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Sociometabolic regimes in indigenous communities and the crucial role of working time: A comparison of case studies

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Sociometabolic regimes in indigenous communities and the crucial role of working time: A comparison of case studies

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Abstract

In the context of the broad discussion of visions for a more sustainable future, we present findings from four case studies of indigenous communities in various world regions. Guided by Sieferle's theory of sociometabolic regime transitions, we compare their profiles in material and energy use, and their time use patterns. Each of these subsistence economy based communities bears some traits marked by interventions from higher scale levels (such as development programs, health services or transport infrastructure) connecting them in some way to industrial society. But apart from these features, the endogenous characteristics of the local communities correspond well to what should be expected according to the theory of sociometabolic regimes: low energy consumption based almost exclusively on biomass as well as low rates of material use, and working time patterns according to Sahlin's "original affluent societies" and Boserup's hypothesis of labour intensification. In conclusion, we suggest that traditional development and aid policies should be aware of the intricate link between demography, labour time, land degradation and subsistence when aiming for sustainable interventions and human well-being.

Keywords: sociometabolic regimes, socioecological transitions, time use, labour and area productivity, scale interactions

1. Introduction

In the 1966 conference on "Man the Hunter", and in several publications thereafter (most renowned (Sahlins, 1972), Marshall Sahlins and colleagues evoked scientific and also broad public attention for the storyline of "original affluent societies", hunting and gathering societies that led a life of "limited wants, by unlimited means" (Gowdy, 1998). Among middle class people in industrial societies thriving on an ever increasing amount of commodities in an unprecedented economic boom, yet experiencing an equally increasing continuous time squeeze on their daily lives, the story of communities who owned practically nothing but could liberally dispose of their everyday time, individually and collectively, without suffering from any deprivation, had quite an appeal. This appeal has not faded yet. Periodically, there are still attempts launched to discredit the story as a mere myth (e.g. Bird-David, 1998), while others defend their findings as however limited but scientifically sound (e.g. Gowdy, 1998; Lee, 1998).

In the context of a broad interdisciplinary discussion of visions for a more sustainable society, and of critical global environmental change, such findings gain renewed relevance. At present, half of the world population sustain themselves in rural communities from subsistence agriculture, gathering, hunting and fishing (FAOSTAT 2009). While large parts of the industrialized world seek for pathways away from fossil fuels, the dominant development model for those rural communities is the eventual industrialization – fuelled with fossil energy – of their agriculture, and the absorption of a large fraction of their population into the industrial labour market of growing cities. To mainstream development economists, well represented by the Millennium Development Goals, this appears to be the only chance for an escape from poverty, bad health, and lack of education, while at the same time providing consumption opportunities – the faster, the better. In contrast, our understanding of sustainable development requires the search for a transition pathway that in the short and longer term avoids an increase of overall pressure on the environment, and avoids increasing the burden and stress on the people in terms of working time. Or, to formulate it in more relativistic terms, it searches for a transition pathway on which the short-term and long-term benefits for the people come at the lowest possible cost in terms of environmental pressure (Haberl *et al.*, 2004; 2009).

It was this applied focus on sustainable development that has guided our research for well over a decade and helped to evolve an overarching conceptual framework for describing society-nature interactions, namely 'social metabolism' and 'colonization of natural systems' (see below). From the onset, each local case study was carried out using a standardized methodology and gradually we improved our understanding of what is common and what is specific to each of our cases.[1] The local cases were

[1] Pioneer work in this research tradition was done by Lyla Mehta (Mehta *et al.*, 1997), on a community in an area later to be submersed by the Narmada dam in India. Subsequently, a European Commission (RP 5, INCO-DEV) funded collaboration with scientists from the Amazon region (Brazil, Venezuela, Columbia and Bolivia) helped to further develop the methodology (Amann *et al.*, 2002; Grünbühel, 2002) and refine it with the support of the Austrian National Bank Fund in an in-depth study of a community in Thailand (Grünbühel *et al.*, 2003); this case is included here in our comparison (Sang Saeng). Another European Commission (RP 5, INCO-DEV) funded research collaboration (with partners from Laos, the Philippines, Thailand and Vietnam, "South East Asia in Transition", see (Schandl & Grünbühel, 2005) generated the data for the second case included here (Nalang). Case number three (Trinket) was studied

expected to deliver empirical data comparable to agro-economic, demographic and sociometabolic data generated on national and regional levels across time. They should provide snapshots on the rural periphery of countries in the Global South to help model development trajectories at the society-nature interface for larger regions. On the other hand, each was a case of its own right, with researchers involved in and worried about the challenges as well as the opportunities embedded in the specific local environmental, socio-cultural and political dynamics.

In this paper, we present a comparison of four local cases (one each from India, Bolivia, Laos and Thailand) with respect to the systemic nature of society-environment interactions using a common set of biophysical indicators. It is a test of our standardized methodology to move beyond the usual 'stand-alone' single case study approach in favour of a comparative one for a sustainability analysis. One needs to be aware that a small number of case studies, even if investigated in a strictly comparative fashion, cannot provide conclusive evidence to put theories to a test, let alone decide between competing ones. All one can see is whether the findings from these case studies contradict what would be theoretically expected, or, in other words, whether the theories provide reasonable guidance to interpreting the findings.

Further, these local cases are seen embedded within a larger context or the framework conditions that influence the environmental relations of the local systems. Thus, the paper also proposes a framework for analysing scale interactions using these cases as examples. Another important contribution our paper aims to make is to see whether our cases follow a smooth, incremental and gradual modernization process or are they characterised by regime shifts with major qualitative changes in material, energy and time use due to higher level interventions or demographic thresholds. In doing so, we also aim to illustrate the crucial role of labour time in driving sociometabolic transitions.

The next section clarifies in some detail our conceptual framework and working hypothesis with respect to those already mentioned in this section. Section 3 provides an overview of the methods used for collecting and calculating biophysical indicators presented later in the paper, along with a brief on the four cases. In the fourth section, we present our main findings followed by a discussion in section 5. In conclusion, the paper summarises the main message of our study in accordance with the objectives specified above.

by Simron Jit Singh with the help of a research grant from the Indian Government, fellowships from the Austrian Ministry of Science, Education and Culture and from the European programme START, as well as with support from the Austrian National Fund (Singh, 2001; Singh, 2003; Singh & Grünbühel, 2003). Case number four (Campo Bello) originated from the Ph.D. work of Lisa Ringhofer (Ringhofer, 2007) and was fuelled by her engagement in improving her professional development work.

2. Conceptual clarifications and working hypotheses

2.1 On social metabolism and the colonization of natural systems

Point of departure of our analysis is a theory of *sociometabolic regimes* as developed by Sieferle (1997a; 2001) and further elaborated by him and other authors since (Fischer-Kowalski *et al.*, 1997). The theory claims that, in world history, certain modes of human production and subsistence can be broadly distinguished that share, at whatever point in time and irrespective of biogeographical conditions, certain fundamental systemic characteristics derived from the way humans utilize and thereby transform nature. While these or similar distinctions are widely used in the literature (dating back to the 19th century political economy), our reading of these distinctions focuses in particular on the society-nature interface and on the interdependence of the dynamics of the respective social systems with the dynamics of the natural systems they interact with (Godelier, 1986). Conceptual tools for describing this interaction are "social metabolism" on the one, and "colonization" on the other hand (for more detail see Fischer-Kowalski & Haberl, 2007, Fischer-Kowalski & Weisz, 1999; 2005).

Social metabolism draws on an organismic analogy by claiming that any social system not only reproduces itself culturally, by communication, but also biophysically (such as its population, built infrastructure, artefacts and livestock) through a continuous energetic and material exchange with its natural environment (and eventually with other social systems). Social metabolism can be quantified in terms of energetic and material flows per time period, usually a year. The size of the flows required depends, on the one hand, on the size of the biophysical structures (stocks) of the social system (i.e. the size of the human and animal population, and infrastructures), on the other hand on the sociometabolic regime. Different sociometabolic regimes have substantially different *metabolic profiles* (i.e. quantity and quality of materials and energy used, see in more detail below). Metabolic profiles can be expressed as total quantities for a complete social system (a society, a community, or, for example, a household), and they can, for reasons of comparability, be referred to the number of the human population the social system sustains, and calculated as *metabolic rates* (in terms of energy or materials required per person and year). The higher the metabolic rate, the more resources per inhabitant have to be extracted or imported and the more outflows of wastes and emissions are produced, therefore the higher is ceteris paribus the impact upon the environment. Once adequate boundaries of the social system are defined (and this has received a great deal of methodological attention by a number of researchers, see for example (Fischer-Kowalski & Hüttler, 1998; Matthews *et al.*, 2000; Schandl *et al.*, 2002), biophysical structures (stocks), flows, metabolic profiles and metabolic rates can and have been measured or estimated in a comparable way for a number of social systems (communities, societies) on various scale levels across history (for an overview see Fischer-Kowalski & Haberl, 2007).

The second concept employed for characterizing the respective society-nature interaction is *colonization.* Social systems not only exchange energy and materials with their natural environment and thereby have, mostly as an unintended consequence, certain impacts, they also deliberately intervene into natural systems with the intention of transforming them in ways they consider more useful for themselves. A classic colonizing intervention is changing the land cover in favour of agriculture, but this term can usefully be applied to processes as varied as breeding, genetic modification or dam building. The important commonality is that natural systems thus transformed by human intervention are usually brought into a state far from natural equilibrium, and need a continuous input of human labour (and typically also energy and materials) to be kept in that state. Thus a social system's colonizing activities are closely related to the amount and quality of human labour they directly or indirectly (by producing and maintaining technologies) draw upon. The more a society modifies its environment, the more metabolic returns it may expect, but the more efforts it has to expend to keep it in the desired state – and this may create the need to invest even more working time. Only by using the "subterranean forest" of fossil fuels (Sieferle, 2001), in connection with industrial tools such as machines and synthetic fertilizers, this relation between intensification and increasing working time can be broken.

2.2 Human time as a key resource, and the link between social metabolism and time use

While common in economics, it is far less common in the sustainability context to look upon human time as a key resource (among the few exceptions: Giampietro, 2003; Ringhofer, 2007; Schandl & Grünbühel, 2005). In our theoretical approach, we try to include human time as a *limited and fairly evenly distributed* resource, its availability depending on the number of people within a social system, their reproduction rates and demographic structure. In contrast to usual sociological time use research (e.g. Gershuny, 2000), we are mainly interested in human time as a resource on the social system level. This is why we distinguish the time use of individuals according to the functional subsystem that is reproduced by this time use – or, put differently, into which a certain number of person-hours are invested. The resulting classification does not differ much from what is commonly found in sociological time use studies (and this is so on purpose to allow for the broadest possible comparisons), but the interpretations may look different. Nevertheless, time use categories for the European Union (EUROSTAT, 2003), which has set the standard for statistical time use monitoring, do not fit entirely to categories required for the observation of non-industrial agricultural societies, whether historical or current. While subsistence societies spend most of their time in household and in economic activities, hardly any time is spent in such activities as »mass media«, »hobbies and games«, or »sports«. In addition, the EUROSTAT categories have been drawn up to reflect statistical time use at the national level. They tend towards the maintenance of data harmonization rather than provide insightful results for local-level case studies. When dealing with national-level data, problems of data aggregation, data sources, and coarseness of data may appear. The opportunity to empirically gather or reconstruct (historical or current) data at the local level necessitates a more fine-tuned categorization, which is adapted to the specific structure of the society under investigation. As a measure of guidance, however, the EUROSTAT Guidelines are useful for time use categorizations and have been largely followed in the case studies presented below. To suit the purpose of the argument presented here, these categories have been aggregated to reflect four subsystems of the social system. The relevant subsystems we distinguish are the person system, the household system, the economic system and the community system.

Time use for the *person system* functionally serves personal reproduction. While personal reproduction can also be supported by other people, much of the basic functions cannot be delegated to anyone else: each person spends part of his/her own time on sleeping, eating, resting, learning, mourning and having fun. So the time devoted to the reproduction of oneself is allocated to the person system. The *household system* functionally serves household / group reproduction (caretaking of children and other dependents, food preparation…), and is usually organized as an exchange of unpaid labour according to some social norms. The functional focus of the *economic system* reaches beyond the household even if part of its function consists in supplying households and persons with life-sustaining commodities (with economic “food provision” being sometimes hard to distinguish from the household’s “food preparation”); the economic system reproduces, in a division of labour and functional interdependence beyond the household, the community/society, and manages most of what we described as social metabolism above. It need not but often does function on the basis of paid labour. Finally, the *community system* is the reference system for activities beyond the household level and the economy; activities devoted to the reproduction of reciprocal relationships, social cohesion and shared beliefs within the community. In the non-industrial society, the community system represents a predecessor of several specialized subsystems, such as the judicial system, religion and social welfare. The advantage of this systemic rather than individualistic perspective on time use should be to draw attention to the specific possibilities and constraints a community has in its interaction both with its natural environment, and for its members among one another.[2]

Human time has some interesting features that we cannot fully elaborate in this context, such as: all human time has to be used somehow (with the person system “idling” as a kind of residual); all human time normally has to be metabolically sustained by the society (each human lifetime hour, whether “productive” or not, requires a certain metabolic input, or else people starve and die) – if this is not possible, it becomes a source of major tension and needs specific institutional solutions (such as seasonal migration, expelling the unwanted, ritual death of the elderly, etc.). Disposal over the use of time (own time and time of other people) is one major main marker of freedom and power.

2.3 Sieferle’s ideal-typical distinction of sociometabolic regimes according to their energy base

Key to distinguishing *sociometabolic regimes*, according to Sieferle (1997a) is the source of energy used, and the main technologies of energy conversion. Not very surprisingly, he distinguishes between the regime of hunters & gatherers, the agrarian

[2] Of course, both in the economic system and eventually in the community system the distinction between paid and unpaid labour plays a role. While paid labour serves to acquire money in order to satisfy some needs that may be completely different from the purpose of the labour, unpaid labour as a rule serves a certain purpose required by the household / community. As in our cases paid labour does not play a major role we do not address this distinction (which we recorded in our observations) in our analysis.

regime and the industrial regime, the latter so inherently unsustainable in its reliance on exhaustible resources, that according to Sieferle it may only be a transitory stage rather than a stable regime. Both the hunters & gatherers regime and the agrarian regime depend (almost) completely[3] on the solar energy flux and its fixation through plant photosynthesis. Phytomass is (directly or indirectly, transformed by herbivorous animals) the base of human food, and the base of fire used for heating and light, and occasionally for protection and hunting. The crucial difference between the energy regime of hunting & gathering and agriculture, according to Sieferle, is the conversion technology. While hunters & gatherers are "passive" users of solar energy, that is they utilize plant and animal biomass wherever they find it[4], the agrarian regime relies mainly on an "active" utilization by colonizing terrestrial ecosystems. In other words, peasants try to channel as much solar energy onto a few plant species they wish to use by changing the land cover and seeking to monopolize selected quality land for their food and feed purposes. In our terminology, agrarian societies actively colonize terrestrial ecosystems, and also other natural systems (such as animal and plant populations and gene pools by selection). And for successfully doing so, they generate particular forms of social organization, and need a lot of human labour. Finally, the industrial sociometabolic regime transcends the limitations inherent in relying on the current flux of solar energy by utilizing fossil fuels, the stock of historical solar fluxes accumulated over millions of years. This allows for an enormous increase in social energy and material use (boosting metabolic rates), for a reduction in human subsistence labour, and for a very different organization of society.

Sociometabolic regimes, according to this theory, are not something static. Rather, they are constituted by a set of opportunities and constraints within which certain dynamics take place; these dynamics can be directional in the sense that one might talk of "maturing" (for example into a high level equilibrium trap), or it may be more cyclical or fractal, starting similar processes over and over again. But if the dynamics transcend or are pushed out of the boundary conditions of the regime by exogenous forces, turbulence will ensue with an unpredictable outcome anywhere between collapse of the social system and a transition into another sociometabolic regime.

For the transition from hunting & gathering to an agrarian regime (which for a long time had been considered simply a matter of evolutionary progress), quite some literature exists demonstrating that peoples had been resisting such a transition, even when circumstances were getting tight and pressures mounting (Layton *et al.*, 1991). Flannery (2006) even argues in an attempt at explaining aboriginal presence in Australia for 50,000 years without ever developing an agrarian society that the specific climatic conditions of unpredictably long droughts (and occasional floods, ENSO) had rendered agriculture as an evolutionarily inferior option. Among the reasons for resisting the transition to an agricultural mode, the dread of too much arduous labour figures most prominently (Carlstein, 1982; Ellen, 1982). Similarly, colonialists who tried to force

[3] Technology historians tend to stress the role of wind energy (sailing boats, mills) and kinetic energy from water (transportation, mills) in agrarian civilizations. This role cannot be denied, as in the face of general energy scarcity it was locally often crucial, quantitatively speaking, however, it never exceeded a few percent of total primary energy input (Krausmann, 2007; Smil, 1991; 2008).

[4] Some hunters & gatherers make the use of fire to get easy access to their prey and to improve hunting conditions. In this sense, some scholars argue that this is a deliberate intervention (or colonisation) into the ecosystem which alters ecosystem parameters and species composition to a certain degree (Goudsblom, 1992; Pyne & Goldammer, 1997).

indigenous hunter & gatherer populations into field or mining work found them unwilling and eventually even physically unable to deliver the amounts of daily hard work European farmers were accustomed to endure (Rawley & Behrendt, 1981; Silver, 1990). So for this transition from the hunter & gatherer regime to the agrarian regime, labour time appears indeed a major barrier.

Except for under very special ecological conditions, the sociometabolic regime of hunters & gatherers allows only for very low population densities (Cohen, 1995; Smil, 2008). Most hunter & gatherer communities seem to have found ways to culturally keep their demographic growth rates low (Cohen, 1995; Harris, 1987; Sieferle, 1997b), thus not endangering their mode of life. Indeed, having many and closely spaced children is hardly compatible with a non-sedentary way of life, and the rewards to parents of having many children are much lower than under agrarian conditions where children's labour power can be used.

In terms of the above theoretical considerations, what would be the endogenous dynamics[5] within the hunter & gatherer regime? Despite culturally prescribed taboos, one of consequences of increasingly refined and successful hunting techniques may be the extinction of the most preferred and convenient prey animals. So "maturing" can lead to an evolutionary deadlock where subsistence (and in particular sufficient protein in the diet) has to be secured by gradually turning towards agricultural practices, but it may also lead to the development of effective cultural barriers to population growth and cultural reinforcements of nature (and prey) conservation, thus preserving the chance to continue this mode of life.

For any ideal-typical social community of hunters & gatherers, according to our working hypotheses, we expect it

- even when eventually sedentary, not to colonize terrestrial ecosystems for its staple food (as distinct from the agrarian regime)
- not to use fossil fuels as a source of energy (as distinct from the industrial regime)
- to have comparatively low rates of population growth, and very low population density
- to have few biophysical structures (stocks) and low metabolic rates in terms of energy and materials per capita
- to have low working times, and barely use child labour and
- to invest much time on shared cultural activities.

In contrast, how should agrarian communities be characterized? Working the land (technically speaking, according to our theory: colonizing terrestrial ecosystems)

[5] Most common will be an "exogenous" dynamics in which foraging communities have to give way to the expansion of agrarian communities in search of additional fertile land. The competitive advantage of the agrarian mode will mainly lie in its higher population density and population growth rate.

implies a sedentary form of life; there will be a built home for the family, and there needs to be an infrastructure for the storage of seeds, food, and tools. Depending on ecological and socio-cultural conditions, there will be a smaller or larger amount of livestock (as draft animals and for food supply), and there will be built infrastructures for keeping them. With further development under favourable circumstances, urban centres and the required transport infrastructures will emerge. All these stocks require a substantial amount of materials and energy for their reproduction, thereby boosting social metabolism.[6] Concerning the maximum metabolic input of agrarian societies, the availability of land in combination with the area under production and its yield – depending in turn on the agricultural technology – determines the amount of available primary energy.

Due to the predominance of "bioconverters", such as humans and animals, the overall efficiency of conversion of primary into useful energy remains low (at less than 5%). The land use system and its limited potentials to supply certain types and amounts of primary energy, therefore, constitute a major bottleneck for physical growth. Increasing yields from the existing land is, therefore, the key strategy to improve the material standard of living. Increasing yields, in the absence of external energy supplies, requires increased labour[7]. Even if this is animal labour, it needs an increased share of the land, plus human labour for supplying feed and caretaking. This sets in motion a vicious cycle of labour intensification and demographic growth that increases the workload on the people and the exploitation of the environment without allowing for a substantially improved standard of living for the peasant family[8]. This is the endogenous dynamics within the agrarian regime as described by Sieferle (2001), and, with more detail on changing agricultural techniques, by Boserup (1965; 1981). According to her, there is an endogenous dynamics driven by increasing population density that leads from foraging to a stage of swidden agriculture (shifting cultivation) and transhumance to permanent agriculture and finally, to intensified forms of permanent agriculture (e.g. multi-cropping).[9]

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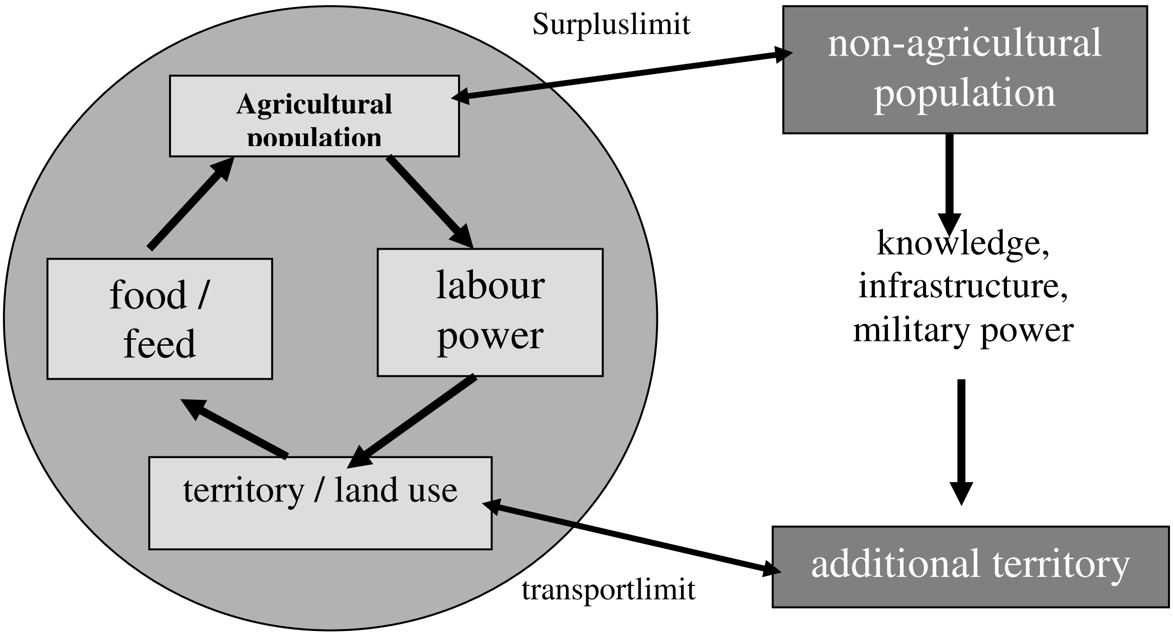
[6] One should be aware, though, that a higher metabolic rate did historically not necessarily imply an increased material standard of living for the people. Food standards of agrarian communities have often been found to be worse than under hunting and gathering conditions: less diverse, less protein and even under threat of longer periods of starvation (in case a whole harvest is destroyed). This was reflected in a reduction of body size and life expectancy (Cohen, 1977; 1989).

[7] Other – but soon exhaustible – possibilities are the extension of territory (at the expense of neighbours), the extension of arable land (at the expense of forests) or the refusal to pay taxes and dues. All these are, in the medium term, zero-sum-games in which gains come at a high price. There also may be substantial technological improvements contributing to raising yields, such as iron ploughs, improved technologies in connecting draft animals to ploughs, more efficient plant rotation systems, better breeds of crops. But these improvements tend to be quickly eaten up by population growth (Grigg, 1992).

[8] For reasons of simplicity we now leave aside interactions on a larger social scale, such as taxes and dues to land-owners, military chiefs and market transactions for the supply of urban centres. See in more detail (Krausmann *et al.*, 2008).

[9] In Boserup's phasing model, there is no distinction between intensified agriculture that is still exclusively solar based, and fossil fuel based forms of intensification (such as mineral fertilizers, chemical pesticides and motorized agricultural machines). In this respect we do not wish to follow her in our theoretical assumptions.

Figure 1: Dynamic equilibrium of the agrarian regime



Source: Krausmann et al. (2008)

Summarizing our theoretical assumptions, we would expect any ideal-typical rural agrarian community to be characterized by

- a largely sedentary way of life, and the community being engaged in working the land for its staple food
- not to use fossil fuels as a major source of energy
- to have many children, at least medium population growth rates, and higher population density
- to maintain substantial biophysical structures (buildings, livestock) and have higher metabolic rates in terms of energy and materials per capita than hunters & gatherers
- to have working times that increase with agricultural intensification, and a substantial share of child labour
- to have less time to spend on cultural community activities.

2.4 Contemporary indigenous communities in a fossil fuelled industrial context, and the interaction of scales

Under the framework conditions of availability of fossil fuels, industrial production and improvements in transport and communication, we cannot expect our case studies dating at the beginning of the 21st century to comply to the ideal-typical ways of pre-industrial sociometabolic regimes in full, however isolated they may be. We have to take into account the impacts on these local systems of economic and political actors on higher scales, actors that are no more constrained by an agrarian sociometabolic regime but are instead in command of industrial resources.

The following interventions from higher scale systems have to be considered, and they most likely have an impact on the metabolic profile, the time use profile and the social dynamics of the local system under consideration.

- **Provision of services**: The provision of *medical services* is likely to impact upon the demographic dynamics. Women from Trinket, for example, willingly participate in the Indian sterilization programme – this is a major reason for their low population growth rate. Another common intervention is *educational services*. No historical foraging community ever sent their children to school, nor any rural agrarian community. Historically speaking, there was no general formal schooling for ordinary children before the onset of industrial society (Gellner, 1989).
- **Regulatory mechanisms**: The state can enforce certain regulatory mechanisms such as *legal instruments* and *market conditions* that help indigenous or rural communities defend themselves against harsh framework conditions.
- **Supply of fossil fuel based technologies**: Even when the community itself does not use fossil fuels (yet), the industrial regime on higher levels creates an impact, for example by building *transport infrastructure.* Once there are a road, or a ship line, opportunities for marketing produce, buying commodities from outside, and for labour migration, exchanges with the outside world will greatly increase, and this will modify the local production and consumption patterns. The inclusion in an *electricity network,* or the establishment of *cell phone, radio, TV and internet connections* will create completely new cultural conditions. Finally, there are development policies of supplying fossil fuel based *technologies for agriculture* (mineral fertilizers, machines) that alter the traditional ways and create some kind of "hybrid" modes of agricultural production.
- **Supply of specific *aid and subsidies***: Even if food aid, for example, is supplied only under "exceptional" conditions such as floods or droughts, it changes the functioning of the local system. This system may have developed its demographic patterns in a long history of periodic extreme events and be "adjusted" to such fluctuations. If they now become buffered by outside intervention and population reproduction patterns remain the same, unexpectedly high growth may occur and offset the local carrying capacity vis-à-vis the specific agricultural system. Exactly this may be the case in Campo Bello, one of our local study sites. In one of our cases, Trinket, their main produce, copra, could be sold by a subsidized price (above the world market

price), and at the same time, the community received subsidized diesel to run their boats. This influences both the metabolic and the time use patterns.

So for our analysis of contemporary local communities we should be able to identify characteristics and dynamics that clearly correspond to the ideal-type descriptions above, but at the same time properly identify impacts from higher scale levels that are likely to create local features that are "hybrids" of sociometabolic regimes.

3. Case studies and methods used

As mentioned before, a standard protocol was used by researchers to generate the data and calculate comparable biophysical indicators for our cases. In this section, we present only a brief description of our methods (these have been published elsewhere in greater detail; references provided below at appropriate places) that were used for the four cases, later introduced in this section.

Methods

The first methodological first step in undertaking a sustainability analysis of the local system is to define the systems boundary of the socioecological system under investigation. This includes not only the *society's stocks* (human population, domesticated livestock and durable artefacts such as huts, buildings, wells, pathways, boats, machines, and so on), but also the territory the social system is entitled to exploit; that is, its 'domestic environment' (forests, agricultural fields, shores, sea zones, and so on). It should be noted that while the 'territory' is a spatially explicit area of land that can be described geographically, its boundaries are not defined naturally but socially, as the area the local community under consideration is entitled (legitimized by political, legal or informal social consensus) to exploit (Fischer-Kowalski and Erb 2004, Singh et al. 2010). This may include areas it shares with other communities (for example, sometimes forests) proportionally. All materials and energy required to maintain and reproduce the society's stocks of the socioeconomic system and therefore organized and channelled through social processes, in particular human labour, are considered its socioeconomic material and energy flows.[10]

Having defined this, researchers were able to make a distinction between two boundaries; one that distinguishes the society's stocks from the stocks in its domestic environment and another that separates the socioeconomic system from other socioeconomic systems. The two boundaries allowed for a distinction of two types of material and energy flows entering the system. Firstly, the extracted and appropriated energy/materials from the domestic environment, which is termed as *domestic extraction* (the most important of these, or course, being biomass harvest), and secondly, *imported* energy/materials from other social units. Equally, on the output side we differentiate between (a) wastes and emissions that are deleted into the domestic

[10] Theoretical considerations have been raised as to whether plants should be included as part of the socioeconomic system or not (Fischer-Kowalski 1997). For pragmatic reasons, however, they have been excluded so as to take advantage of available agricultural statistics as well as avoiding complications on where to draw a boundary between the socioeconomic and the natural system (Schandl et al. 2002).

environment and (b) material *exports* to other social units. Clearly, when balanced by ancillary flows of water and air, material inputs have to equal outputs.

For a stock account of the social system an inventory of the local population, livestock and the most important man-made structures was undertaken. Subsequently, weight (metric tons) to these stocks was attributed. Whenever possible, this was done by weighing these artefacts. However, in some cases, researchers had to rely on factors from externally available sources. All other durable artefacts such as furniture, boats, power generators, sewing machines, and so on, were categorized by sizes such as large, medium and small and average weights were attributed to each of them. All data concerning the society's material flows was collected in accordance with the key distinction between materials domestically extracted and traded materials as defined by the two system boundaries mentioned above. All biomass flows were calculated both in terms of weight of dry matter and fresh weight when harvested[11] or traded. To account for the energetic input and energy conversion processes, the same system boundaries as in material flow accounting were considered (Haberl 2001 and 2002). Material flow data for biomass and fossil fuels was converted to energy units by using calorific values.

The indicators generated are standard indicators developed in the framework of material and energy flow analysis on the level of national economies (EUROSTAT, 2007; Haberl *et al.*, 2004), and they express the amounts actually used by a social system during the course of a year (metabolic rate), while the stocks represent the system size.

1. *Weight of Stock* (WoS): The total weight of man-made artefacts in metric tons
2. *Domestic extraction* (DE): materials extracted domestically
3. *Direct Material Input* (DMI): Domestic extraction + material imported
4. *Domestic Material Consumption* (DMC): DMI – exported materials
5. *Direct Energy Input* (DEI): Energy domestically harvested + Energy imported
6. *Domestic Energy Consumption* (DEC): DEI – exported energy

Land use was studied using the same logic as with defining the systems boundary. First, we accounted for the 'total area' owned and used by the social system to meet its metabolic requirements. As a next step, we calculated the area representative for the different ecosystem types (such as primary and secondary forests, grasslands, mangroves, horticultural gardens and agricultural fields) and their uses as well as an overview of the total land-cover of the social system (including area under settlements and related infrastructure). Data for land-cover and ecosystem types were either taken from official statistics (especially in case of forest cover, grasslands, mangroves and

[11] Livestock grazing was estimated and considered as part of the harvest

beaches) or manually measured (as in the case of settlements, agricultural fields and coconut plantations). Combining land-use data with material and energy flows we were able to derive the following pressure indicators:

Material burden on the environment: DMC tons / hectare / year

Energy burden on the environment: DEC GJ / hectare / year

Fossil energy inputs: GJ / hectare (also indicative of the level of industrialisation of agriculture)

Including time use in our metabolic analysis is rather recent, and so there were differences in how the researchers collected their time use data on the field. Meanwhile, a more systematic methodology on time use has been developed (Singh et al. 2010, Ringhofer 2010), and we took considerable efforts to calculate the time-use data from the cases presented here into our new scheme. So far, two methods have been applied, and both methods rely on observation. One method selects certain households or individuals and records their time use from observation during the waking hours of one or more days. The other method focuses on labour only and records certain tasks (such as renewing a roof, feeding a certain number of livestock, or planting rice) repeatedly and in great detail on what kind of persons participate, for how long, and in which intensity. In order to arrive at system level data, the frequency of these processes across the year has to be estimated and used for weighing. Both methods are sensitive to the choice of season when the recording takes place[12], and eventually need to be adjusted. For practical reasons, both methods operate with small to moderate samples, and therefore create data with limited reliability. Wherever possible, we sought to enhance data reliability with cross checks using interviews and metabolic data.[13] Again, there often arise ambiguities in allocating a certain activity to one of the four sub-systems discussed in section 2.2 (person system, household system, economic system and the community system). For example, breast-feeding a baby while cooking, or listening to the radio while sewing, easily raises doubts on where to allocate this time. Some of these challenges and considerations have been discussed in greater detail elsewhere (Singh et al. 2010). In combining time-use data with land-use and agricultural harvest, we calculated some indicators on the annual food production system and energetic return upon investment:

Land productivity in terms of edible biomass: food energy GJ / hectare

Labour per area: hours / hectare

Labour productivity: MJ / hour

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[12] The Nalang study used both methods. While it relies on the 24h observation method, labour patterns were taken into account to accommodate for seasonal fluctuations of time use patterns. In addition to observation, interviews were used to validate the context and meaning of activities performed.

[13] For example: for how long do large groups go out for fishing every day (observation of samples); interview question: how much was the catch the last time you went fishing and how many people and for how long were you out at sea? How many kilogram of fish are being consumed annually (metabolic data)? Are both annual estimates congruent?

Now we turn to a brief description of the cases that we use in our paper.

3.1 Trinket (India)[14]

The Nicobarese of Trinket Island provides us with a case that exhibits the most pronounced characteristics of a hunter & gatherer regime. Located some 1,200 km off the east coast of India, Trinket Island, with an area of 3,626 hectares and a population of 399 in 2001, is part of the Nicobar archipelago in the Bay of Bengal. Of the twenty-four tropical islands of the Nicobar Islands, only twelve are inhabited by an indigenous community commonly referred to as the Nicobarese. Since 1956 the Government of India has afforded protection to the Nicobarese through a special legislation, the *Andaman and Nicobar Protection of Aboriginal Tribes Regulation* that regulates entry to these islands. As a consequence, the Nicobareses' contact with the outside world has been very limited; usually with the officials of the various departments of the Indian Administration and their sub-contractors, or with mainland traders. Nicobarese villages are located along the coast sheltered by mangroves or natural bays with their dwellings perched on stilts facing the sea. Outrigger-canoes provide for easy access to villages located either along their own coastline or on another island. By and large, the Nicobarese are rather shy, and live in their (metaphorically) secluded world with less needs and a preference for leisure, festivities and rituals (Singh, 2003).

The Nicobarese are largely subsistent and exhibit an economic portfolio that combines hunting & gathering, fishing, pig and chicken rearing and bartering copra (dehydrated coconuts) in lieu of rice, sugar, cloth, kerosene, and other necessities on the nearby market located on Kamorta Island where also the administrative headquarters of the Indian government are established. Some families maintain food gardens where they grow an assortment of crops such as bananas, pineapples, yam, sugarcane, oranges, lemons, papaya and jackfruit. Besides these, the Nicobarese select from a large variety of a widely available range of edible leaves, tubers, fruits as well as seafood from the surrounding mangroves. Thus, unlike typical hunters & gatherers, the Nicobarese do lightly colonize part of their ecosystems to grow food in their horticultural gardens and for coconut plantations. The Nicobarese do not use any elaborate technology for growing fruits and coconuts, nor do they depend on animal power. Simple tools like sickles, axes and spades are used for clearing, planting, or harvesting (Singh, 2003).

Although their dependency on the market has increased considerably, they still exhibit characteristics of a foraging community that has survived over a long time. Trading with the outside world owes much to their geographical location on an ancient sea-route when vessels anchored off their shore for shelter and replenishment of food and water supplies in the long and arduous journeys during colonial times. First surplus food (coconuts, yams, chickens and pigs), then copra was the main exchange for commodities such as rice, cloth, tools and tobacco (Singh, 2003). Copra is made only

[14] Trinket was devastated by the 2004 tsunami. However, the profile for Trinket we present in this paper is for pre-tsunami conditions, although some estimates on time-use were corroborated during field work in the aftermath of the tsunami.

when there is a requirement of food or other commodities from the market, money rarely changes hands and capital accumulation is literally absent. Since a couple of decades, the Indian government has introduced a variety of welfare programmes for the Nicobarese such as education, health services, transport infrastructure and a variety of subsidies including the sale of cheap fossil fuels (diesel and kerosene). Consequently, this has led to a high consumption of fossil fuels among the Nicobarese mainly to run their engine boats that transport their copra to and goods from the market (Singh, 2001; Singh & Grünbühel, 2003).

The Nicobarese engage in elaborate festivals and ceremonies, some lasting months, and others even a year that bring together hundreds and thousands of participants from neighbouring islands. The Nicobarese celebrate nature spirits and those of the dead ancestors. There are festivals to celebrate the shift in winds, and others to commemorate the dead, or even right of inheritance is settled via the famous ossuary feast. Thus, the role of rituals and ceremonies is strongly linked to the regulation and use of natural resources. Organization of these festivals requires abundant resources in the form of coconuts, pigs, rice and cloth, and the cooperation of relatives and community members (Singh, 2006).

3.2 Campo Bello (Bolivia)

The village of Campo Bello (231 inhabitants) is quite remotely situated in the Bolivian Amazon plains. Being one of some 120 indigenous Tsimane' communities scattered along the meanders of the Maniqui river, it lies about a day downriver from the next commercial centre. In the absence of proper roads, the community can be accessed only by canoe or motor-driven boats, by moped, bicycle or simply on foot. During the rainy season, it is often only accessible via the river. Domineered by evergreen seasonal forest and humid and dry savannah formations, villagers engage in subsistence farming and forage on forest and river resources. Land is part of the Indigenous Tsimane' Territory (TICH) that was officially titled in 1997 and there are no particular rights or restrictions over forest for field clearance. However, once a spot is decided upon by the residents, it becomes theirs and people are automatically granted traditional tenure rights. Campo Bello has witnessed a steady population growth from 210 inhabitants in 2003 to 231 in 2005, 235 in 2006 and 250 in 2008. From the period observed (2004-2006) it can be deduced that roughly one third of this growth (3.8% annually) was due to a positive migration balance and two thirds to births exceeding deaths.

The conjugal household can be seen as the minimal unit of production, consumption and social reproduction. The villagers tend to live in single-family dwellings within extended family clusters, often spaced far away from their neighbour's houses. Families regularly practice *sobaqui* that is visiting relatives for extended periods that can last for days or up to weeks. The production of manioc beer *(shocdye')* plays a central role in daily family life, with each extended household producing it at least once a week. Whereas only female household members are involved in the laborious four to five hour beer preparation process, men and women alike, often including neighbouring families and visitors, indulge in its consumption.

Campo Bello is characterized by both, a monetary economic system (marketing of agricultural crops, forest products and wage labour) as well as by reciprocal kinship relations of barter. In line with other communities in the area, Campo Bello's economy rests upon four main pillars. Whereas swidden agriculture takes up the central place, fishing, hunting and gathering activities are almost equally important for the villagers. Raising livestock and erratic wage labour complete the local economic profile. Slash-and-burn agriculture is practised by all households in the village and constitutes the main source of income with rice making up for 40% of all cash incomes within the community. The rice harvest is the most time and labour-intensive agricultural task in which all able-bodied family members are involved. Besides rice, the villagers also grow plantains, maize, manioc and other crops of lesser importance, such as peanuts, sugar cane, citrus and varieties of sweet potatoes. Plantains have a high economic value as they can easily be marketed all-year round. Fishing is practised throughout the year in streams, lagoons and the main river. The raising of livestock, on the other hand, is only of minor importance. While all families own at least some poultry, only one family owns cattle. Wage labour is an economic activity normally engaged in by younger male residents. With the exception of the teacher, wage opportunities for local people are confined to working as agricultural farm hands and petty labour for cattle ranchers.

Like on Trinket, the contemporary Tsimane' belief system has somewhat merged its traditional spiritual domain with Christian elements that have been introduced by missionaries fairly recently. Nonetheless, much of the Tsimane' world is still charged with supernatural significance. The Tsimane' sense of community is also reinforced through cheerful communal feasts. The people of Campo Bello clearly enjoy such recreational gatherings and prepare for them with enthusiasm. During important festivals people from neighbouring communities drop their work to flock to the feast where communal food is enjoyed, manioc beer and purchased alcohol flows in abundance, people dance and youths participate in sports competitions.

Still largely secluded and self-contained, the village is becoming growingly exposed to outside influences. The village has witnessed a number of development projects introduced by the local administration and non-governmental agencies. Development efforts include the construction of a concrete school in 1993, the installation of electricity for the school building and a solar panel for the operation of a communal telephone, the installation of several individual latrines and concrete wells. In 2006 and still ongoing, a new project was established at the village, involving various families in the cultivation of beans and the raising of poultry.

3.3 Nalang (Laos)

The multiethnic community of Nalang lies in the district of Fuang, Vientiane Province, Lao PDR, at a distance of about 200 km from the capital city Vientiane. Comprising an area of 1630 ha, Nalang has a total population of 702 (in 2001); the population density thus being 43 cap/km^2. Due to its fairly mountainous topography, large stretches of the available land though cannot be converted for permanent agricultural use. Furthermore, parts of the area potentially available for agricultural production is protected by the Lao government and therefore not allowed to be used for agriculture. The land pressure is therefore higher than one would expect from the figure of 43 cap/km^2. The main land cover types include ‘evergreen forest’ in the lowlands, ‘high density mixed deciduous forest’ in more inclined areas, and ‘limestone rock’ for the Nalang landmark, the *Phalang*, located in the center of the village. Annual precipitation rates for the entire area amount to approximately 1,500-2,000 mm (Mayrhofer-Grünbühel, 2004).

Nalang can be classified as a subsistence economy dominated by rice farming, primarily through permanent paddy farming and in addition shifting cultivation. The village therefore fits well within the regional productive economy where rice farming represents the main agricultural activity for rural producers. Like most Laotians, the local people produce primarily glutinous rice (*Oryza glutinosa*) that is consumed locally. In very productive years, a harvest surplus may either be sold to other villagers or outside traders. In line with regional practices, rice is cultivated in the rainy season only. Owing to the lack of irrigation systems, rice productivity is subject to natural precipitation. Paddy fields are invariably located at the bottom of valleys and are all fed by a network of free-flowing rain water channels.

Besides rice cultivation, gathering, fishing and hunting activities are also common pursuits the villagers frequently engage in. These activities complement the local people’s diet primarily based on rice consumption as the gathering of bamboo shoots along with a great variety of plants, roots, tubers, palms, insects and mushrooms diversify their daily nutritional sources. The ingestion of game and fish, on the other hand, provides the people with the necessary protein intakes. To catch fish, people apply a variety of techniques ranging from line fishing to casting nets. Hunting is carried out either by using traditional hunting devices like traps or bows or more elaborate home-made guns. In former times, the rearing of buffaloes portrayed another significant feature in the community’s agricultural system. Their use was primarily in agricultural work and general transport, yet at the same time, buffaloes have a strong cultural meaning and value, since their meat was regarded as a ceremonial food during rituals and village festivities. The possession of buffaloes also meant an additional asset for families, and was widely used as a currency for dowries. The arrival of the motor-plough in the mid 1990s, however, has somewhat diminished the need for buffalos, especially in the farming system. For meat production, buffaloes have largely been replaced by cattle, since maturing times are more rapid. In 1980, the impacts of a road construction connecting two district centers in the area were felt at various levels. The road was constructed to facilitate timber extraction by a company under contract from the government. Notwithstanding the loss of forest in the region, the intervention also provided temporary wage labour opportunities for villagers.

Due to now greater accessibility and exposure to outside markets, the originally subsistent economy has moved towards more market orientation. In the late 1990s, the production of cucumber was introduced as an important cash crop during the dry season. The cultivation of cucumbers takes place after the annual rice harvest, when small cucumber gardens are created along the waterways on the area of the recently harvested fields. Cucumbers are grown for sale on local (district) markets and require large manual labour inputs. Besides cucumbers, bananas provide an alternative source of income for the villagers of Nalang. More ease of transport has also had an impact on the extraction of natural resources from the forest. Timber is logged for village use as well as for sale to traders. Increased market integration has further instigated an influx of agricultural machinery and, in doing so, brought about some changes in the local agricultural system.

Despite growing market integration, however, subsistence production still remains the most important economic activity in Nalang. People depend little on traded food items and dwellings are built without dependence on imported raw materials. Still today, the villagers have a profound knowledge of their local environment and use of natural resources.

3.4 Sang Saeng (Thailand)

The village of Sang Saeng with 171 inhabitants (in 1998) is situated in northeast Thailand, in the province of Ubon Ratchathani near the borders of Laos and Cambodia. As a part of the Thai–Lao cultural and linguistic area, the Isan are ethnic Lao and display very similar traits to the majority population of the neighbouring People's Democratic Republic of Laos. Despite national integration efforts, the twenty-one million inhabitants of Isan maintain a regional cultural identity. They speak Lao and maintain a lifestyle strongly connected to subsistence rice farming and their natural surroundings. Like most other rural Thais, the Isan are Buddhists and farm rice. Isan is characterized by sandy soils and was formerly covered by semi-deciduous forest. Today very little of the forest remain. Annual precipitation amounts to approximately 1,400 mm. Similar to the entire Isan plateau, the area of Sang Saeng is flat and there are no continuous natural waterways close by. The only main waterway of Isan, the Mun River, passes some 20 km away from the village.

Isan society is little stratified (Keyes, 1995 in Mayrhofer-Grünbühel, 2004). Besides the existence of some leading figures such as the village headman, the schoolteacher and the head of the temple community, Sang Saeng may be described as socially homogenous as everyone - with the exception of the temple population - farms rice. Having said so, there are however differences in the social status of individuals. Well-to-do migrants, for example, who instigate the influx of luxury goods often transformed into status symbols, are highly respected by the village community. Nevertheless, reciprocity and a culturally ingrained sense of solidarity are common features in the village fabric of Sang Saeng. Mutual assistance within a family compound (that is two or more households) or between neighbours is quite common, especially during the labour intensive rice harvest season.

Traditional laws control access and use of natural resources. As in most agricultural societies, land is privately owned, while wild animals and forest plants (except for fresh wood and timber) are free resources for all villagers, regardless on whose land they might occur. Besides widespread individual land ownership, a small number of community-owned agricultural plots still remain.

The Isan region does not contain any major economic hubs and rural society is arguably little integrated into the emerging modern national economy of Thailand. The region is relatively arid, characterized by poor soil fertility and a high level of deforestation. The inhabitants of Sang Saeng are engaged in an economy that revolves around three main axes: agriculture based on rice-farming, foraging and labour migration. Rain-fed paddy rice cultivation makes up the central element of the people's subsistence economy. Glutinous rice is the most important constituent of the Isan diet and normally consumed

at least three times a day. Only a small fraction of harvest surplus is sold on the market. Cash crop rice is usually of the state-promoted non-glutinous rice varieties, which the producer families hardly consume themselves. Besides rice, other commercial production is rather limited. Villagers own vegetable gardens and keep chicken and ducks for their own consumption. Buffaloes are raised as working animals, meaning that only cattle are destined for the local market.
Hunting and gathering activities also feature prominently in Sang Saeng's livelihood strategies. Foraging helps to diversify the diet, especially during the dry season, when gardening is limited or made virtually impossible. A wide variety of animals, such as fish, birds, amphibians and insects, as well as different kinds of leaves, flowers, herbs, mushrooms and roots are extracted from the fields and adjacent forests.

Off-farm wage labour provides for Sang Saeng's third main economic pillar. Temporary migration to urban centres or to coffee and rubber plantations in southern Thailand has become a common strategy for most local families. Labour migration should not be regarded as unrelated to the village economy: migrants supply their families with regular monetary remittances, and take food from the village (especially rice) with them to the location of their work. Thus they spend the low-work dry season away from the village and return for the peak work season of rice production, for the preparation of rice nurseries, ploughing, transplanting, and harvesting. During that period, all able-bodied family members are expected to work together, even those family members not suited to performing heavy fieldwork, such as the elderly and children.

4. Findings

4.1 Metabolic profiles, metabolic rates and sociometabolic transitions

Table 1 presents the standard sociometabolic descriptions for the four villages. These descriptions contain a quantification of biophysical stocks (population size, size of territory, size of livestock and size of stock of artefacts, the latter two for easier comparison on a per capita base), and a description of relevant material and energy flows, mobilized by the social system to maintain its stocks. In this table, we selected those indicators that relate most closely to our concepts and hypotheses developed in section 2. If we look at the interrelations between stocks first, we can see that population density varies strongly between the communities: while Trinket has 11 persons per square kilometre (which for a hunter & gatherer community is very high, but much lower than in the agrarian communities it is compared with[15]), the two swidden / transhumance villages have a density around 40 persons / km^2, and Sang Saeng's density with its permanent agriculture amounts to 93 persons / km^2. All four communities have fairly low amounts of livestock: the livestock's cumulated body weight amounts to 300 kg per person or less (in a typical agricultural village in contemporary Austria, for example, there is about a ton of livestock per inhabitant (Krausmann, 2004). In Trinket, it is not easy to decide what belongs to the livestock:

[15] Compare with 0.01 person / km² for the Algonkian Indians of Great Viktoria Lake (Hallowell 1949), 0.06 person / km² for the Murngin and 0.01 person/km² for the Walbiri (Yengoyan, 1968).

while pigs are partially fed with coconuts (while scavenge the forest for the rest) and consumed at festivities; goats, hens and dogs are taken care of and used; some cattle left over from previous trading relationships roam about to graze, and are consumed only partially for their milk and meat. We have nevertheless included all of these animals in our account of livestock.

Table 1: Comparison of sociometabolic indicators

	Trinket 2000	Campo Bello 2004	Nalang 2003	Sang Saeng 1998
Population (cap)	399	231	702	171
Size of territory (ha)	3,626	615	1,630	184
Livestock (t/cap)	0.09	0.0	0.1	0.3
Stock of artefacts (t/cap)	8.3	1.4	1.7	18.6
Pop density (cap/km²)	11	38	43	93
Pop growth (%/a)	1.5	3.8	3.0	1.4
Energy metabolic rate (DEC GJ/cap/yr)	29.5	20.6	26.3	40.5
Share of fossil fuel (% in DEC)	6.4	1.0	1.5	8.3
Energy burden on environment (DEC GJ/ha/yr)	3.2	7.8	11.3	37.7
Material metabolic rate (DMC t/cap/yr)	3.7	1.6	2.6	3.6
Share of biomass (% in DMC)	61%	98%	96%	64%
Industrial products (DMC t/cap/yr)	0.01	0.02	0.01	0.50
Material burden on environment (DMC t/ha/yr)	0.4	0.6	1.1	3.3
Sociometabolic regime / mode of production	Hunting & Gathering + trading	Shifting cultivation (short fallows)	Permanent agriculture + some shifting cultivation	Permanent agriculture
higher scale interventions	Subsidy on diesel for boats, subsidy on copra price, government welfare programs (education, health, sterilization, paved pathways) research & advice	School, infrastructure such as (largely unused) toilets, boat transportation, food subsidies in case of flooding	Some mini-tractors, motorcycles and rice mills, road, public transport	Threshing machines, electrical water pumps, non-potable water supply, electricity, semi-permanent road provided by provincial government, seasonal migrant labour into cities

Also, the stocks of artefacts (i.e. buildings, permanent structures, ploughs, and tools – all artefacts in use for at least one year) are very low, but differ widely between the communities. While Campo Bello and Nalang resemble each other with a stock of 1-2 tons/capita[16], Trinket stands out with more than 8 tons. Most of this is not due to the indigenous way of life, but to government intervention: The government built a school, a medical service centre and paved the pathways between the settlements to remain passable during monsoon (not a very successful endeavour). This reflects itself also with the metabolic flows – some 80 tons of cement imports delivered by government were complemented by almost 600 tons of sand and gravel (locally extracted) to provide for these construction activities. In effect, for Trinket this results in a much lower share of biomass in annual flows (61%) than with the two swidden/transhumance villages. Much of the rest is mineral materials set in motion by government development initiatives. Sang Saeng instead, much more in line with its sociometabolic regime of permanent agriculture, has a stock of about 18 tons/capita (in comparison, for contemporary Japan and Switzerland artefact stocks amount to 230 and 350 tons/capita respectively (Hashimoto *et al.*, 2007; Rubli & Jungbluth, 2005).

Concerning the energy metabolism, again Trinket is a special case. Its metabolic rate is higher than in both Campo Bello and Nalang, and its share of fossil fuels in total energy consumption at 6.4% also exceeds the respective share in Campo Bello and Nalang. This is entirely due to government supply of diesel for trading boats by which the Nicobarese exchange their copra for rice. And as they get this diesel delivered as imports, it counts as part of their domestic consumption – while the traders' diesel boats used to transport the rice from Campo Bello to the market and exchange it for pasta and alcohol, for example, does not count as part of Campo Bello's metabolism. With all these metabolic rates, though, one should be aware how low they are – the 20-40 GJ/capita in those indigenous communities compare to some 70 GJ/cap calculated for representative historical Austrian villages in 1830 (Krausmann, 2004) and to roughly 200GJ per contemporary inhabitant of the European Union and 400 GJ per contemporary US citizen (Haberl *et al.*, 2006).

The materials metabolic rate for all four communities ranges between 1.6 and 3.7 tons per capita – this compares to more than five tons per capita for the historical Austrian villages mentioned, and to 16 tons per contemporary inhabitant of the European Union. If we consider the metabolic burden on the local environment, represented by the indicators of material and energy consumption per hectare, we see a tenfold increase from the hunting & gathering mode to the mode of permanent agriculture as reflected by our 4 case studies. This is a combined effect of increasing population density and increasing metabolic rates.

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[16] One should be aware that these weights were actually established empirically. The inhabitants considered it quite interesting to find out how much their house weighs ("ah, there is really a lot to carry when we build it"); of course only the material flows in construction could actually be weighed, and then the totals were established by multiplying them with the number of houses of a similar type.

4.2 The role of working time

For the description of time use we can draw on three case studies only. In Sang Saeng, first efforts to do time recording were made, but their results, unfortunately, cannot be presented in a comparable manner to the other cases. This is particularly regrettable as, according to qualitative reports, Sang Saeng differs from the other cases by a much tighter time regime. In the dry season, when there is not so much agricultural work to do, a substantial fraction of the younger males migrate to other places to be hired as wage workers, taking their rice provisions with them. This is fortunate for the village for at least two reasons: during the dry season, it is difficult in Sang Saeng to provide sufficient water – thus reducing the number of inhabitants helps. Second, those migrating workers use their income to supply the village with industrially produced commodities (per inhabitant, there is an annual flow of half a ton of products into the village, from radios to motorcycles and cement for building construction). During the wet season, though, all the migrant workers have to come back to the village, and everybody is very busy in the rice fields. According to field reports, the inhabitants of Sang Saeng use to dread this season to arrive, exactly for its enormous work load for everyone. An average work-day in agriculture has been calculated at 6.7 hours for adults in the workforce. This does not include work performed for wages nor cattle husbandry, gardening, hunting/gathering, and homestead maintenance.

Table 2: Comparison of time use, daily hours for adults, and per inhabitant

Daily hours	**Average adult 16-60**			**Average inhabitant**		
	Trinket[17]	**Campo Bello**[18]	**Nalang**[19]	**Trinket**	**Campo Bello**	**Nalang**
Population size	244	91	356	399	231	702
Number children 0-15				155	137	318
Person System	18.45	13.21	14.34	20.33	18.18	18.33
Sleeping		7.90	7.82		10.28	9.48
Eating		1.59	1.17		2.19	1.59
Hygiene		0.77	0.59		1.21	0.91
Rest and Idleness		2.43	0.95		2.10	2.12

[17] For Trinket, a different method was used. Certain activities were observed repeatedly (sample size 3-5 each activity) and records were made how long they lasted and who (in terms of gender and age) participated in them. These activities were then weighted according to their annual frequency and thus the average daily hours could be calculated. The activities recorded were: changing the roof of a house (in detail), copra production (in detail), pig rearing (in detail), fishing and ceremonies (preparation and participation). For the household activities interviews were conducted. Time use for the person system was calculated as a residual.

[18] In Campo Bello, the latest of our case studies, the time use analysis was done most systematically, on the basis of observing people for days during their waking hours. The sample consisted of 12 male and 13 female days (containing 4 children between the age of 6-15 each). Adding to these samples, a total of 112 spot checks were carried out, thereby obtaining two more person days. Standard deviations for adults amounted to 1,5 hrs for the person system, 3,2 hrs for the household system, 1,9 hrs for the economic system and 5,6 hrs for the community system. This high variability is substantially reduced to within gender-homogenous samples.

[19] In Nalang, sample size was 23 females (among them: 10 girls) and 23 males (among them 11 boys). Standard deviations for adults amounted to 3,0 for the person system, 3,5 for the household system, 3,6 for the economic system and 0,6 for the community system, a variability that was not reduced by differentiating according to gender.

Leisure Activities		0.14	3.37		1.50	2.50
Studying & Education	0.00	0.16	0.44	0.25	0.90	1.73
Household System	3.23	3.79	3.68	2.14	2.11	2.13
Care for Dependents	0.00	1.59	0.46	0.00	0.84	0.25
Food Preparation	1.09	1.07	0.69	0.72	0.48	0.46
House Building	0.00	0.26	1.43	0.00	0.10	0.78
Repair/Maintainance Work	0.16	0.34	0.00	0.11	0.24	0.00
Domestic Chores	1.98	0.64	1.10	1.31	0.45	0.63
Economic System	1.19	4.69	5.85	0.79	2.46	3.47
Agriculture/ Horticulture	0.07	2.53	3.06	0.06	1.08	1.83
Animal Husbandry	0.14	0.02	0.61	0.09	0.05	0.35
Hunting	0.03	0.46	0.00	0.00	0.26	0.00
Fishing	0.55	0.35	0.44	0.38	0.28	0.24
Gathering	0.02	0.17	0.15	0.00	0.22	0.11
Trading	0.39	0.43	0.00	0.25	0.19	0.00
Wage Work	0.00	0.27	1.46	0.00	0.10	0.87
Handicraft	0.00	0.41	0.13	0.00	0.29	0.07
Community System	1.13	2.32	0.12	0.75	1.25	0.06
Public Sports and Games	0.34	0.09	0.00	0.23	0.34	0.00
Visiting friends and relatives	0.49	1.56	0.00	0.32	0.66	0.00
Ceremonies & Festivals	0.30	0.39	0.12	0.20	0.14	0.06
Community & Political Participation	0.00	0.27	0.00	0.00	0.10	0.00
TOTAL	24.00	24.01	24.00	24.00	24.00	24.00
daily working time household + economic system	4.42	8.48	9.54	2.92	4.57	5.60

As we can see from table 2, in all villages the person system draws more than half of the available daily time of adults, and three quarters of the available time of all inhabitants.[20] The next largest "time consumer" is the economic system – in the two agrarian villages, it requires an average of 4-6 hours from each adult every day. This means an annual (economic) working time between 1,711 (Campo Bello) and 2,135 (Nalang) hours per adult. These annual working hours are in the same range or above the working times per economically active in the US and Japan (about 1,800 hours annually in the year 2005), and above those for the European Union (1,600 hours) (Groningen Database). If we consider the average (economic) working time per inhabitant, we arrive at 900 hours for Campo Bello and 1,270 hours for Nalang (in relation this is 900 hours for the US and Japan, and 700 hours for EU15, according to the Groningen OECD database for the year 2005).

The data for Trinket, our hunting & gathering case, look very different, though: for an average adult, daily (economic) working hours amount to little more than an hour, and for less than an hour of the average inhabitant. Annually, this amounts to no more than a quarter (434 hours per adult, 287 hours per inhabitant) of the work load common in OECD countries. Even if we assume (which from closer knowledge we do not) some of this difference to the other cases to be due to the different method of time accounting, we still remain with a substantial difference in favour of Trinket.

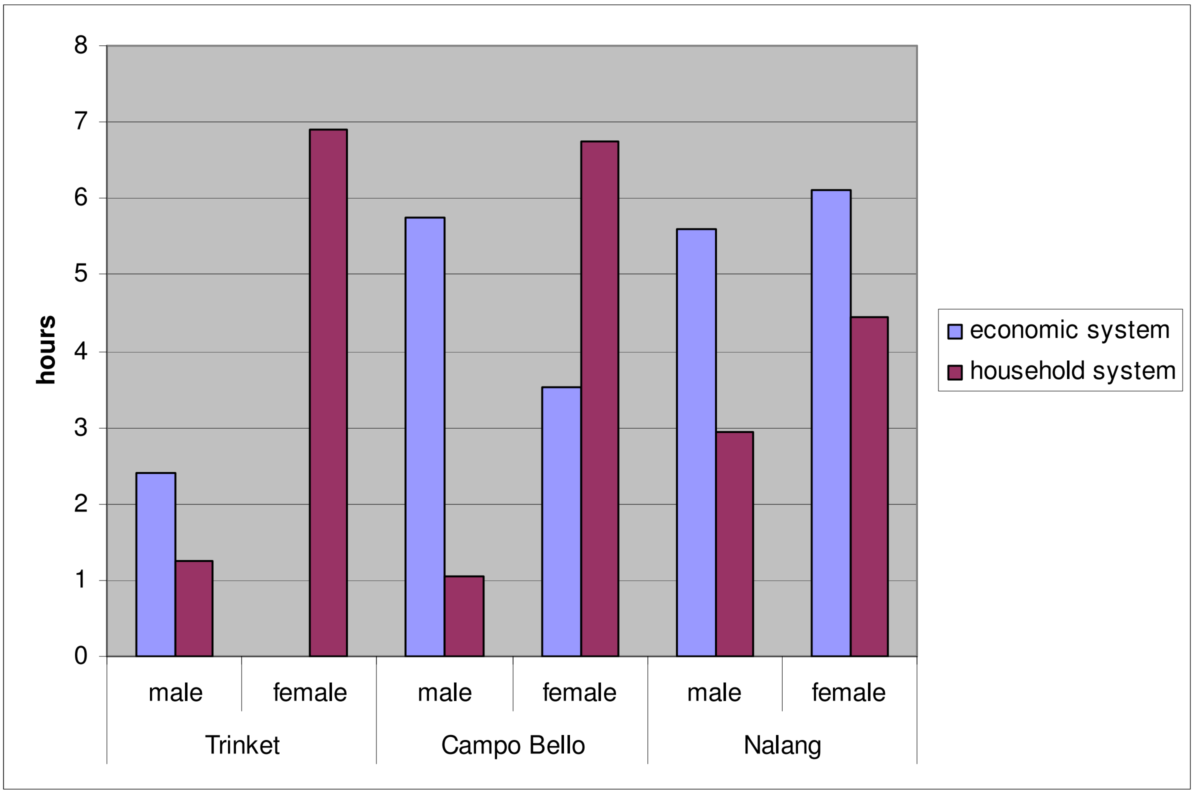
[20] For all children age 0-5, in lack of better evidence, we assumed that all their 24 hours were spent on the person system.

Looking at the details of working time for the economic system more closely, it is clear that agriculture / horticulture and animal husbandry amount to a lion's share of daily work that is almost missing in Trinket (for a closer discussion see section 4.3). Next, hunting, gathering and fishing draw close to an hour per adult's day. Cash producing economic activities (trading, wage work and the production of saleable handicraft) only in Nalang surpass an hour per day. Household work everywhere is about equally time consuming, amounting to 3.2 – 3.8 daily hours per adult and somewhat more than two hours per inhabitant.

Finally, the community system receives highly variable time investments in the three villages. In part again, this may be due to slight methodological differences in time use attribution to purposes, but the overall differences comply well with the qualitative field reports that document the extensive tradition of festivities in Trinket (Singh, 2006) and the widespread custom of moving around and paying long visits to relatives and friends in Campo Bello, while the culture in Nalang is more marked by longer hours of hard work.

A common feature of all three cases is a pronounced division of labour between males and females, as documented in Figure 2.

Figure 2: Gender differences in time use



According to figure 2, males contribute very little to the household system, leaving this to the women. On the other hand, females have a substantial share in “economic” work, i.e. food procurement. In effect, they therefore work 2.3 hours / day more than men. This difference is less pronounced for children age 6-15, but already tends in the same direction. As a result, females can invest less time into their person system than men; detailed data show they are even sleeping less. While all these data confirm the common assumption that even very archaic and otherwise hardly stratified communities practise a pronounced division of labour by gender, it is still surprising to see to what extent this works at the expense of women. It is also important to note that a community not strained by hard work in the fields like Trinket displays about the same disparity in household work between females and males[21] as the other communities. Even if in Trinket all economic work would be done by men only (which, according to non quantified observations, is not the case), it would not compensate for the excess working time of females within the household system (see estimates in figure 2). Quite obviously, we are dealing with a phenomenon so fundamental for human societies that it is replicated across continents, cultures and sociometabolic regimes alike.

The same seeming universality does not apply for child labour, as displayed in table 3. Our data should be interpreted with care. Both in Campo Bello and in Nalang very young children were not monitored; so about the age group 0-5 we only may make assumptions, and these assumptions are very crude: we attribute all their time to personal reproduction and do not assume they contribute to labour processes[22]. Thus we attribute all the “child labour” observed to the age group 6-15.

Table 3: The share of children in the communities' working time

	childrens' share in the community's time investment in %			daily time distribution in %		
	Trinket	Campo Bello	Nalang	Trinket	Campo Bello	Nalang
Person system						
children 6-15				*0.93*	0,75	0.92
children 0-5				*1.00*	1.00	1.00
all children				*0.96*	0.88	0.96
all inhabitants				*0.83*	0.76	0.76
Household system						
children 6-15	*0.08*	0.30	0.06	*0.03*	0.09	0.02
children 0-5	0.00	0.00	0.00	*0.00*	0.00	0.00
all children	*0.08*	0.30	0.06	*0.02*	0.04	0.01
all inhabitants				*0.10*	0.09	0.09
Economic system						
children 6-15	*0.20*	0.30	0.10	*0.03*	0.11	0.06
children 0-5	0.00	0.00	0.00	*0.00*	0.00	0.00
all children	*0.20*	0.30	0.10	*0.02*	0.05	0.03

[21] It should be noted that the household labour data by gender were gathered by personal interviews two yeas later, after a tsunami had devastated the islands and swept away all coconut trees, so that the typical economic activities of the pre-tsunami period could not be resumed. Nevertheless, household chores and food preparation were taken up pretty much the same way they had been organized before.
[22] Of course also small children are taken along to communal festivities and ceremonies, but we did not count this as an active contribution to the community system.

all inhabitants				*0.04*	0.10	0.14
Labor: household + econ.system						
children 6-15	*0.12*	0.30	0.08	*0.07*	0.20	0.08
children 0-5	0.00	0.00	0.00	*0.00*	0.00	0.00
all children	*0.12*	0.30	0.08	*0.04*	0.09	0.04
all inhabitants				*0.14*	0.19	0.23
Population system						
children 6-15	0.23	0.28	0.23	0.23	0.28	0.23
children 0-5	0.16	0.33	0.23	0.16	0.33	0.23
All children	0.39	0.61	0.45	0.39	0.61	0.45
All inhabitants				1.00	1.00	1.00

In Trinket, also a certain (rather low) amount of child labour was observed but not systematically registered. In order to allow for comparison between the communities with reference to the "average inhabitant", we estimated a certain contribution from children marked in table 3 (in italics). As a result, our comparative data on child labour are not as strong as we would like them to be. It should be noted, though, that in most studies on time use, children tend to be ignored altogether.

The share of children in the communities' overall time budget varies between 61% in Campo Bello to 45% in Nalang and 39% in Trinket. Thus in terms of available "live" hours, children below the age of 15 play a major role in all three communities. For Campo Bello, we can see that children aged 6-15 carry an even slightly over proportional labour burden both in the household and in the economic system. It may well be that they do lighter work, and that they do it less efficiently than adults – but they invest about the same share of their day into working like an average inhabitant, and only one third less than a typical working age adult (age 16-60). We can see here that 30% of the total labour hours of the community (both household and economic system) are contributed by children – quite a substantial contribution.

Nalang and Trinket not only have a lower demographic share of children, they also seem to put less of a labour burden upon their shoulders. The share of children in household and economic work remains around 10% - much lower than their population share. Children have the opportunity to spend 90% or more of their day on their own person system – sleeping, eating, playing, resting, or going to school.

These results, however selective, support the interpretation of a functional interrelation of demographic reproduction patterns and the use of child labour. In our example, the community with the highest reproduction rate also makes most use of child labour.

4.3 Strategies of food provision and agro ecological parameters

In order to compare strategies of food provision and agro ecological parameters, it is essential to draw comparable system boundaries. In table 4, we portray, for each community, two interdependent systems: the system of production of the key staple food (and the fossil energy invested therein), and the system of food consumption (including imports, minus exports). With Trinket, there is a definition problem concerning the “key staple food”: What the Nicobarese do is collect coconuts, produce copra, and exchange that copra for rice, which is then their staple food. We had to define the food production system of Trinket as encompassing this whole process, in terms of area of the coconut palms, in terms of labour time required to collect the coconuts and produce copra as well as the trading time in exchanging copra for rice, and the fossil fuel inputs (for transportation). In terms of energy, this exchange is very favourable for Trinket: while investing less than 800 GJ fossil fuels for transportation, they gain about 1,500 GJ of food energy by exchanging their copra for rice (table 4), although it has to be noted that this is only possible by subsidies for rice as well as for the diesel fuel. For Campo Bello and Nalang, where there is shifting cultivation, the fallow areas had to be included in the area of staple food production, as they functionally are indispensable for this mode of production. Labour time for all three agrarian communities encompassed only the time for the production of the staple food, which is rice in the case of Sang Saeng and Nalang, and plantains, rice, manioc and maize in the case of Campo Bello (all products of the shifting cultivation system). Fossil fuels were only accounted for if used in the production process of the staple food.

Table 4: food production and food consumption systems

Annual flows		Trinket	Campo Bello	Nalang	Sang Saeng
		Coconut gathering, production of copra and exchange for rice	Shifting cultivation (short fallow periods)	Intensive rice cultivation + shifting cultivation (marginalized)	Intensive rice cultivation
Reference data	Area [ha]	51	200	246	146
	Food production [GJ]	1528 (copra)			
		3070 (rice)	1590	4,989	3148
	Labour [h]	6434 (copra)			
		7376 (rice)	109,609	377,925	83,249
Food production system[23]	Fossil energy inputs [GJ/ha]	0 (copra)			
		15 (rice)	0	0.7	2.2
	Land productivity [GJ/ha]	30 (copra)			
		43 (rice)	8.0	20.3	21.6
	Labour per area [h/ha]	126 (copra)			
		145 (rice)	549	1534	570
	Labour productivity [MJ/h]	238 (copra)			
		297 (rice)	15	13	38
	Food exports relative to all food production and extraction [% in GJ]	100% (copra) 0% (rice)	37.5	17.4	82.5
Food consumption system[24]	Nutritional energy from agriculture, incl. imports [%]	31	84	89	90
	Nutritional energy from hunting/fishing/gathering [%]	69	16	11	10

23 The food production system refers only to the staple food consumed by the communities (rice in Trinket, Nalang and Sang Saeng; plantains, rice, maize and manioc in Campo Bello).

24 The food consumption system and the food exports refer to the total production, excluding domestic animals (negligible in terms of nutritional energy).

	Food imports relative to consumption [% in GJ]	31	20	7	42
	Food consumption [kJ/cap/day][25]	12,033	11,146	11,217	13,452

If we now compare these four food production systems, the first thing we see is that the role of fossil fuels is fairly small, although not negligible. In Campo Bello, there is no use of fossil fuels for food production at all, in Nalang it is 0.7 GJ/ha and in Sang Saeng it is a little more than 2 GJ/ha. In industrial cereal production systems, the corresponding use of fossil fuels amounts to a value of between 3 and 7 GJ/ha (e.g. Bonny, 1993; Golley *et al.*, 1990; Swanton *et al.*, 1996; Tsatsarelis, 1993).[26] This shows that to a certain extent Nalang and much more so Sang Saeng are hybrid systems, already including industrial elements. The land productivity of around 20 GJ/ha for Nalang and Sang Saeng is within the range of intensive rice production systems that use no or little synthetic fertilizers (see Pandya & Pedhadiya, 1993; Rijal *et al.*, 1991). The low productivity of 8 GJ/ha of Campo Bello is due to the large fallow area. If we exclude, although functionally indispensable for shifting cultivation, the fallow area from this account, the productivity of Campo Bello would amount to 24 GJ/ha and thus be equal to the other villages. The high productivity of 30 GJ/ha for copra production on Trinket is due to the high calorific value embodied in coconuts, and the fact that there is no fallow land.

The labour input per hectare in two of the four villages amounts to about 549-570 hours annually, but three times as much for Nalang: this production system is obviously more labour intensive. According to Boserup, we should have expected the highest labour intensity not for Nalang, but for Sang Saeng. Within the theory of sociometabolic transition, though, Sang Saeng's lower labour intensity would be attributed to the change in the energy system towards fossil fuel use. Whether this interpretation is adequate in our case we have not enough evidence to judge. Trinket, on the other hand, has a much lower labour input as compared to the other cases with only 126 hours per hectare in terms of copra production, and an additional few hours for transporting the copra to the market and exchanging it for rice. Finally, the results concerning labour productivity are quite remarkable: by far highest for the hunter & gatherer case Trinket, lowest for the two subsistence agriculture systems, and higher again for the more intensive and partly fossil fuel based case of Sang Saeng.

The food consumption system as described in table 4 comprises not just the staple food, but all the food consumed by the inhabitants of the communities. Here of course our hunter & gatherer case Trinket stands out with only one third of its nutritional energy derived from agriculture (namely the imported rice in exchange for copra) and two thirds from hunting & gathering (in particular fishing and coconut meat), while all other three communities depend for 80-90% on agriculture, and on their own agricultural

25 Translated into kcal, this amounts to 2,876 kcal for Trinket, 2,664 kcal for Campo Bello, 2,681 kcal for Nalang and 3,215 kcal for Sang Saeng.

26 It should be noted that this includes only the direct input of fossil fuels (e.g. for the machines used in the fields). Industrial systems additionally depend on the indirect use of fossil fuels used for the production process of fertilizers and other industrial tools.

production in particular, for their nutrition. The overall food consumption/day of all four communities is very similar.

5. Discussion: which hypotheses have survived, which were disproved, which remain in suspense?

In section 2 we introduced our concepts and hypotheses on the distinct "ideal type" characteristics of hunter & gatherer and agrarian communities. We also attempted to describe some "endogenous" evolutionary mechanisms, and a number of "exogenous" typical development policy interventions from higher scale social systems. Does the theory of sociometabolic regimes allow ordering our four case studies? Does it make sense to distinguish between "endogenous" and "exogenous" dynamics, and can we explain regularities and irregularities reasonably that way?

When interpreting the data, we repeatedly addressed Trinket as a hunting & gathering community. Is this labelling warranted in face of the empirical evidence? With reference to our description of hunting & gathering sociometabolic regimes in section 2.3, Trinket can now be summarised as follows:

1. The inhabitants of Trinket are sedentary – as all populations on small islands are more or less bound to be - but they do not colonize the island's terrestrial ecosystems for their staple food. Coconut palms grow on the sandy beaches of the island[27], they bear coconut after the age of 15 and remain productive for almost 100 years without any caretaking by humans. The only occasional intervention is to dig a coconut into the sand at the right season and a convenient place and protect it from pigs for the first few years – this is only a very "light" colonizing intervention into terrestrial ecosystems. The coconuts are "harvested" by letting them fall down and gathering them, or occasionally by climbing the trees and cutting them down. For a long time, the Nicobarese have exchanged these nuts with ships passing by and bartered them for rice. If they did not get rice, they used to gather pandanus and other tubers for a staple food, but never planted any (Singh, 2003). Today, they do not barter the nuts themselves but copra, coconut meat they need to dry over fire. This requires breaking the nuts open, scooping out the flesh, and collecting firewood. All this cannot be really considered agricultural work. The only activity that comes close to agriculture is the feeding of the pigs with coconut flesh. However, feedstuff provided for comprises only 30% of the pigs' diet - the remaining 70% is scavenged in the forest. Furthermore, pork forms an insignificant part of the diet of the Trinket inhabitants (4gms/cap/day), and pigs are being slaughtered almost exclusively for ceremonies and festivals.

2. They do not use fossil fuel as a source of energy? This hypothesis does not hold for Trinket. They do use diesel for their trading boats by which they bring copra to the market and rice back to their island – but they hardly use fossil fuels for

[27] We use the present tense although a few years after our field research the 2004 Indian ocean tsunami swept away all coconut trees and broke the island Trinket into three pieces.

anything else. Nevertheless, fossil fuels amount to 6% of the energy use on Trinket. This diesel becomes available by government subsidy.

3. They do have comparatively low rates of population growth (the 1.5% annually are substantially less than the Indian average), and a low population density. The population density on Trinket with 11 inhabitants per square kilometre is lower than for the other cases, but still high in relation to other known hunter & gatherer communities. This can be attributed to the particularly rich natural environment that provides them amply with coconut and fish. Historically, there were traditional birth control measures in place, while nowadays, the Nicobarese women willingly participate in India's sterilization programme. They prefer the forest on their islands to remain fairly untouched – no encroachment is allowed, and settlements are on the beaches, connected by boat.

4. Physical stocks and flows: In the case of Trinket, the stocks and flows are not as low as one would expect – they are higher than in the agrarian village Campo Bello. Evidently though, this is due to government intervention: government has been constructing a whole number of buildings and paths.

5. Low working times and no child labour: people from Trinket work substantially less for their subsistence than the inhabitants from the two (three) agricultural cases. There is field evidence that they make little use of child labour, but we cannot present robust evidence for this.

6. They do invest substantial time and effort for shared cultural activities, but we see a similar share in Campo Bello does. But if we would consider "pig rearing" a ceremonial activity, as it really serves for communal festivities and ritualized "gifts" (and not for daily nutrition), we would arrive at a higher time investment for the community in Trinket.

Much of the other data we have been presenting confirm the status of Trinket as a hunter & gatherer community, such as the high share of food from hunting and gathering in the nutrition system, (see table 4). Nevertheless, Trinket is far from an "ideal typical case": there is substantial influence on its metabolism from the fossil fuel based industrial world, in particular via Indian state intervention. What we do not see, though, is an ongoing transition to agriculture. The community seems to be very willing to accept elements of an industrial metabolism as part of its daily life, but not the transformation of work habits required for agriculture. This resistance to longer hours of hard work seems to pertain mainly to males, though; the females on Trinket carry a labour burden that is not so dissimilar from the agrarian villages.

If we now turn to the other three cases, how do they comply with our description of the agrarian sociometabolic regime as sketched out in section 2.3?

1) Inhabitants do live a largely sedentary life, and most of the community is engaged in working the land for its staple food. Some non-sedentary elements can be found in Campo Bello's custom of travelling for extended visits to relatives and friends and in

the frequent shift of homes. Another non-sedentary pattern is labour migration, mostly of young males, in all three communities.

2) The communities do use (some) fossil fuel, as input into agriculture and otherwise. The amounts are very low, though: the share of fossil fuels in the overall energy metabolism is between 1-2% for Campo Bello and Nalang, and 8% for Sang Saeng, comparing to a share of 25-50% in industrial countries, and only 10-20% of the respective amounts per capita.

3) They do have many children, substantial population growth rates, and a population density between 40-90 persons / km^2.

4) The communities maintain only few biophysical structures and livestock, even less than in our hunting & gathering case, and so their energy and material flows are very low.

5) There are distinctly higher working times (about twice as high) than with hunting & gathering. Working times in the agrarian communities roughly equal European industrial standards. Child labour plays a substantial role.

6) The time inhabitants spend on shared cultural community activities varies and seems to decline with labour intensification.

Can we interpret differences between those agrarian communities in terms of an endogenous dynamics of agrarian intensification in the Boserupian sense? Based upon the mode of production there is a clear ranking from Campo Bello (shifting cultivation only) across Nalang (permanent agriculture and some shifting cultivation) to Sang Saeng (permanent agriculture). In terms of their metabolic profile (table 1), Campo Bello and Nalang are fairly similar, except that Nalang exerts a higher amount of pressure on its environment (in terms of material and energy flows per unit area), reflecting itself also in a higher labour burden on the individuals (table 2) despite a slightly higher share of fossil fuels. Sang Saeng, on the other hand, displays a metabolic profile that already shares several features with industrial communities: a high population density and low growth rate, metabolic rates of energy and materials twice as high as Campo Bello (with burdens upon the environment three times as high), and a substantially higher share of fossil fuels. At the same time, Sang Saeng is more strongly integrated into the market economy (exporting more than 80% of its agricultural produce and gaining much higher income from regular seasonal wage labour). If we then look at the labour time data from Sang Saeng (table 4), we find their agriculture less labour intensive than that in Nalang, and more on a level with Campo Bello.

These findings, together with the results on food production in table 4, comply much better with the theory of sociometabolic transitions than with the classical Boserupian theory. There seem to be really qualitative differences between a hunting & gathering regime that only thrives if there is a high land productivity that requires little work (here exemplified by Trinket), the regime of non-fossil-fuel-based (subsistence) agriculture as exemplified by Campo Bello and Nalang, and a fossil-fuel-based industrial regime which Sang Saeng is stepping into. With increasing inputs of fossil fuels into agriculture, the Boserupian link between decreasing labour productivity and increasing population density is overridden by the industrial link between increasing use of fossil fuels and industrial technology on the one, and increasing labour productivity on the other hand.

Our results point in the direction of our theory of regime transitions, and the crucial role of working time. While of course there are numerous small steps that lead from the sociometabolic regime of hunting & gathering to agriculture (and in most agrarian communities there are still elements of hunting & gathering preserved), in terms of labour this seems to imply a major transition, requiring maybe shocks or strong pressure beyond gradualism. Similarly, as far as our few cases warrant even a tentative conclusion, the "Boserupian" endogenous dynamics looks plausible among agrarian communities, but as soon as fossil fuels substantially come into play, the dynamics change, and there, again, is some kind of "transition" leading out of the trap of labour intensification, but into an increasing burden on the environment.

6. Conclusions: What can be learned for a sustainability transition?

Despite the limited number of case studies, we felt Sahlin's theses about hunters & gatherers and the Boserupian theory of agricultural development as synthesized in Sieferle's theory of sociometabolic regime transitions give adequate guidance to interpret our findings. In contrast to Boserup's continuous developmental process from a foraging mode to intensive agriculture, our findings comply better with the assumption of qualitative transitions between foraging, the – pre-industrial – agrarian mode and finally fossil fuelled intensive agriculture. These transitions reflect themselves in a number of sociometabolic indicators, and particularly in labour time. Labour time is low with foragers, rises substantially with agricultural colonization and then with each step of intensification, but can in a next transition be lowered through the use of fossil fuels. However, the pressure on the environment (at least in terms of anthropogenic mass and energy flows per unit area) rises from one transition to the next.

What can be harvested from these findings for a potential next transition, and potential policies towards such a next transition? The key insight we gained was the systemic character of society-nature interactions. Even seemingly trivial and well-meant interventions may trigger a whole chain of consequences in the sociometabolic system that can be detrimental either to the social or to the ecological balance, or both. This becomes very clear from a closer look at the impacts existing policy interventions have or have had on the communities under consideration.

For Trinket, it seems, policy interventions from the Indian state have mainly had the impact of allowing for a continuation of the hunting & gathering mode despite relatively high population density, by stabilizing beneficial terms of trade between copra and rice and by subsidizing transport fuel. They did not trigger any dynamics away from the established mode, and the traditional mode seems to be resilient by itself[28] and as "sustainable" as it may get.

[28] It was of course destabilized by the tsunami in 2004 that killed about a quarter of the population, broke the island in parts and washed away all coconut trees, as well as by the aid measures thereafter.

For Campo Bello, an endogenous dynamics of increasing land degradation can already be observed: as a consequence of high reproduction rates[29]: there are decreasing fallow periods and increasing encroachment into virgin forest. Earlier development agencies' attempts to convince the Tsimane of the need of lowering the number of children remained without consequence, as did the public construction of some concrete houses and toilets in the village – they are not utilized. But now state intervention manifests itself in the person of a publicly paid influential teacher who advises the community to secure its livelihood by keeping cows. If this development should actually take place, it would very likely accelerate land degradation.

Nalang is further down this line of land scarcity and degradation. While earlier the supply of some fossil fuel powered agricultural machinery did not find too much use, the construction of a road nearby that allows the inhabitants to bring their produce to market was making a difference: they started to grow cucumber as a cash crop, and this does not only promise better income but also adds another burden on their strained time budget. Currently it is hard to foresee how this situation will be resolved.

Traditional developmental and aid policies tend to overlook the intricate ties between demography, labour time, land degradation and subsistence / income. Which pathways are viable, and which will be beneficial in the long term, needs a thorough consideration leading to maybe very different conclusions for different socioecological systems.

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[29] This may have had less impact in the past as major floods had periodically increased mortality, now relieved by aid measures

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