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Energy Integration in Agriculture in Sustenance-based Societies: A Case of *Sinja*

Dip Pandey [a], Sudarshan Raj Tiwari [b]

[a,b] *MSESSD Program, Department of Architecture, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
Corresponding Email: [a] 073msed454dip@pcampus.edu.np, [b] srtiwari@ioe.edu.np

Abstract
Agriculture is the main livelihood strategy in rural communities for food production and income for which energy is a critical input that drives all the associated activities through mobilization of human and natural resources. Agro-production is regulated by key ecological processes (nutrient cycle, organic matter, agrobiodiversity and hydrological cycle) along with social context (labor system, technology, activity cycle, knowledge) as an integrated social-ecological system (SES). In absence of modern means, chemical fertilizers or pesticides, farming in such communities, driven predominantly by animate energy and ecosystem services can be regarded as model for sustainability with production at sustenance level as is the case in Sinja. However, with changing political-economic (migration patterns, access to market) and bio-geo-physical conditions (rising winter temperature and reducing snowfall) the existing system may not continue to thrive and necessitates some degree of modification that leads to sustainable and resilient practices, besides people are anticipating modern means. In this context, energy integration is one possible way which may enhance efficiency of farming activities relieving farmers to some degrees from manual labor on one hand and improve productivity for food security and better income as a ripple effect on the other. This paper aims to discuss scope of energy integration in agriculture in sustenance-based societies and strategies for such integration to enhance resilience of farmers taking an integrated SES approach in an exploratory case study research. The methods applied are literature review, observation, semi-structured interviews and focus-group discussion. The findings show that based on the idea of intermediate technology which fits in the unsophisticated rural environment and looking at the existing activity cycle that is entirely powered by animate energy, application of mechanized tools of small-scale can improve current situation. Frugal Innovation is a way to develop such tools with incremental improvements to existing technology in collaboration with local blacksmiths. This also requires willingness of experts, industries and government to collaborate. Following agroecological principles, mixed species farming, crop rotation and animal manure can substitute all indirect energy inputs necessary for regulating soil fertility, pest and weed management. These strategies have positive impact on both social context and ecological processes, thus maintaining the system in stable state by allowing change to happen.

Keywords
Agro-productivity, Social-Ecological System, Interactions, Energy-integration, Frugal Innovation

1. Introduction

Agriculture is the main livelihood strategy in rural communities for food production and income where energy is a critical driving force for all associated activities through mobilization of human and natural resources. Until the advent of modern technology, animate energy was the only available option. Farmers in rural communities still labour manually using animals and manual tools due to their limited ability to afford modern means despite availability. Although choice of energy depends primarily upon its availability and affordability, its diverse impacts on both society and nature must be equally considered for sustainable adaptations and resilience. In spite of high productivity and convenience, modern agricultural practices of monoculture, dependence on massive inputs of fossil fuel, chemical fertilizers, pesticides or seeds of high yield varieties degrade ecological processes. In seeking energy integration strategies for future resilience, any agricultural system should equally consider maintaining biodiversity,

natural nutrient cycle and hydrological cycle in addition to acknowledging indigenous knowledge on farming. A rich biodiversity can control pests and weeds without use of pesticides or herbicides; likewise, mixed species farming, polyculture and crop rotation maintain soil fertility without chemical fertilizers. Adopting such strategies can reduce demand for energy also. Traditional farmers are equipped with knowledge of such strategies.

The key ecological processes that regulates agro-production are nutrient cycle, soil organic matter, agro-biodiversity and hydrological cycle. Labor system, available technology, organization of activity cycle, institutions and knowledge together builds social context for farming. Agro-production is an outcome of complex chain of interactions between components of both ecological processes and social context working as an integrated social-ecological system (SES). Since, energy integration strategies has a direct impact on these social components and impacts ecology in one way or the other, this calls for an understanding of SES – a complex and adaptive system that regularly interact in a resilient and sustained manner consisting of bio-geo-physical unit and its associated social actors and institutions [1, 2]. The strategies can be formulated only then.

1.1 Background of Sinja

Sinja valley in Jumla district is situated at an average altitude of 2600m comprising of three rural municipalities – Hima, Kanakasundari and Sinja. The historically important sites like *Kanakasundari* temple, palace of legendary King *Birat* and *Pandavgufa* lies in *Kanakasundari* rural municipality. There are eight wards in *Kanakasundari* rural municipality. The major occupation of people in Sinja is farming and known for growing *'Kalo Marshi'* rice variety with cold tolerant gene, a unique red rice that is sought after for its special taste. Apple farming is also one of the major sources of household income. The rural municipality is now connected by road to *Surkhet*, the provincial headquarters. Since, it lies on the way to *Rara* lake, March-May and September-October are tourist season when locals benefit from hotels and lodge business or sales of apple and local products.

1.2 Rationale of Research

Human-environment interactions are the most determinant drivers of major change across nearly all mountain regions on Earth but research into the decisive interactions and feedbacks of such coupled social–ecological systems is still limited [3]. So far, such research has not been done in case of mountain regions in Nepal. This paper aims to bridge the gap taking Sinja, a remote, rural and sustenance-based area in mid-western mountain region as a case for energy integration in agriculture. From a SES perspective, agro-production involves complex chain of interaction involving broad range of social and ecological factors of varying scales where energy is a critical input. Such sustainability issue requires interdisciplinary or transdisciplinary approach to scientific investigation that allows analysis of two-way dynamics between social and ecological systems [4, 5]. Because all human activities related to farming has potential relevance with environment and ecological context conditions human decisions, research should be structured comprehensively to understand reciprocal impact of natural ecosystems and social context for developing energy integration strategies in agriculture, for which SES perspective is pertinent.

1.3 Problem Statement

Changing political-economic conditions coupled with bio-geo-physical conditions influence agriculture. Many studies show rise in temperature, changes in precipitation patterns, hydrological imbalances, warming winters and decreasing snowfall in HKH region [6, 7, 8]. In the rural, remote and mountainous valley of Sinja, local people responded during interviews that they have been experiencing rise in winter temperature and reduction in both snowfall period and quantity. The impact of this change is on winter crops in midland farms *(bhuwa)* for which snow is the only available source of irrigation.

The opening of road and access to market has in one way or other influenced both local production and consumption. Since, local produces are valued higher than their corresponding market product there is a tendency to sell local produces for example red rice at higher price and substitute it with cheaper white rice from market for local consumption.

In most of the households, younger generation prioritized education and non-farm jobs. A family

displaced to district headquarters during insurgency said that after staying away from the village and having acquired higher education, their children are now not interested in returning back and become farmers. In yet another informal talk, a village youth pursuing higher studies in *Surkhet* expressed his concern about lack of job and leisure activities for educated people in the village - a factor that pushes youths to cities. This indicates that out-migration will keep growing for better education and employment and it will ultimately influence existing labour system in the long run resulting in labor shortage. At present, all the activities related to agriculture are driven by animate energy (human labour and animal labour). The only modern means of energy available in the region are solar PVC and micro-hydropower plant (MHP) that are limited to household lighting. The region is not yet connected to national electricity grid.

The traditional mode of farming practice may not continue to thrive under these changes and necessitates some degree of modification that leads to sustainable and resilient practices. Energy integration in agriculture is one possible way which can improve efficiency of farming activities relieving farmers from burdensome manual labor on one hand and increase productivity for better income as a ripple effect.

1.4 Research Purpose

The general objective of this paper is to discuss scope of energy integration in agriculture and provide strategies for such integration to enhance resilience of farmers in sustenance-based societies taking an integrated SES approach. The specific objectives are:

- To map activity cycle in agriculture focusing on energy use for present and future scenarios,
- To identify implications of energy on interactions between components of social context and ecological process for agriculture,
- To develop energy integration strategies for enhancing resilience of farmers in sustenance-based societies.

1.5 Limitation of Research

This is paper is based on an exploratory case study research and iteration of literature review. The findings are theoretical in nature and although further research is necessary for its field application, the recommended solutions in general are applicable in similar geographic locations.

2. Literature Review

2.1 Energy in Agriculture

Agricultural energy demand can be divided into direct and indirect energy needs. The direct energy needs include energy required for land preparation, cultivation, irrigation, harvesting, post-harvest processing, food production, storage and the transport of agricultural inputs and outputs. Indirect energy needs are in the form of sequestered energy in fertilizers, herbicides, pesticides, and insecticides.

Animate energy resulting from combination of human and animal labour is the key driver of traditional farming which constitute about 41 percent and 36 percent, respectively in Nepal, whereas machine power is only one-fifth of total power [9]. More than 85 percent of tools and implements used by farmers especially in hilly areas are made and repaired by local blacksmiths based on their limited capital, raw material and indigenous knowledge [10]. In rural areas, due to limited availability of capital and energy sources combined with difficulties of transporting heavy machinery and using it on small terraces, mechanization and automation, that can reduce drudgery and increase the productivity of labour (i.e. worker/output ratio), is not yet introduced. Gauchan and Shrestha (2017) mention about field evidences from some parts of Terai and accessible central hills which indicate that use of small-scale machinery has helped reduce women drudgery and improved efficiency in the production. For instance, the capacity of corn sheller technology is 15 kg maize shelling per hour whereas a woman can shell manually only 5-8 kg per hour. Millet thresher cum pearler which has a capacity of threshing and pearling 40-50 kg/hour of finger millet, threshing efficiency of 97 percent and pearling efficiency of 98 percent has been very useful to provide relief to women engaged in millet threshing. Therefore, under the constraints of small and fragmented land holdings, difficult terrain and limited capital availability, it is recommendable to focus on small-scale and environmental-friendly mechanization in order to reduce drudgery for which capital investment can be avoided by provisioning custom hiring of machines through cooperative or community-based farming.

Modern agriculture is intensive in both direct and

indirect energy needs and consumes significant proportion of fossil fuels and equally contributes in release of GHGs. In general, mechanized ploughing and the associated seedbed preparation require the highest energy inputs beside numbers of negative impact. Mechanical tillage systems are energy-intensive and expose soil organic matter (SOM) to decomposition, leading to enhanced GHG emissions, reduced SOM concentration in soil and, potentially, in the short and longer term, to soil erosion and degradation [11].

Whilst shifts from human work to mechanized processes may offer more efficient use of resources, and deliver productive and economic benefits, the agricultural sector does provide a source of paid employment for rural people in developing countries.

2.2 Intermediate Technology

To bridge the otherwise impossible gap between less productive indigenous technology and capital-intensive modern technology, Schumacher (1993), based on 'regional' and 'dynamic' approach to development, proposed an alternative as 'intermediate technology' that fits into a relatively unsophisticated rural environment for creation of an 'agro-industrial structure' calling an end to twin evil of rural unemployment and mass migration to big cities. Instead of few highly capitalized workplaces in and around big cities that obtain high output as advocated by static economists for achieving quickest possible rate of economic growth, regional approach to development aims to do justice to the real situation considering reaction and capabilities of people and not to confine to machinery or measurements in terms of output or profit. Therefore, regardless of the static belief that capital/output ratio grows if capital is concentrated in fewer workplaces, employment through creation of large number of workplaces is the very precondition of everything else in regional development policy because output of a poorly equipped man is positive contribution whereas that of an ideal man is nil [12].

The real task for rural development in areas with shortage of capital and rich in labour requires creation of workplaces where people live and not in big cities that are cheap enough to be created in large numbers without calling for high capital through simple production methods minimizing demands for high skills to produce from local material for local use [12].

In some earth moving job, manual lifting and mechanical lifting are two extremes but both undesirable the former because of low productivity and the latter due to high capital requirements. A more desirable solution would be in-between – moving earth in wheel barrows! Such intermediate technology obtains fair level of productivity without having to resort to the purchase of expensive and sophisticated equipment. The products of an intelligently chosen intermediate technology could actually be cheaper than those of modern factories in the nearest big city [12].

The development of intermediate technology, therefore, means a genuine forward movement into new territory, where the enormous cost and complication of production methods for the sake of labour saving and job elimination is avoided and technology is made appropriate for labour surplus societies [12].

2.3 Frugal Innovation

Frugal innovation is a means and ends to do more with less for more people because of resource scarcity, affordability constraints [13].

Frugal innovation encompasses (re)designing products, services and business models in order to reduce complexity and total lifecycle costs while providing high value and affordable solutions for Base of the Pyramid (BOP) customers in developing countries, for example GE's cardiogram that removed all unnecessary components and reduced product and process complexity significantly by using substitute locally available materials, used printers from local bus terminals and off-the self-components [14]. Other examples include TATA nano-car, TATA Swach (water purifier), Jaipur leg (prosthetic legs), medical devices and services, communication and IT services.

Frugal innovation does not necessarily involve new technologies. Frugal innovation describes a process that reduces the complexity and cost of goods or services e either during production or the utilization phase or both [14]. innovations in developing countries tend not to involve technological breakthrough which drive innovation in developed countries rather involve novel and innovative combinations of existing knowledge and technologies in order to solve local problems [14].

After recognizing that low-cost competitors from

emerging markets in developing countries would take over the resource-constrained market segments, Mettler Toledo, a Swiss company manufacturing weighing machine established its subsidiary in China with Chinese engineers in the R and D team. In contrast to MT's existing product offerings, this basic scale was characterized by a considerably lower yet still high-quality gauging accuracy, cost-efficient materials, relying on high-quality synthetic materials in place of the metal, a different design, and the absence of advanced features such as fully automated adjusting, protective covering, dynamic weighing, electronic data analysis via PC, and programmability.

Frugal innovations can re-engineer products to account for affordability constraints and local socio-cultural differences. One specific approach to reduce resource consumption is to make use of waste and renewable materials, e.g., TATA *Swach* utilizes rice husk, the Bamboo microscope and bike are made of fast-growing bamboo and the Solar Bulb is made of waste plastic bottles. By involving local people in making of essential services and products work is created. frugal innovations highlight the environmental and social dimension of sustainability and have a high impact on society [14].

Frugal innovations are the result of unique value architecture that is grounded in the drive to meet basic requirements at lowest possible costs [15].

3. Methodology

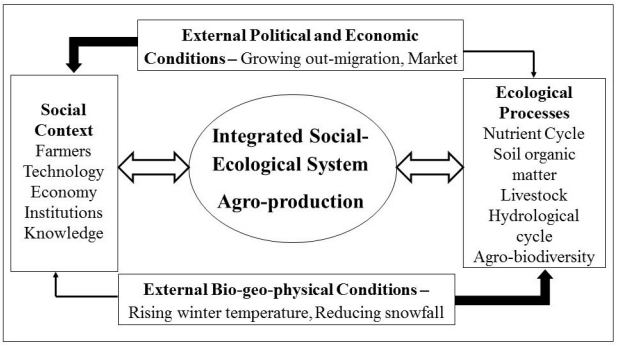

Figure 1: Social-Ecological System Framework applied for Agro-production

This research is based on an exploratory case study of farming practices in Sinja, a sustenance-based society, taking an integrated SES approach. The methods applied are iterative literature review, observation, semi-structured interviews and focus-group discussion. Data were collected from field study on topics covering available natural resources, farming practices, major crops and sources of energy. This helped in understanding the real context, problem identification and needs of the people. To find solution, cases from literature were studied during data analysis to find suitable solution and make recommendations. SES is a comprehensive concept for structuring a research framework that allows analysis of two-way dynamics between social and ecological systems [4]. This is relevant in case of agro-production as it is an outcome of a complex interaction within the components of and between social context and ecological processes.

4. Data Collection and Analysis

4.1 Land

Taking advantage of complex geographic features, existing land use in *Sinja* reflects ecological sensibility to certain degrees. While the narrow strip of fertile valley floor, *'jiula'* in local language, facilitated with gravity-flow based irrigation canals is used for cultivation of rice and barely in rotation, farms in terraced hill slopes within settlements where irrigation could not be facilitated through gravity flow take advantage of monsoon rain for summer crops and snow for winter crops. Forest predominately of pine species covers the hill slope above the settlement all way to the top, safeguarding natural water spring that supplies water to settlements based on gravity-flow. In this way, there was no necessity of energy for irrigation or water lifting. But as snowfall has reduced and become erratic, it is now necessary to facilitate irrigation on terraced farms for winter crops which require energy.

Landholding in lowland *(jiula)* ranges from twenty to twenty five *bhari* per household to only one or two *bhari* (according to a respondent one *bhari* equals 127.23 sq.m.). Mostly *bahun-chhetri* caste group own more land whereas *dalits* are either landless or own very less land and earn their livelihood by laboring on other's farm as sharecroppers. In the hill slopes within settlements *(bhuwa)*, landholding on an average range between 3 to 5 *hal*. (1 *hal* equals to land area ploughed by a pair of oxen in a day).

4.2 Crops

The major produces are rice and barley in lowland farm and wheat, beans, maize, millet, potatoes and apple in upland farm. Mixed species farming, crop rotation and animal manure regulate soil fertility, pest and weed management – a strategy that is used in converting conventional energy intensive modern agriculture towards sustainable practices so that use of chemical fertilizers, pesticides and herbicides can be avoided. Agriculture residue remaining on the field after harvesting helps in maintain soil organic matter in addition to animal manure mixed with dried leaves. Apple farming that was introduced by Nepal government in Jumla in 1970s had not gained momentum when there was neither road access nor market link, however, with access of both road and subsequently market since 2007, apple plantation is growing [16]. In the field study, all the interviewees owned varying numbers of either matured or growing apple trees and earning varied between Rs. 200,000 to Rs.50,000 in the last season from sales. Many interviewees complained about absence of inputs from government in farming activities.

Except for potatoes, apple and beans, other produces are limited to local consumption only. Yet, they are not enough for year-round consumption. Depending on the size of landholdings, the sufficiency of local production ranges from three or four months to eight or nine months. The deficit is met through purchase of market supplies coming from nearby markets in *Nepalgunj* or *Surkhet*. The opening of vehicular road from *Surkhet* since 2007 has made access to market goods easier. When there was no road, people walked for over a week all the way up to *Nepalgunj* to bring necessary supplies.

Today, local products also reach market in cities fetching income in cash. *Gothijiyula* is the nearest small market for the entire rural municipality.

4.3 Energy

The national electricity grid has not yet reached Jumla district. In Kanakasundari of Sinja valley, most households depend on solar photovoltaic panels for lighting and charging mobile. For last four year, a micro hydro powerplant has been supplying electricity to some wards of the rural municipality although customers reported that the supply was not reliable. But these sources serve only basic domestic needs. All the activities associated with agriculture is driven by animate energy through human labour using hand held manual tools or animal drawn implements resulting in a vicious drudgery. This scenario has a negative impact on educated youth population putting question to availability of labour in future. Younger generation in every household are searching for alternative employment opportunities. There is an urgency for some modification in farming practices so that manual labour can be lessened to certain degrees and youths find farming as an attractive occupation in days to come.

Few solar greenhouses of rudimentary samples constructed by covering polythene sheets over a timber structure, were observed in Sinja. The rural municipality provided 50 percent subsidy for the sheets to two households in every ward. Although this is an effective way to create a controlled environment for farming vegetables during the winter, the rural municipality should think of implementing more appropriate and holistic, not just provide subsidy for the sheets. In an appropriately designed SGH, for example in Ladakh, it was found that, owners of specially designed SGHs had grown varieties of vegetables even during winter when temperatures dropped to -25°C, ate eight times the volume of vegetables they had eaten prior to acquiring these SGHs and have seen their incomes rise by 30 percent [17].

4.4 Livestock

Since animal are integral part of traditional farming, each household in Sinja, irrespective of land ownership and size of landholding rear oxen for ploughing the fields and cows and buffalos to provide milk for household consumption. The economic and environmental benefits of using animal waste as farm manure includes relief from the additional cost of chemical fertilizers and maintenance of nutrient cycle without impacting the environment. In many modern monoculture farming, production cost is increased by inputs of chemical fertilizers and its harmful environmental consequence is compromised. Agricultural residue and fodder from forest constitutes livestock feed. During summer, the livestock are sent to pasture land on higher altitude for four months from mid-June to mid- September.

4.5 Activity Cycle

The activities associated with agriculture are ploughing and puddling for land preparation, sowing seed and transplantation, irrigation, weeding, harvesting, threshing, winnowing, drying, storing, milling, grinding, livestock management and transportation of crops and manure between field and home. These activities run in a cycle according to cropping pattern. In Sinja, till date, animate energy using manual tools (plough, how, rakes, sickle) drives all of these activities operated through a long-established division of labour based on gender and caste. The daily routine of farmers revolves around burdensome manual laboring. Ox-driven plough are used for tilling the land and only men from dalit caste are assigned to undertake this job. Women look after manuring, sowing, transplantation, milling and grinding let alone household chores. Households exchange labour locally known as 'perma' which is a labour system in which people from a number of households work together in each other's farm on a rotational basis. Such practice of labour seen during transplanting, weeding and harvesting reflects cooperation within the community and especially by singing folk songs during transplantation with the arrival of monsoon, the labour activity takes form of about a month-long festival. Post-harvest activities are undertaken by women. Sun-drying of grains and hand milling in mortar and wooden pestle consumes time and energy. Water mill is an indigenous technology that partially relieves women from manual labour for grinding grains.

5. Discussion and Results

From a SES perspective, in absence of modern means, chemical fertilizers or pesticides, farming in Sinja, driven predominantly by animate energy and ecosystem services can be regarded as a resilient model with production at sustenance level. The state was stable until external conditions influenced the social context and ecological processes. While growing out-migration has an impact on labour availability, access to vehicular road and market impacts local economy. Similarly, rising winter temperature and reducing snowfall has an impact on ecological processes. For instance, most of the respondents were critical about reducing snowfall. Snowfall is the only source of irrigation for winter crops in upland farms where alternative irrigation facilities are not available. Whereas rising winter temperature is a positive impact on the social context as pattern of seasonal migration during winter has changed. In the past, most of the male population migrated to warmer places during winter for employment and only old people, women and children stayed back to look after cattle. Due to heavy snowfall, people mostly stayed indoors and to do any work was impossible. Although the climatic harshness has subsided and it is now possible to work in winter also, but there are no opportunities.

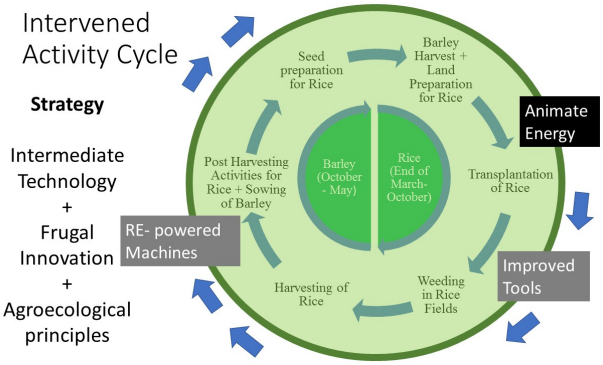

Figure 2: Energy Intervention Strategies for Activity Cycle

The system is now experiencing perturbations under these dynamic changes and to gain stability, interventions are necessary. The system will not return to past stable state. In these regards, the system can be resilient under dynamic changes by flipping to different domain if energy is integrated in farming practices. This also responds to people's anticipation of modernizing agriculture and creating work opportunities during winter. While talking to people during field visit, their limitations to only traditional means in farming was expressed as backwardness and having access to modern means was regarded as move towards development. This is true regarding the direct energy needs, but there are specific practices in traditional farming that are still relevant to overcome some drawbacks of modern farming related to indirect energy needs. Taking these into consideration, energy integration strategies is a two-fold approach. On the one hand, it follows the overarching idea of intermediate technology and highlights the necessity of frugal innovation for direct energy needs, on the other hand following principles of agro-ecology are relevant for indirect energy needs. These strategies have positive impact on both social context and ecological processes.

Application of modern means in farming practices requires high capital investment. Such an investment according to economists fit only in big city environment that generates high output and subsequently higher economic growth rate. In rural environment like Sinja valley where there are more unemployed people and limited financial resources what counts more is application of measures that are low in capital and rich in labour. Since modern means are financially not feasible and traditional means are labour intensive and less productive, the pragmatic transition could be to intermediate technology. Taking this concept which fits in the unsophisticated rural environment and looking at the existing activity cycle that is entirely powered by animate energy, application of mechanized tools of small-scale like jab planter, pedal thresher or renewable energy like improved water mills are some examples that can improve the situation. But these solutions are limited to few activities only. In order to find solutions for other activities based on the overarching idea of intermediate technology more tools are necessary that can locally be produced with limited means. This is where frugal innovation is relevant which is a means and ends to do more with less for more people because of resource scarcity and affordability constraints [13]. Local blacksmiths have been producing manual tools for farming since ages based on their indigenous technology and knowledge amidst limited resources. Moreover, they are also the ones who have understood local situation and the needs of local people. Training blacksmiths to develop better skills and supporting them for improved technology can be a way out for innovating efficient hand tools or repair and maintenance of equipment. This would indeed require willingness of experts and industries to collaborate. It is a way towards local entrepreneurship development. Innovations in developing countries tend not to involve technological breakthrough which drive innovation in developed countries rather involve novel and innovative combinations of existing knowledge and technologies in order to solve local problems [14]. Combining principles of intermediate technology and frugal innovation provides solutions to direct energy needs based on small-scale mechanization and renewable energy.

Some strategies of traditional farming like mixed species farming, crop rotation and use of animal manure can still be retained and expanded which are remedies to solve ecological problems arising in conventional modern farming that depends excessively on use of chemical fertilizers, pesticides or modern seed varieties. Such practices are supported by two cases from literature study. Traditional agriculture such as rice-fish-duck system in China and *milpa* practice in Latin America is model for sustainability and resiliency as it is a complex farming system adapted to local conditions that have helped small farmer to sustainably manage harsh environment and to meet their sustenance needs without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agriculture [18]. Indirect energy inputs are detrimental to the environment throughout their lifecycle and worse situations result after application in farmlands. During field visit, one respondent reported about the impact of use of a particular herbicide called *'butachlor'*. The women who went to field spraying this herbicide were prone to uterine prolapse, besides it affected the soil health not just in the plot where it was sprayed but also neighboring plots through water contamination.

These interventions can result in elevating quality of life for people in rural areas, most specifically is lessening drudgery. Combination of intermediate technology and frugal innovation can result in development of local entrepreneurship where collaboration with local blacksmiths, the economically poor and low caste, is an action that can mainstream this social group. On a general level, the rural society will also acquire new knowledge and improved technology. Increase in productivity will increase livelihood assets of people. Since food requirements can be met through local production, the society can achieve food security.

6. Recommendation

While agriculture in sustenance-based societies seek energy inputs for improved efficiency and effectiveness, negative spillover effects (exposing SOM to decomposition leading to enhanced GHG emission, reduced SOM concentration in soil) of high energy inputs in modern agricultural practices also suggests alternative methods. Energy integration strategies should be based on design of overall agricultural system taking into consideration preservation of natural nutrient cycle, soil organic matters, agro-biodiversity and hydrological cycle.

Although energy integration reduces drudgery of farmers raising their quality of life, its environmental implication should be taken into consideration. Based on the above discussion, following recommendations are proposed.

6.1 Introduce small-scale machinery

Under the constraints of small and fragmented land holdings, difficult terrain and limited capital availability, it is recommendable to focus on small-scale mechanization in order to reduce drudgery for which capital investment can be avoided by provisioning custom hiring of machines through cooperative or community-based farming. Further the mechanization should be environmental-friendly giving priority to renewable energy as far as possible. For example, mechanical tiller is much easier, efficient and effective but from ecological point of view, it has negative spillover effect. However, instead of hand threshing, pedal thresher is an alternative which has positive impact on both farmer and ecology. The millet thresher-cum-pearler has a capacity of threshing and pearling of 40-50 kg/ h with a threshing efficiency of 97 per cent and pearling efficiency of 98 per cent [19]. Similarly, for maize planting in hills and mountains a jab planter can be used for simultaneous manual seeding and fertilizing. The jab planter can be used in untilled land, conserves residual moisture of soil required for seed germination and increases fertilizer use efficiency. These are example of intermediate technology.

6.2 Maintain Agrobiodiversity

Maintain Agrobiodiversity: This is the core principle of sustainable agriculture which comes under threat when a traditional system seeks modernization. Modern agriculture is based on monoculture, high yield modern seed varieties, high-scale mechanization, intensive use of fossil fuels. Maintaining agrobiodiversity is essential to maintain soil fertility, control pest and weeds, cycle nutrients which can be done by adopting mixed species cultivation, crop rotation or agro-forestry. These are being practiced in *Sinja* valley. Following principles of agroecology, mixed species farming, crop rotation and animal manure can substitute all indirect energy inputs necessary for regulating soil fertility, pest and weed management. In mixed species cultivation one crop modifies the environment in a way that benefits a second crop, for example by lowering the population of a critical herbivore, or by releasing nutrients that can be taken up by the second crop illustrated by milpa practice in Mexico – a system in which maize, squash and common beans are typically grown in association, sometimes along with tomatoes, multiple varieties of chilies and semi-domesticated herbs where beans not only fix nitrogen which benefit maize but also harbor beneficial insects that control maize pests. Squash plants suppress weeds and protect against erosion by quickly covering the soil whereas maize provides support to climbing beans and shade for beans creating a microclimate unfavorable to certain insect pests while also preserving moisture [18]. Maize and beans are common crop in *Sinja* also. The design of agricultural systems should be such that ecological interactions and synergisms between biological components replace inputs to provide the mechanisms for sponsoring soil fertility, productivity, and crop protection [18].

6.3 Conclusion

Since high-tech mechanization requires high capital investment, it is not feasible in the case area. However, people's anticipation for modern means for farming has to be addressed. The findings show that based on the idea of intermediate technology which fits in the unsophisticated rural environment and looking at the existing activity cycle that is entirely powered by animate energy, application of mechanized tools of small-scale can improve current situation. But such tools are not available for all activities which shows relevance of frugal innovation in developing them. Frugal Innovation is a way to develop effective and efficient small-scale mechanized tools with incremental improvements to existing technology by about anyone, entrepreneurs as well as users. In case of Sinja collaboration with local blacksmiths in development of such tools is relevant. This also requires willingness of experts, industries and government to collaborate. Thus, direct energy needs can be addressed taking activity specific approach with incremental improvement in existing practices but specifically in collaboration with local people. Following agroecological principles, mixed species farming and crop rotation can substitute all indirect energy inputs necessary for regulating soil fertility, pest and weed management. These strategies have positive impact on both social context and ecological processes. Partial relief from drudgery, greater food security, entrepreneurship and employment opportunity, social inclusion are some of

the positive social impacts. Maintenance of agro-biodiversity, mixed species cultivation, crop rotation, use of animal manure will continue having positive ecological impacts. Thus these positive impact of energy integration strategies help maintaining the overall agro-production system in stable state by allowing change to happen.

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