonized land (NCL)—mainly riparian. Colonized land is then split into the main activities, agriculture (37 %), livestock (62 %) and infrastructure (1 %). The main category is clearly livestock, followed by the combined use for agriculture and livestock. We already see that soy is the main cultivar, higher than cotton (another cash crop) and horticulture and fruits (subsistence).

The spatial distribution of actual land uses over the taxonomy of categories is shown in Fig. 3 The map shows small-size producers[4] have a greater diversity of crops, and they also share plots[5] between households. The medium-size producers generally cultivate a particular crop depending on regional market demand. And finally, the large-size producers are distributed in areas closer to the semi-colonized land. It is important to observe that both small- and large-size producers use the semi-colonized land for extensive livestock. In general, this is private land where the owner leases access for grazing to livestock owners.

The profile of distribution of land uses in La Primavera community is shown in Table 2. In this case, non-colonized land consists of a lake and forestland that is currently the focus of a dispute between the community and the Rio Pilcomayo National Park. The community land of the Qom people was included in the National Park in 1951, and since the year 2000, they have lost use rights to the lake for their livelihood.

[4] The small producers have less than 10 hectares.

[5] Every defined area has in general one property that could be one extended family (meaning two or more households).

Table 2 Distribution of land use types

Type of LU	Tacaagle (Ha)	%	La primavera (Ha)	%
Colonized	3,961	71	1,722	33
Semi-colonized	1,599	29	1,715	33
Non-colonized	16	0	1,749	34
Total LU	5,576	100	5,186	100

Source Own elaboration

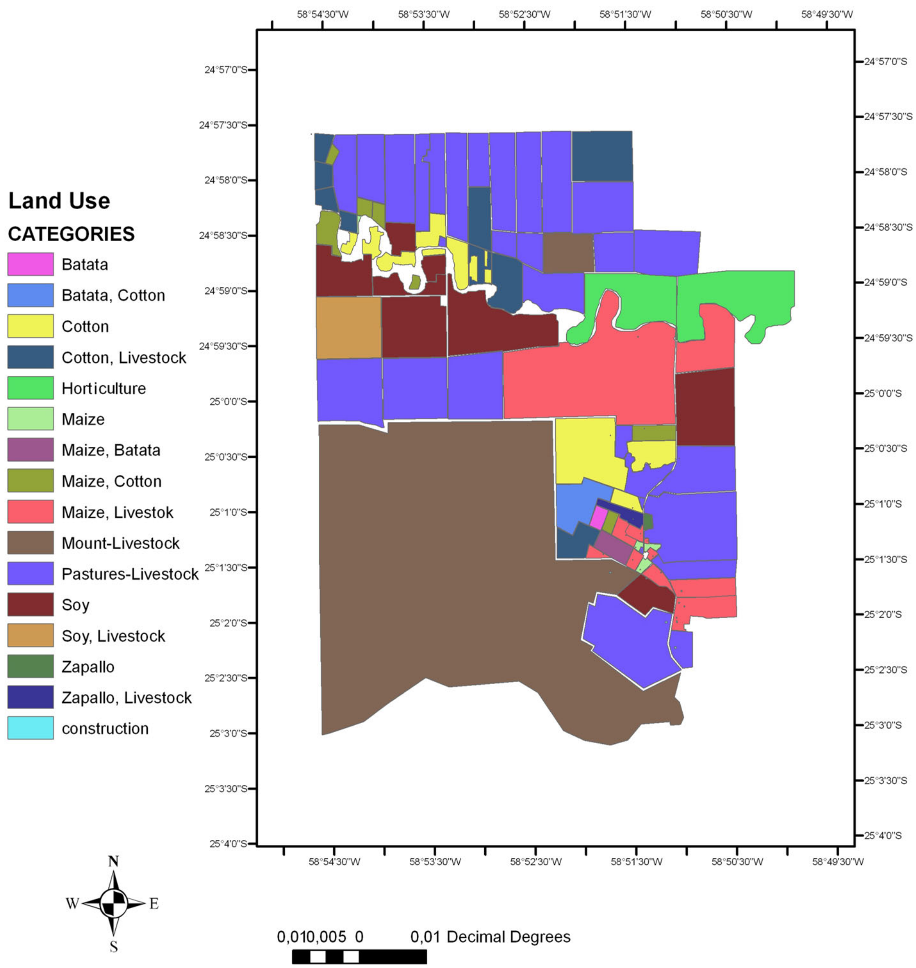

Fig. 3 Map of the land uses in Tacaaglé's community

Although having 90 % more population than Tacaaglé, La Primavera community has a higher proportion of non-colonized land (33.2 %) due to the overlap with the National Park. The community also has smaller plots of land related to their density.

Non-colonized land (30 %) consists of the lake, and other water bodies, as well as wetlands. Colonized land is then split into the main activities, agriculture (30 %), livestock (31 %), forest (8 %) and infrastructure (3 %). The main category is agricultural land and livestock, followed by forest. We already see that soy is the main cultivar, higher than cotton and horticulture and fruits for subsistence. Most of the cotton production has been displaced by soy.

The indigenous population does not use the land for industrial agriculture. They generally rent it to non-indigenous producers. However, they take care of crops and livestock.

The spatial distribution of actual land uses (2008–2009) over the taxonomy of categories is shown in Fig. 4. From this figure, we can immediately see that the spatial distribution of the land use is quite different from that found in Tacaaglé: There is less crop diversity (agriculture) and a major share of non-colonized land or semi colonized land—i.e., wetlands, lakes and forests. The forest land is important to obtain resources such as food (gathering and hunting), fuels (wood) and water. A large area (rapidly expanding) allocated to soy (10 % of arable land) can be identified in the middle of the community.

4.2 The pattern of time use at the community level

The characterization of the fund element "human activity" in the two communities is carried out using the taxonomy of categories defined in Sect. 3.1. In addition to this classification, the information obtained via interviews, at the household level, made it possible to distinguish the different profile of human time allocation of men and women.

As expected, the largest fraction of human time is spent in physiological overhead (47 %)—sleeping, eating and personal care of each individual during the day—followed by unpaid work time (30 %). Within this category, women not only have household maintenance activities, but also contribute to gathering forest products and other farm activities. With regard to leisure time, the assessment includes resting time (e.g., naps after lunch) and cultural activities (e.g., terere or mate).[6] As shown in Table 3, the two communities generally spend little time in paid work (8 %) mostly because they get food from their own "chacras" or government support. Very little time is spent for transport (3 %) although this category is usually important for rural societies where people do not live in nuclear villages.[7]

In Table 3, we can identify the different categories of human activities used to study time allocation (measured in hours/year) and their share (%) of the total. From this comparison, we can see that the amount of human time allocated to physiological overhead is almost the same, with a small difference in sleeping and eating between the two communities.

Human activity in unpaid work includes hours dedicated to the following tasks: subsistence crops (4 %); non-agricultural activities (2 %); household activities (10 %)[8]; and other activities (11 %). In terms of unpaid work, some activities such as hunting and gathering and collection of firewood and water are more important in La Primavera community.

Human activity in the paid work category reveals interesting differences. La Primavera shows a lower proportion of time devoted to paid work; however, commercial agriculture and handicrafts are the main sources of paid work there. In contrast, Tacaaglé doubles the

[6] A traditional drink.

[7] The distribution considers an urban area in the center and the chacras around this area.

[8] Activities mainly related to women's roles such as caring of children, preparing food, cleaning the house.

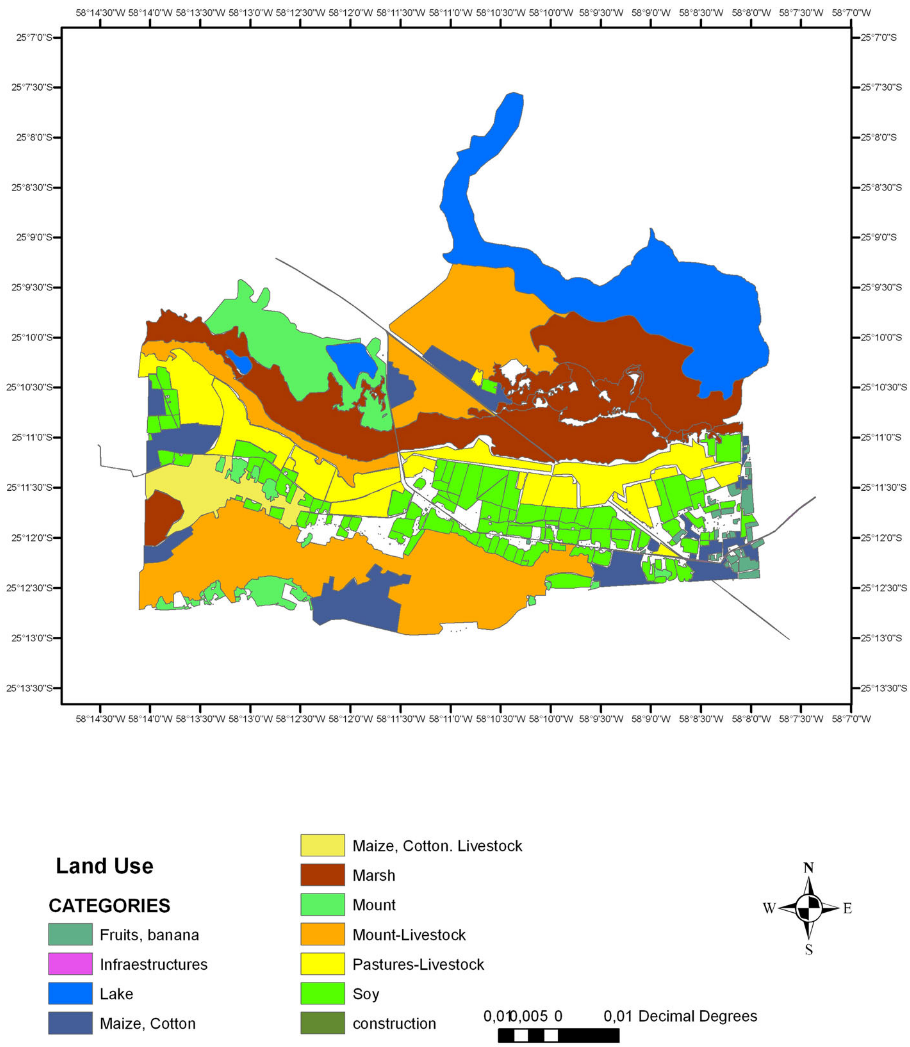

Fig. 4 Map of the land uses in La Primavera "Potae Napocna Navogoh" community

amount of time allocated to commercial agriculture, more than doubles that in livestock and practices no handicrafts at all.

4.3 The land-time budget analysis (LTB): the integrated analysis of the two fund elements "land uses" and "human activities"

The two fund elements "land use" and "human activity" are essential for the reproduction and operation of rural systems. In this way, it becomes possible to couple the two dendrograms of the distribution of fund elements across levels distributed over the same taxonomy of categories (Giampietro 2003; Grünbühel and Schandl 2005) adapted in Tacaaglé and La Primavera communities—as illustrated in Fig. 5 and described in Sect. 3.1.

Table 3 A comparison of the profile of time use in the two communities

	Activities	La primavera		Tacaagle	
		Hr/year	%	Hr/year	%
HApo	Sleep	9,865,871	36.1	856,071	34.4
	Personal care	1,446,098	5.3	147,197	5.9
	Eat	1,488,607	5.4	159,932	6.4
		12,800,576	46.8	1,163,200	46.8
HAuw					
Subsistence crops	Self-land (Chacra)	814,975	3.0	79,512	3.2
	Communal Land	481,151	1.8	10,238	0.4
	Others	14,417	0.1	0	0.0
		1,310,543	4.8	89,750	3.6
Non-agriculture activities	Fishing	64,616	0.2	2,851	0.1
	Food gathering	74,038	0.3	2,851	0.1
	Small farm/tending animals	196,499	0.7	16,797	0.7
	Livestock/tending animals	36,466	0.1	28,302	1.1
	Hunting	214,154	0.8	3,628	0.1
		585,772	2.1	54,429	2.2
THA					
Home activities	Care of children	2,213,812	8.1	207,550	8.3
	Preparing food	226,922	0.8	33,171	1.3
	Cleaning the house	102,091	0.4	15,852	0.6
	Construction	64,590	0.2	3,672	0.1
		2,607,416	9.5	260,245	10.5
Others	Collecting firewood	399,698	1.5	12,279	0.5
	Collecting water	435,742	1.6	5,701	0.2
	Educational	1,582,708	5.8	179,120	7.2
	Health	304,058	1.1	22,298	0.9
	Communal gatherings	309,768	1.1	10,753	0.4
	Buying/shopping	260,093	1.0	22,637	0.9
		3,292,066	12.0	252,788	10.2
		7,795,797	28.5	657,212	26.4
HA_{pw}	Handicraft	138,756	0.5	0	0.0
	Comercial agriculture	391,694	1.4	71,854	2.9
	Livestock	52,735	0.2	41,395	1.7
	Others	203,295	0.7	15,611	0.6
		786,480	2.9	128,860	5.2
HA_{le}	Play	2,622,388	9.6	246,430	9.9
	Terere	784,321	2.9	72,562	2.9
	Friend/familiar visiting	826,747	3.0	78,263	3.1
	Religious activities	985,693	3.6	81,709	3.3
		5,219,150	19.1	478,964	19.3

Table 3 continued

	Activities	La primavera		Tacaagle	
		Hr/year	%	Hr/year	%
HA_{tr}	Buying/shopping	231,113	0.8	20,214	0.8
	Health	327,289	1.2	21,509	0.9
	School	76,918	0.3	8,552	0.3
	Others	111,398	0.4	9,329	0.4
		746,718	2.7	59,605	2.4

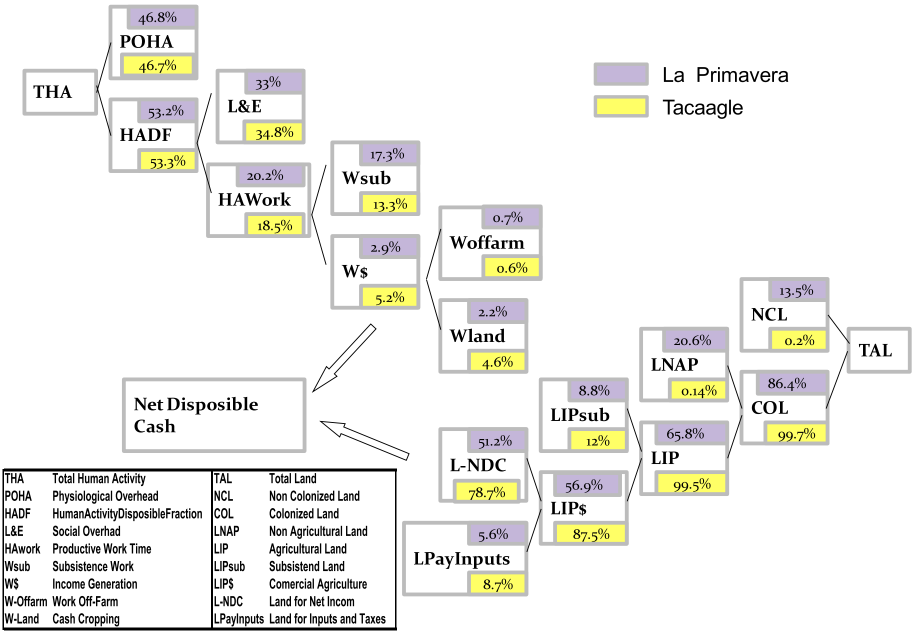

Fig. 5 Land-time budget analysis

By using these categories, it becomes possible to generate more effective comparison among the communities, for example we can observe both communities in the upper level, the human activity for POHA and HADF, have similar patterns. In the case of land use, La Primavera has major NCL and minor arable land for farm production. La Primavera has major Wsub that implies customs like fishing, hunting, collecting fire and collecting water. Tacaaglé has 35 % more LIP and major W$ that implies 25 % more L-NDC.

The accounting of monetary flows has been done using the same taxonomy of categories used for the land-time budget. This choice is required to make it possible to generate two sets of ratios flow/fund elements characterizing the specific metabolic pattern of the two communities.

The monetary flows (US dollars/year) are measured in US dollars 2008. The data are organized in 4 main categories: (i) total production at the community level; (ii) the fraction of farm production self-consumed by the community; (iii) the fraction of the production sold outside; and (iv) flows of subsidies. It should be noted that in this way, we are assessing two categories of monetary flows: (i) cash flow and (ii) the economic value of the goods consumed in subsistence.

By looking at these data, we can see that Tacaaglé community has a greater share of traditional agriculture, barnyard and livestock, as well as higher farm consumption. La primavera, on the contrary, focuses on industrial agriculture (soy), and an important share of their income comes from renting land to companies.

The total crop production in the two communities, estimated for the year 2008, is shown in Table 4. Such estimation has been obtained by combining information gathered via questionnaires to producers, fieldwork records and land use analysis. We have converted crop production into energy units using conversion factors from FAO statistics. This allows us to assess the degree of self-sufficiency by comparing production with consumption.

The metabolic pattern of the Tacaaglé community is shown in Fig. 6, which summarizes the results that have been presented earlier for time use, land use and monetary flows. The breakdown of the total human activity of the community into different compartments (associated with functional tasks) is indicated in the left pie. Besides the human activity going into work in agriculture (cash crops; subsistence and off-farm work), most of the human activity goes in physiological overhead and household chores, plus the residual of human activity going into leisure. The breakdown of the total colonized land (including the semi-colonized) of the community is given in the pie on the right. Plots in Tacaaglé are small, ranging from 2 to 10 hectares, while in the 25 de Mayo community, producers are mostly medium-sized who specialize in some type of cash crop to be sold in the regional market.

The monetary flow accounts for all earnings obtained in the community from working activities are performed outside the agricultural sector or by renting out land. The combined input of monetary flows makes it possible for the community to buy goods and services from the market.

The metabolic pattern of La Primavera community is shown in Fig. 7. Most of the land for agriculture and livestock is generally rented. Indigenous population tends to rent the land to companies and work for them. Ninety percentage of livestock does not belong to the indigenous. They simply take care of it, on behalf of the owners, and they get wages in exchange, plus some cattle as food. This represents a large amount of cash flow, as compared to that of Tacaaglé, to which significant amounts of subsidies from the government have to be added. These large amounts, however, are quite low if we compare them with the profits of soy companies. The community receives less than 10 % of those profits.

Profits from the sale of agricultural production are not kept within the community La Primavera, since they only rent the land. Coming to a comparison of the allocation of human activity with Tacaaglé, they spend less time in working on farm, which in any case is a new activity for this historically hunter-gatherer community. We can also see that an important fraction of the total earnings goes to buying goods and services from the market. The time allocated to transportation is significant because there is no access to public transport, while the communities are dispersed and 5–20 km is a normal travel distance to the next market, hospital or school. The growing income, however, is increasing now the use of motorcycles or bicycles.

The difference of flows and funds of the two communities can be seen in the Figs. 6 and 7. We can observe in the flow of agricultural production sold outside that La Primavera has 70 % less agricultural production than Tacaaglé. La Primavera has a flow of soy

Table 4 Energy production in the Tacaaglé and La Primavera"Potae Napocna Navogoh" communities

Products	La primavera			Tacaagle		
	Production T/year	Production 10kcal^3	Community consumption %	Production T/year	Production 10^3kcal	Community consumption %
Maize	710	504,508	80	660	1,963,263	100
Sweet potatoes	–	–	–	1,272	1,091,999	70
Vegetable(pumpkins)	8	2,223	30	127	33,658	70
Bananas	109	61,679	20	2,620	1,000,829	30
Cottonseed	250	–	–	716	–	–
Soybeans	1,489	–	–	1,201	–	–
Bovine meat	105	241,386	10	187	451,710	50
Poultry meat	2	3,128	100	3	4,164,911	80
Pig meat	–	–	–	2	6,402,529	50

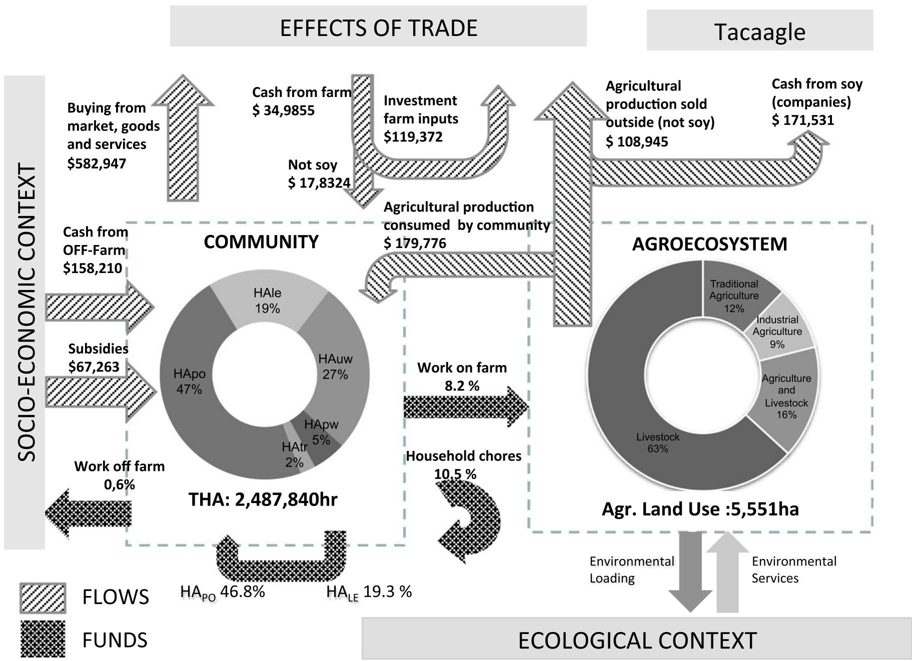

Fig. 6 Metabolic pattern of the Tacaaglé community

production that is about 80 % more than Tacaaglé; thus, soy expansion has become more evident in the community of La Primavera. The flow buying from market, goods and services is observed that La Primavera community is more dependent than Tacaaglé community. By looking at these data, we can see that Tacaaglé community has a greater share of traditional agriculture, barnyard and livestock, as well as higher farm

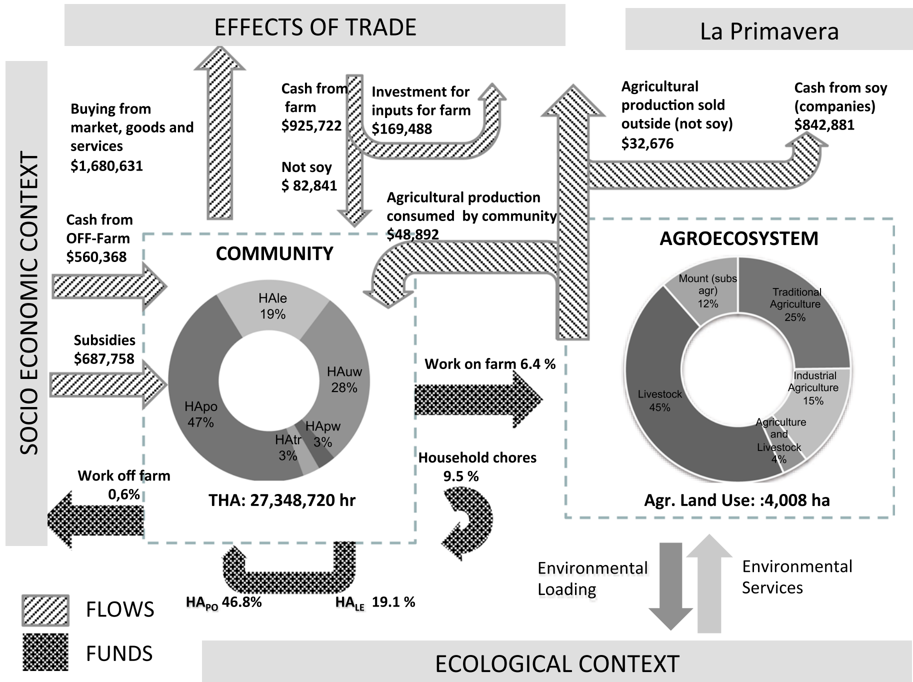

Fig. 7 Metabolic pattern of La Primavera "Potae Napocna Navogoh"community

consumption. La primavera, on the contrary, focuses on industrial agriculture (soy), and an important share of their income comes from renting land to companies.

The funds of time use shows more work time in agricultural activities in the community of Tacaaglé, and La Primavera has a higher percentage of unpaid labor, mostly by women.

Flows and funds that are not evident are due to different profiles of household types; for a better understanding, it is essential to make a household-level analysis that is discussed in another paper (Arizpe et al. 2012), which will give more details of the differences between different household typologies.

5 Discussion

In this paper, we tested the usefulness of the MuSIASEM approach as an integrated analysis tool to understand the effect of changes induced by the expansion of soy monoculture over two rural communities operating in the north of Argentina. MuSIASEM can be used to establish a bridge between different dimensions of analysis (interfacing socioeconomic variables with ecological and biophysical variables) and different scales of analysis (the local-scale characterization of households and communities can be related to variables and benchmarks referring to regional or national analysis).

From our case studies, we identified first the rapid expansion of transgenic soy and cotton monocultures in the north of Argentina. The LTBA demonstrates that the introduction and expansion of soy production has altered the pattern of human time use in both communities. Tacaaglé has seen a disassociation with the production process—landowners preferring to hire equipment or lease land. This contrast with the attitude they used to have with respect to cotton production, where landowners were more involved and were responsible for all activities associated with production. In La Primavera, this disassociation with the production process is even more pronounced as they used to be nomadic hunter-gatherers who have been confined in a protected area. As a result, they just rent their land, although at a much lower price, and perform no further activity on that land. This means that their dependence on the market for sustaining their metabolism is larger, and this gets reflected in their land use, as can be seen in land use diagram of metabolic profile land uses, visualizing the reduction in forest land, and increase in industrial land.

Second, multi-level analysis makes it possible to individuate the relations that flows have with fund elements at different scales and levels of analysis. For example, soy monocultures certainly boost the monetary flows associated with a hectare of colonized land. However, when looking at the metabolic pattern of the community, we can clearly see that the larger cash flow does not remain with (=it is not spent by) the rural communities. This is seen in the case of La Primavera in Fig. 7 by the cash flow from soy and agricultural production. Also we can identify in La Primavera that the change of land use from forest to extensive agriculture implies less human activity; they do not have access to subsistence food (for example, gathering and hunting); also the greatest gains are for the companies. La Primavera community shows a higher share of work time even though not necessarily agricultural work. In fact, hunting and gathering are time-intensive activities. In relation to this categorization, Tacaaglé community has a larger fraction of human activity dedicated to working the land, which is the main source of income. In terms of land use, this translates into a structure of small- and medium-size plots.

Some issues to considered in MuSIASEM framework is the complexity of societies and the patterns of the communities; for example, in our analysis, we found two communities operating within the same region, but totally different in cultural aspects and still expressing similar land uses.

Second, the versatility of the framework in field work makes it possible to effectively use the information generated using participatory methodologies for better understanding of the dynamics and complexity in the communities. The information generated in this way can be used to make it possible an informed deliberation, within local communities, over the pros and cons of soy expansion. In fact, information and communication technologies can be used to enhance the effectiveness of participatory processes for community capacity building. When local communities can generate (and be in control of) their own information—that is, when they can record such an information in the form of data referring to relevant categories, maps, pictures and videos, they can enrich the discussion over possible sustainable paths because their cultural diversity can be translated in a more effective perception of relevant issues to be considered.

Finally, scaling up and interfacing variables, we can remark impacts with the soy expansion: (i) related to ecological aspects, the soy is an extensive crop that implies the deforestation, which can visualize in land use patterns. If we compare both communities, La Primavera is suffering major land use changes, which implies less forest for gathering and hunting implied cultural changes; (ii) social aspects imply less human labor in paid work; basically, the land is rented to companies. In this sense, the population is not integrated to this crop production. Other social aspect implied is the changes in lifestyles, for example, more time spend in collecting water or wood; (iii) economically, the major benefits of GM production are for companies; the communities rent the land for little money. Furthermore, nearby households closer to where agrochemicals are handled suffer more illnesses which implies mayors expenditure in the health sector; (iv) in political aspects, the rural development programs is not adequate for the local communities.

In conclusion, the abandonment of agriculture–livestock rotation or exploitation of forest coupled with the expansion of RR[9] soy or cotton monoculture generating important and long-lasting changes in these two communities. When adopting an agroecological perspective, one could say that the soybean monoculture is a critical path away from environmental sustainability.

Changes in relative prices, in particular, the recent increase in the price of soy, plus unfavorable economic policies have led to the disappearance of small- and medium-size farmers and to the concentration of land and economic power in the region (Azcuy and León 2005). When assessing the economic result of this change at the large scale, we can perceive this change as a positive economic growth for the region, meaning a larger flow of added value (monetary flow) per capita and more revenues from taxes at the province and nation level. However, when characterizing these changes in a multi-scale integrated analysis, we can easily detect that this larger monetary flow does not reach households or rural communities, as it remains concentrated in the hands of tenants producing soy. Therefore, the monoculture expansion generates more monetary flows for urban elites, but supports fewer rural households. This cannot be considered a desirable development path for the rural communities analyzed here.

Multi-scale integrated analysis of the metabolic pattern applied to the local analysis of soy expansion provides a useful representation of the sustainability predicament by providing a holistic vision of the various aspects (dimensions of analysis) and perceptions of the various social actors (socioeconomic units reproducing at different hierarchical levels). In our view, this richer representation can help a better informed discussion over policies more suited to the needs of communities.

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[9] Roundup Ready Soybeans. The Roundup Ready® seeds contain in-plant tolerance to Roundup® agricultural herbicides, allowing growers to spray Roundup agricultural herbicides to kill the weeds without harming the crop.

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