(A) Shan state in Myanmar

| Type	n	Loop Process
Reinforcing	1	An increase in the household economy leads to an increase in the means to upgrade skills; allowing more locals to engage in secondary vocations like baking or repair work. The secondary vocations are more profitable than agriculture for the locals, increasing their income and thus, the household economy increases.
Reinforcing	2	A decrease in the household economy leads to a decrease in access to all sorts of energy (solar, diesel and electricity). Which, in turn, decreases the use of these energy sources and decreases the use of energy. Fewer households will be involved in secondary vocations and thus decreasing the household economy.
Reinforcing	3	A decrease in the household economy leads to a decrease in access to all sorts of energy (solar, diesel and electricity). The decrease in access to energy increases the time spent by the locals to gather firewood and thus decrease the working hours available for the locals. The less working time available leads to less income for primary and secondary vocations and thus a decrease in the household economy.
Reinforcing	4	Natural calamities or external shocks like landslides or floods will increase the impact of hazards on the community. The hazards decrease the income from farming, decreasing the household economy. A weaker household economy translates into fewer means for the locals to upgrade skills and thus fewer locals in secondary vocations. This decreases income diversity and increases the impact of hazards in the community.
Balancing	1	An increase in the household economy leads to an increase in aspiration. The aspiration leads to the increasing use of energy due to a higher work volume. Greater energy use increases the access costs for energy and decreases the household economy.
Balancing	2	An increase in the household economy leads to an increase in the means to upgrade skills, allowing for more locals to engage in secondary vocations like baking or repair work. This increase the use of energy, the access cost and thus decrease the household economy.

effect of hazard on secondary · effect of hazard on primary · hazard · time to fetch diesel · <diesel purchase> · male working hours · male to female population ratio · <excess energy> · means to upgrade · <in training> · <aspiration> · primary vocation · farming income · total earnings · average working hours · economically active population percentage · going to train · price management · training cost · in training · total population · number of households · secondary vocation income · <effect of hazard on secondary> · female working hours · water gathering time · availability of wells · completed training · secondary vocations · poverty line · household income gap · purchasing power per person · <total population> · firewood gathering time · effect of energy on firewood · <excess energy> · income · household economy · economic aspiration · aspiration · <training cost> · spending · cost of solar panels · market access · phone buy rate · purchase · phones and electronic gadgets · percentage of population with phones · <number of households> · <percentage of population with phones> · percentage of population with solar · <total population> · cost of living · <household income gap> · diesel cost · diesel purchase · <secondary vocations> · energy use for secondary vocations · energy consumption · commercial energy use · cooking · energy from solar panels · phone charging · gathered · solar energy · household energy mix fraction · diesel · diesel consumption · household energy use · <household energy use> · heating needs · solar energy consumption · excess energy

(A) Scenario testing and Sensitivity Analysis
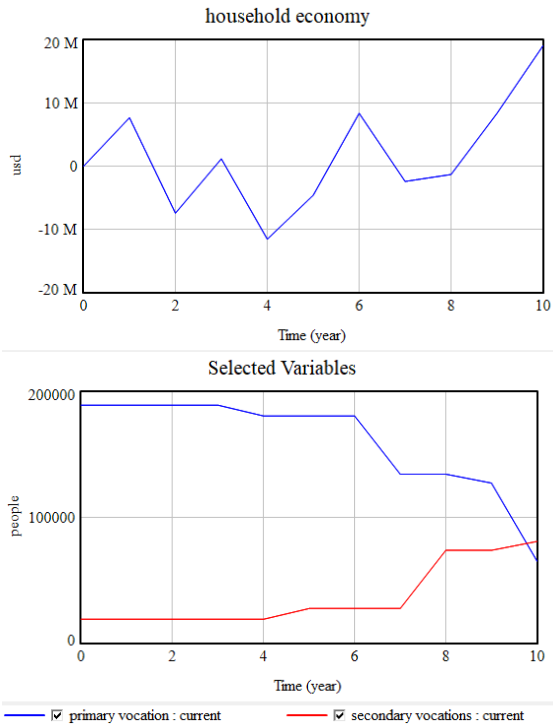
household economy

In the _business as usual scenario_ the system is dominated by an oscillatory behaviour of the household economy, caused by the presence of random hazards and multiple balancing feedbacks. The market-related and farm-level interventions from the Himalica project result in an increase in the household economy that drives people's aspirations to earn more and also adds to their means to upgrade skills necessary for getting into relatively more profitable secondary vocations. With an improved household economy, market access also increases as more of the population purchases phones and access online sources for information. Greater exposure to market trends causes innovative enterprises to emerge, signalling the increase in the number of people involved in secondary vocations. The energy use increases due to the greater use of machines in secondary vocations. However, after a time this limits the accumulation of excess energy which in turn puts a constraint on the number of people transitioning to secondary vocations. Simultaneously, a decrease in excess energy would cause more people to rely on firewood. The time spent gathering firewood increases and the number of working hours decreases. The working hours are affected and enterprises are unable to continue operations due to lack of energy. Even if development agencies provide funds for planned interventions in the farm sector and training to move into secondary vocations, the community is unable to grow past a particular stage due to energy poverty. If too many people transitioned to secondary vocations now, energy poverty would cause the economy to collapse.
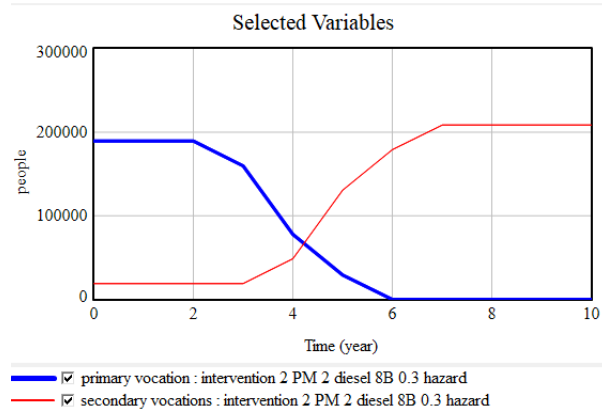
household economy
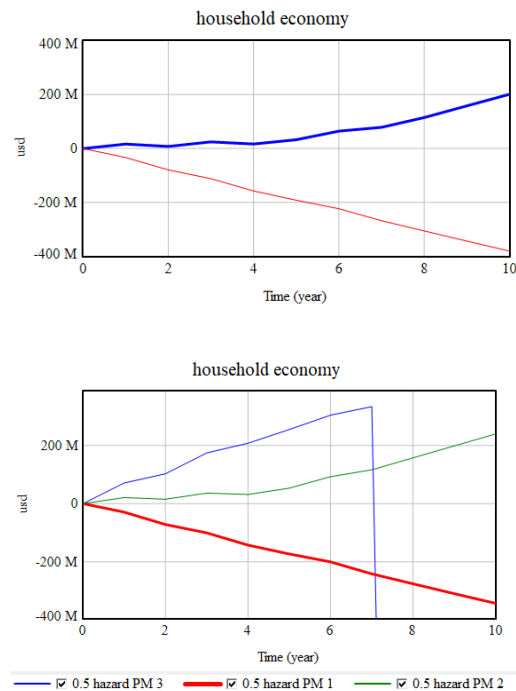
Scenario 1 is a world with little to no climate change but with random hazards. The system is resilient when the farm and market-related interventions – interventions aimed at 'price management' (PM) - are applied to improve the profits of farmers and cause the household economy to bounce back whenever there is a dip.

household economy

Scenario 2 is a climate change world where climate extremes are increasing in frequency and intensity. When PM is at 1, the economy is unable to sustain itself, leading to economic collapse from the onset. PM beyond 3 stimulates the scaling of intervention and the economy completely transitions from primary to secondary sources of livelihood. The household economy is found to be not resilient in this case and collapses due to energy poverty in the context. When the PM is at 2.3, the economy bounces back and increases, indicating resilience. In this scenario, there is a healthy mix of population in both primary and secondary livelihoods. This indicates how essential diversity in livelihood is for managing the resilience of this farm SES.

(A) Policy interventions

We have two recommendations for policies to improve the household economy of the system and lessen or negate the constraints imposed by energy poverty.

Selected Variables

☑ primary vocation : intervention 2 PM 2 diesel 8B 0.3 hazard
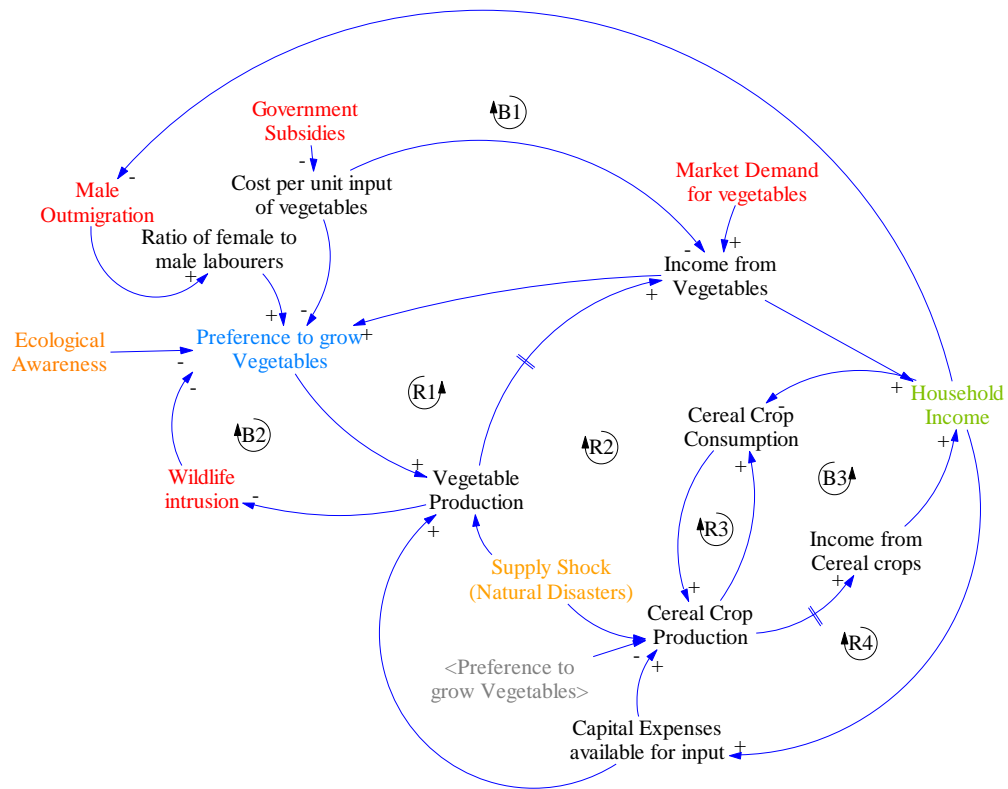☑ secondary vocations : intervention 2 PM 2 diesel 8B 0.3 hazard

Intervention 1: Access to Myanmar's power grid would allow the community to have a consistent supply of energy. The community moves entirely into secondary vocations, and the economy increases exponentially due to the removal of the energy constraint. This however is unrealistic as the cost to gain access to the energy grid is too high.

household economy

☑ intervention 2 PM 2 diesel 8B 0.5 hazard
☑ intervention 2 PM 2 diesel 8B 0.3 hazard
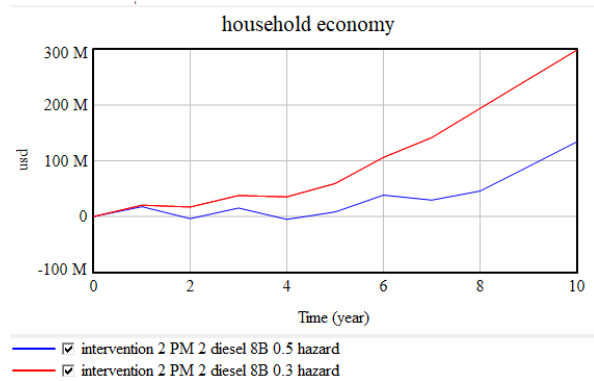
Intervention 2: The second policy recommendation is for the community to adopt a 'smart grid' using various renewable energy sources. The reliance on diesel decreases and could eventually be rendered unnecessary with the smart grid system. The variety of energy sources builds the resilience of the SES. The smart grid diminishes the effects of the balancing feedbacks arising on account of energy poverty and allows the economy to grow beyond the theoretical maximum. Eventually, the community will transition entirely to secondary or tertiary industries. However, this model does not account for the initial construction costs and possible political repercussions from land-use necessary.

(B) Case study of Dadeldhura in Nepal

| Type	n	Loop Process
Reinforcing	1	An increase in *Preference to grow vegetables* leads to an increase in *vegetable production*, this causes an increase in *income from vegetables* and eventually a *greater Preference to grow vegetables* again. The impact of exogenous variables, namely *Government Support* and *Market Demand*, has led to a further increase in *Income from vegetables*.
Reinforcing	2	As *Income from vegetable* increase, the generated *Household Income* will increase. This will lead to more *Capital Expenses available for input* in the next crop season, which will result in greater *vegetable production*.
Balancing	1	When *male out-migration* increases, there is a greater *ratio of female-to-male* labourers, leading to an increase in *Preference to grow vegetables*. This will cause an increase in *vegetable production* and *Household Income.* A rise in *Household Income* will result in a decrease in *male outmigration* as there is less incentive to migrate to seek alternative sources of income.
Balancing	2	As *wildlife intrusions* increase, there is a greater *Preference to grow vegetables*. This will lead to an increase in *vegetable production*, and subsequently a fall in *wildlife intrusion*.
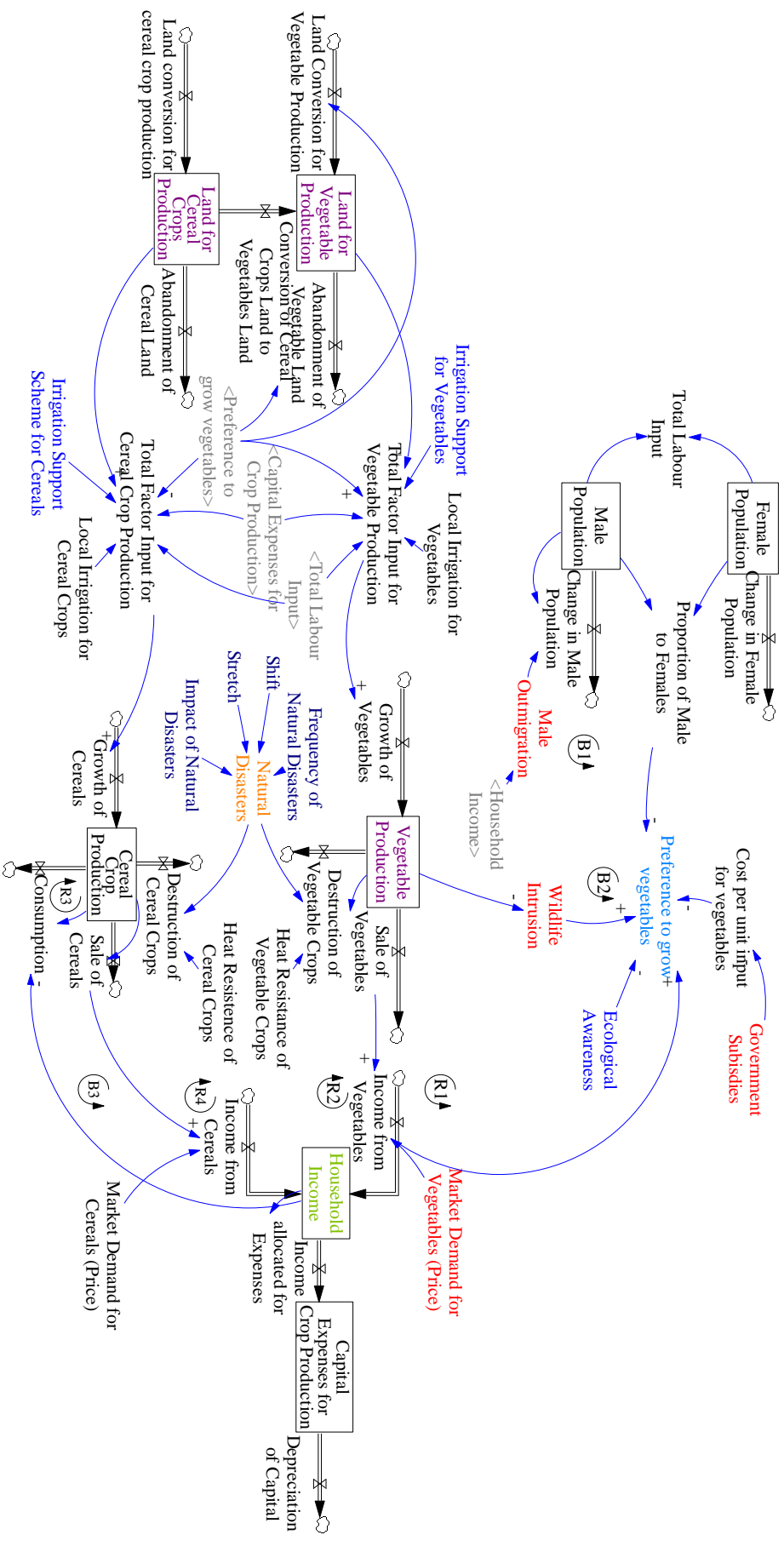
(B) Sensitivity Analysis

Sensitivity analysis is carried out to observe the effect of natural disaster (drought) on household income, which represents the major indicator of Nepalese farmer welfare. The model tests the effect of increase in drought on vegetable and cereal production and is subsequent effect on household income in different scenarios. Model tests were also conducted for policy intervention (ecological awareness and irrigation support) scenarios on vegetable and cereal production and is subsequent effect on household income.

Drought scenarios without/with climate change: Farmers and policy makers' overestimation of vegetable cultivation capacity may cause a collapse of household income.

Moderate Frequency of Droughts: Incidents of drought (mean frequency of droughts is λ = 0.364) cause vegetables production to significantly decline, cereal crops on the other hand initially decline but recover (in 4 years). [A need to preserve heat resistant cereal crops]
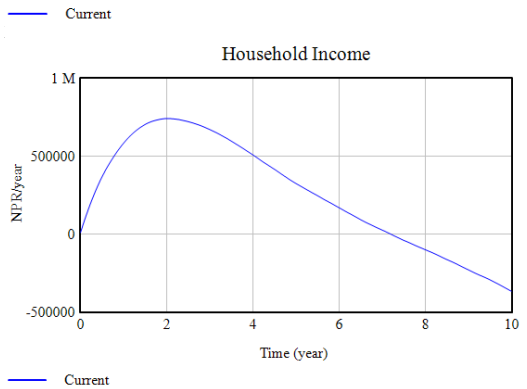

Drought with climate change (Extreme): Incidence of drought with climate change (mean frequency of droughts is λ = 0.364) cause collapse of both cereal crop and vegetable production, indicating household income are extremely vulnerable to climate change and increase in drought frequency.)

(B) Policy Testing

Intervention and climate change scenarios: The combined intervention of increasing ecological awareness and irrigation support significantly increases systems resilience (to potential drought and climate change).
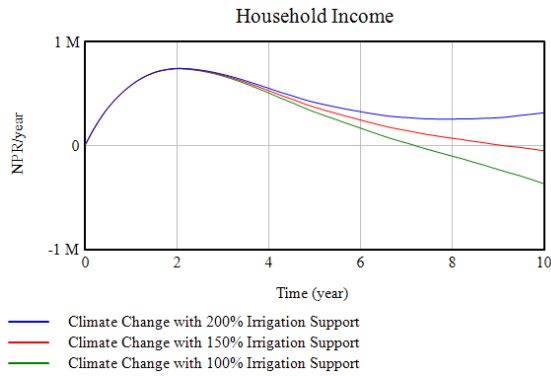
Irrigation support in vegetable: Increase in irritation support for vegetable increase both vegetable and cereal crop production. However, it may not be viable due to the expenditure required for irrigation investment to make significant income increase
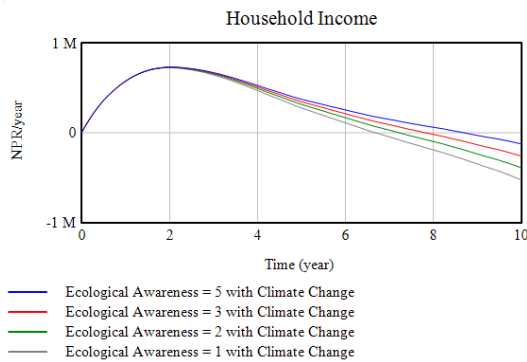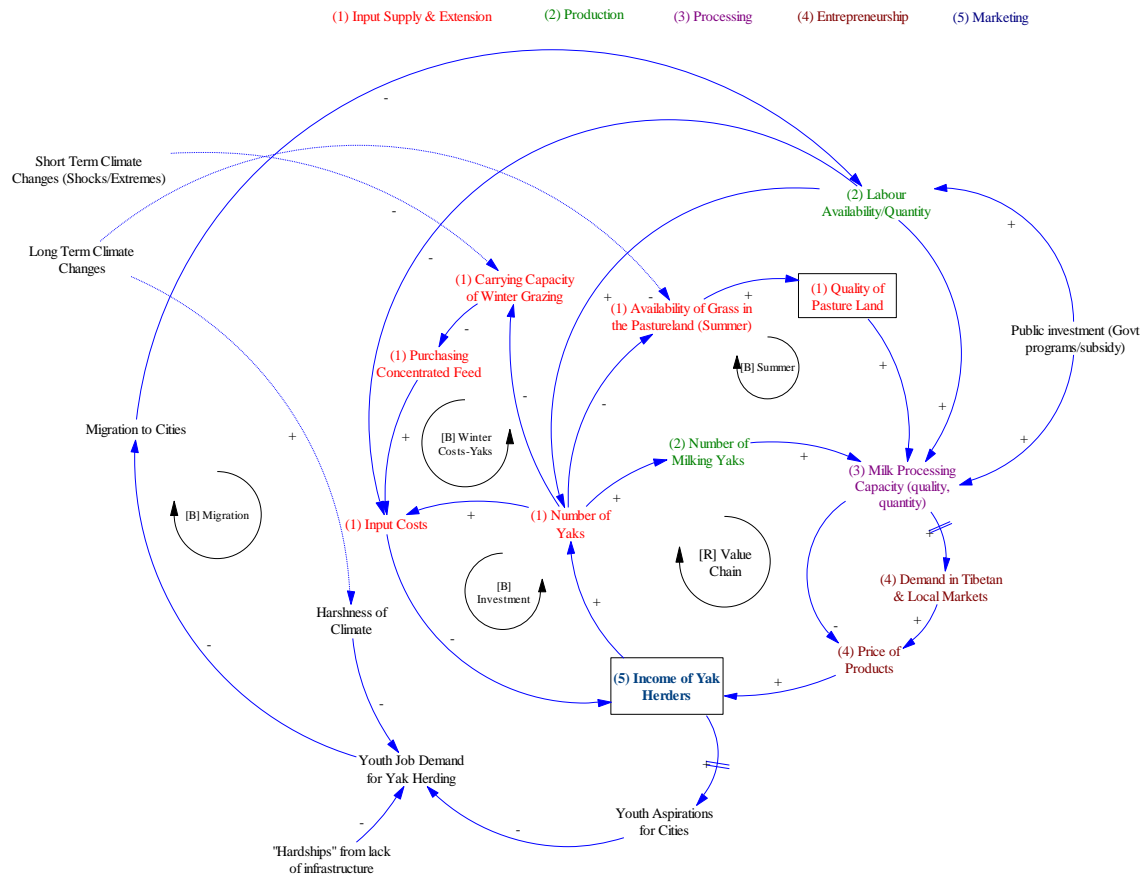

Increase in ecological awareness: Ecological awareness increase cereal production only. The increase is not sufficient to increase household income.
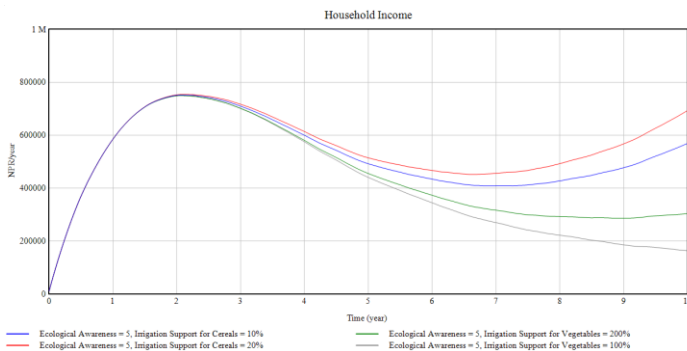
Increase in ecological awareness and irrigational support: A combined intervention of ecological awareness and irrigation support has drastic positive influence in household income.)

Underestimation of drought risk may crease a false sense of security based on the current situation amongst the policy makers and farmers. To prevent the system from collapsing the policy makers must promote drought resistant cereal crops to maintain crop diversity, promote ecological awareness to facilitate management and provide support system for heat resistant crops.
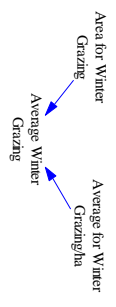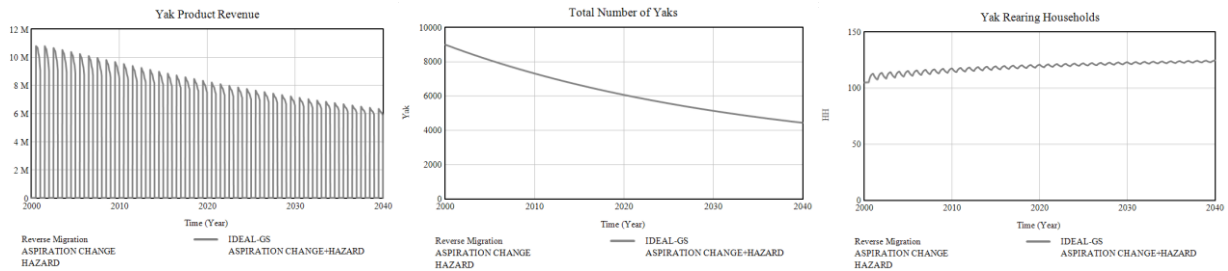
(C) Case study of Haa in Bhutan

(1) Input Supply & Extension (2) Production (3) Processing (4) Entrepreneurship (5) Marketing

Short Term Climate Changes (Shocks/Extremes)

Long Term Climate Changes

(2) Labour Availability/Quantity

(1) Carrying Capacity of Winter Grazing

(1) Availability of Grass in the Pastureland (Summer)

(1) Quality of Pasture Land

Public investment (Govt programs/subsidy)

(1) Purchasing Concentrated Feed

[B] Summer

Migration to Cities

[B] Winter Costs-Yaks

(2) Number of Milking Yaks

(3) Milk Processing Capacity (quality, quantity)

[B] Migration

(1) Input Costs

(1) Number of Yaks

[R] Value Chain

(4) Demand in Tibetan & Local Markets

[B] Investment

Harshness of Climate

(5) Income of Yak Herders

(4) Price of Products

Youth Job Demand for Yak Herding

Youth Aspirations for Cities

"Hardships" from lack of infrastructure

| Loop	Name	Loop Process
Reinforcing	Value Chain	The income of herders determines the total Yak population and the yak population thereof link to the milking yaks and milk productivity. When the milk productivity is high, the amount of processed milk products also increases. However, the market demand is not saturated (note: in normal market study, if supply increases then demand reduces and price also reduces due to oversupply, but this is not the case here) and the demand in the market (Tibet and local market in Haa) for the processed dairy products is increasing, so the market price is also increasing which directly contributes to the income of the yak herders. The increase income encourages the yak herder to continue and or increase yak numbers to produce more dairy products. Thus, reinforcing the system.
Balancing	Migration	Due to hardship in yak rearing due to harsh climatic conditions and unavailability of infrastructures like road access, electricity, milk processing plant etc. the youths are not interested to continue yak herding. The increasing youth aspiration to find better job opportunities have also led to discontinuation of this traditional practice thus, increasing migration to cities. Due to increasing migration, there is labor shortage for yak herding, fuel wood collection (production system), as well as milk processing (processing system). Labor shortage lead to selling the yak herds, thus reducing quantity/quality of processed products and the income of yak herders. With a decrease in income, the youth's aspiration to cities likewise decreases hence, balancing the loop.
Balancing	Summer	The household income of yak herders determines the number of yaks they raise. The total number of yaks and other grazers in the highland summer pastureland and the biomass productivity limit its carrying capacity, which is currently within the threshold limit providing sufficient and quality of forage from the pastureland hence, continuing milk productivity in summer. During this season the milk is processed and sold in the local markets of Tibet and Haa which contributes to household income and the herder continue or invest on yak herding. This continues until the carrying capacity of the pastureland has reached a threshold.
Balancing	Winter - Costs Yaks	In winter, yak population usually face scarcity of green fodder, so the herders have to buy concentrated feed as alternative supplementing feed source. Purchase of concentrated feed increases the input costs (expenses) of the herders ultimately affecting their income and thus checking the yak population.
Balancing	Investment	The total number of yaks determine the investments in the input costs incurred for yak rearing. This will affect the household income and ultimately checks the yak population to minimize investment costs.

**(C) Scenario testing:**

A <u>baseline scenario</u> was modelled to understand the three integrated subsystems on yak population, socio-cultural values and market dynamics to get an insight into how the overall system functions without introducing any drivers of change such as climate hazards and youth aspirations. The main indicators of each subsystem, namely *Total Number of Yaks*, *Yak Rearing Households* and *Yak Product Revenue* respectively have exhibited a goal-seeking behaviour, implying that the system is moving towards an equilibrium state.

Several scenarios were tested to understand the influence of climate hazards and changing aspirations of youths:
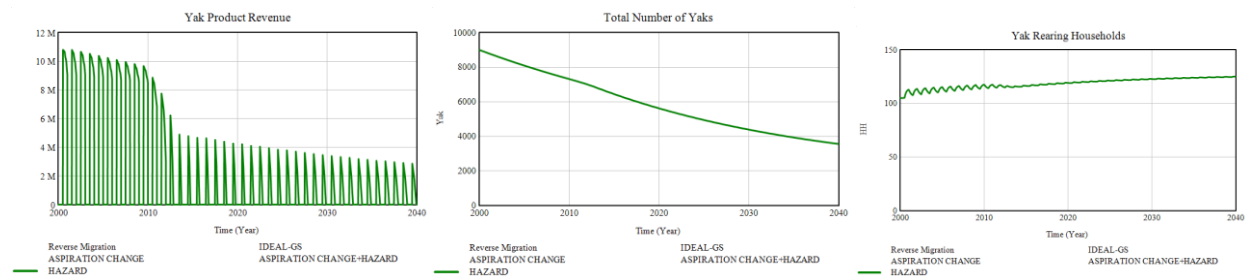
<u>Climate hazards</u> present an immediate decline in the *Yak Product Revenue* but return to a goal-seeking behaviour immediately after. Other indicators were affected negatively but not too significantly. This implies a degree of resilience inherent in the livelihood system deeply rooted in cultural values to respond towards climatic shocks and stresses.
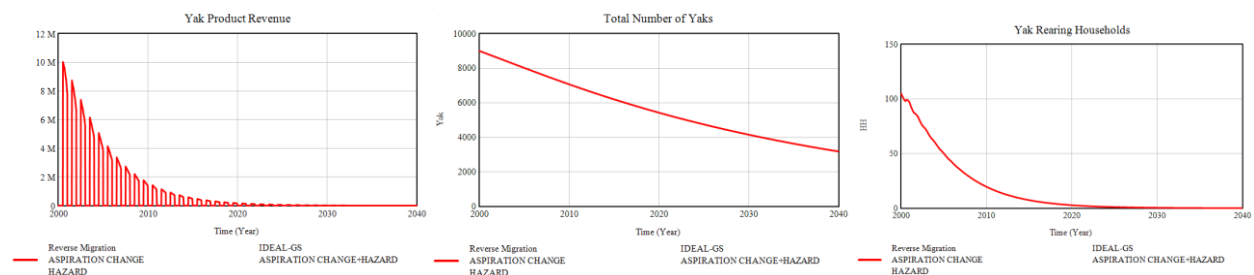

<u>Changing aspiration of youths</u>, on the other hand, shows how a reduction in *Yak Rearing Household* will similarly result in a collapse of the *Yak Product Revenue*. This demonstrates how long and gradual socio-cultural changes have a huge potential to disrupt an otherwise stable livelihood system.
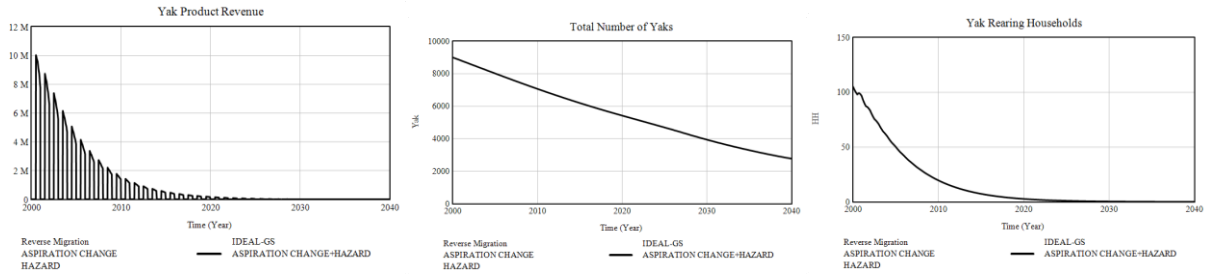
Additionally, <u>a combination of climate hazards and aspiration change</u> was simulated to observe the combined effect. The trend results of the main indicators are almost identical to that of the aspiration change scenario. This further asserts that changing aspiration of youths is a much more influential driver of change to the yak-based livelihood system than climatic shocks. This highlights the disruptive potential of socio-cultural change in the system which may finally lead to system collapse.


(C) Policy Analysis and Testing

Through a model analysis, the changing aspiration of youths appears to be a crucial factor that causes reduced labour availability and finally a decline in the yak industry. Hence, an analysis was conducted to simulate the effect of policy interventions on labour availability. This also evaluates the possible long term effects of the *Gyensun* programme which the Bhutanese government implemented to retain youths in the village through subsidies and technical support mainly on agriculture and livestock.
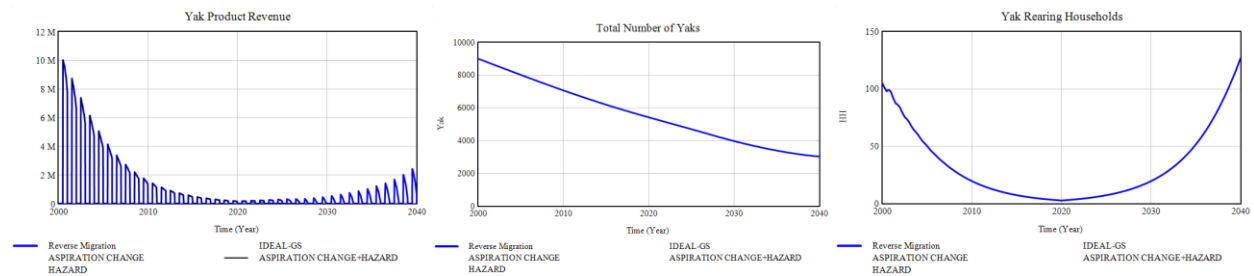

Findings show that all 3 subsystems could bounce back, however, the change will be rather gradual and it will take time to fully recover. Also, the rate of increase in the *Yak Rearing Households* is expected to be much faster than the *Yak Product Revenue*. It is to be expected that the earlier years of reverse migration will see low profits/revenue. This calls for the government to prepare enough safety nets and invest in developing an entrepreneurial ecosystem to keep citizens engaged while linking the industry to local and regional markets so that the social-ecological system can recover sooner.

**(D) A Systems Archetype; Drawing similarities from Myanmar, Nepal and Bhutan**
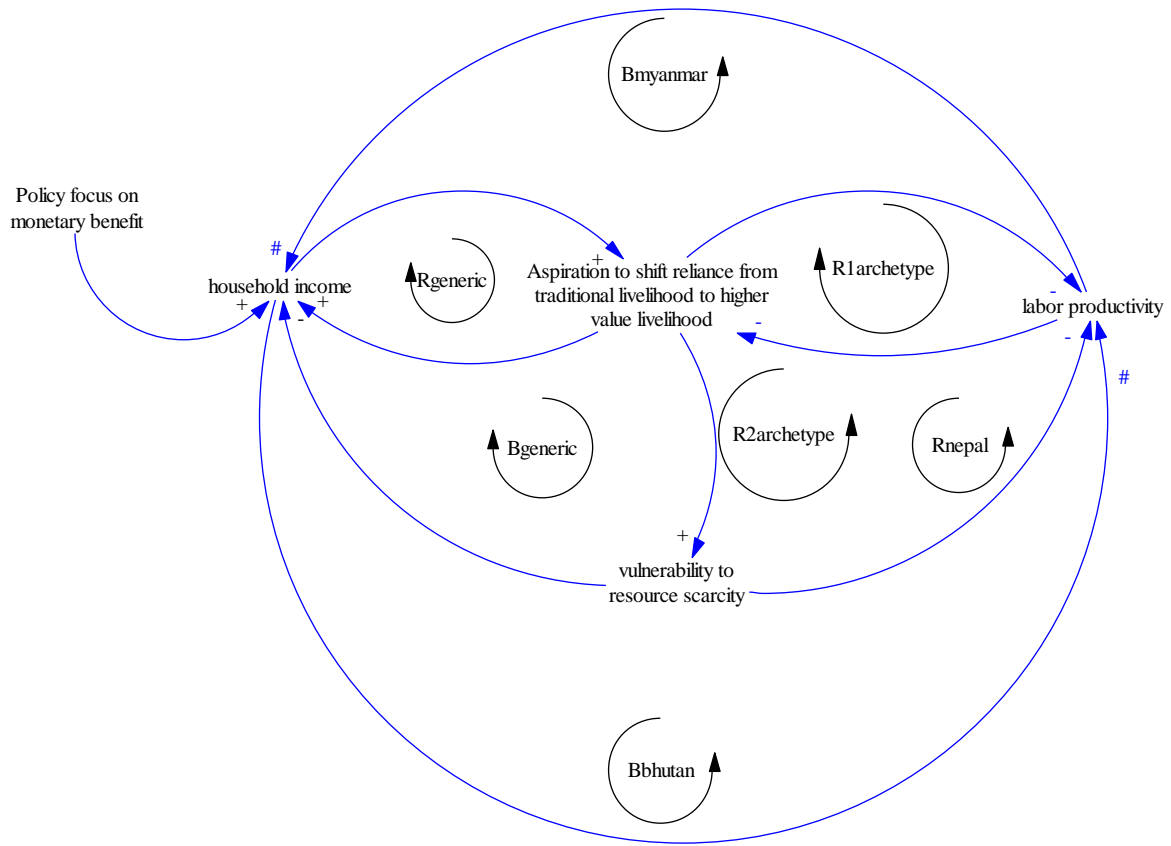
# here signify either + or − polarity depending on the case

Myanmar
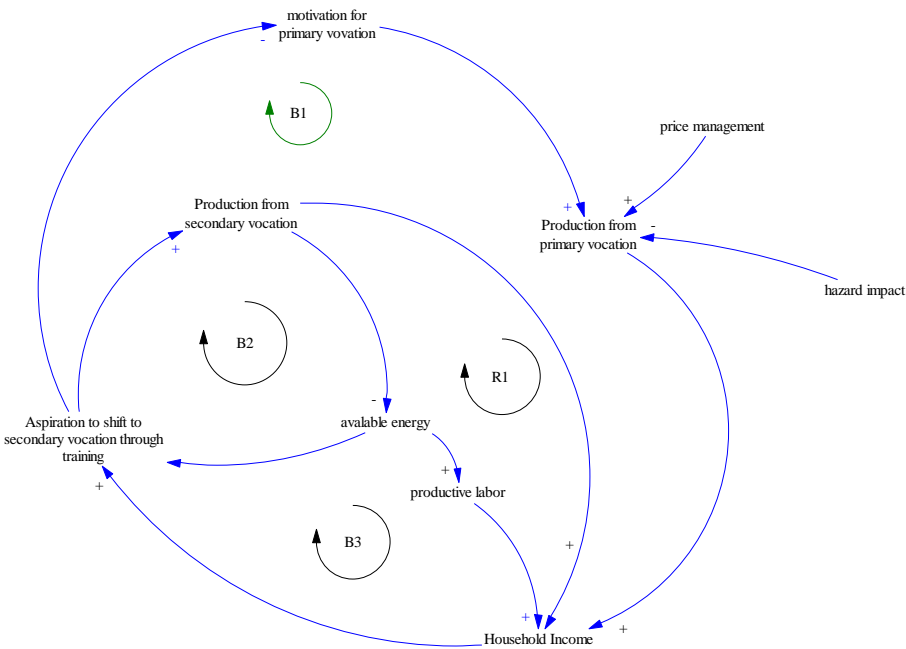
R1 starts with Policy of Price management. As policy is implemented successfully, people get benefits from primary vocation i.e. agricultural production which thereby increases household income. As household income increases, people can access means for training to channel their aspiration towards moving for secondary vocation like enterprises. Secondary vocation brings in more household income starting R1. However as more people get engaged in enterprise, they may try to totally shift out of farming thereby decreasing one source of income, thereby balancing the increase of total household income which is captured by B1. However as engagement in enterprises increase, consumption of energy increases decreasing the available energy which checks the growing aspiration to shift. This energy poverty also increases women's time to gather firewood rather than productive labor which has detrimental effects on household income that is illustrated by B3. Given the limitation in availability of energy source and its access, people have to check their aspiration towards shifting totally into enterprise. The current context of energy poverty may not be ideal for the total shift to enterprise as B2 and B3 may lead to collapse of household income if reliance is totally on enterprise. But it is important that people engage with enterprise as such diversity of livelihoods is important to support household income if hazard of landslides hampers agriculture production greatly. Hence, policy has to calibrate how much support it can offer only to primary vocation in this context such B2 and B3 do not take over the dynamics or should it also use alternative sources of energy as a leverage point to increase the energy pool.

Nepal
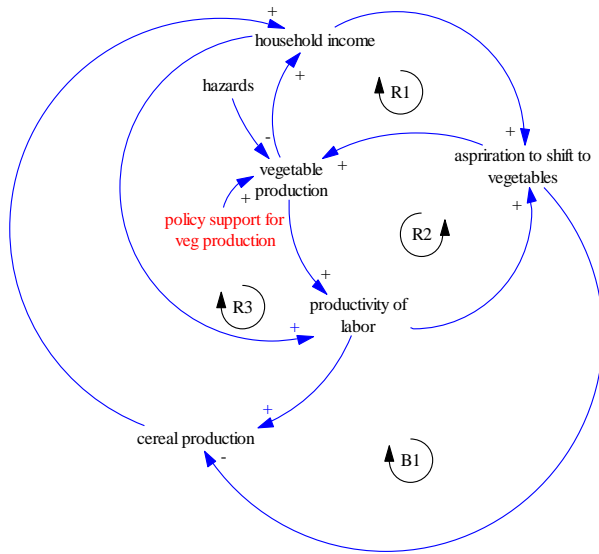
As policy support with irrigation and subsidies start to encourage vegetable production, household income increases which increases the aspiration to engage more in vegetable production, thereby starting R1. This increase in vegetable production and resulting income also increases labor productivity as it decreases wildlife intrusion, thereby starting R2. This affluence generated aspiration also leads to change in consumption pattern and decreases motivation for cereal production which balances the increase of household income, hence B1. As household income increases, there is a slight chance of increase of productivity of labor as it checks outmigration of males which can help in continuing some cereal cultivation as illustrated by R3. If frequency of droughts increase, vegetable production will be impacted most owing to its minimal heat tolerance which can lead to collapse through R1 and R2. In order to avert the collapse, the shift has to be balanced, through policy focus on management of diversity of crops maybe through infrastructure support for cereal production to match the support given to vegetable production and also awareness generation for this diversity.

Bhutan
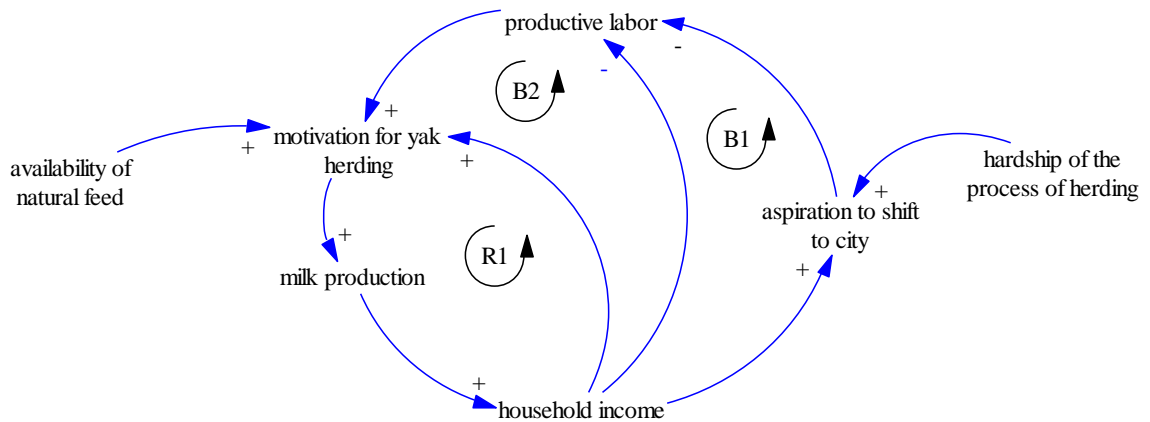
As milk production and market for its products increase, the household income increases among the yak herding community which thereby increases the motivation for continuing the livelihood, thereby R1. But as income increases combined with the continued hardship of the herding process an aspiration to disengage from the livelihood and shift to city builds up which thereby decreases the youth in the livelihood i.e. the productive labor which further decreases the motivation to continue the livelihood, illustrated by B1 and B2. If the natural feed i.e. the grass decreases than a particular threshold due to changes in climatic factors this will lead to decrease of yak influencing the motivation continue in this livelihood negatively. In this case study policy is not initiating the change but currently policy is looking at market mechanisms and yak life cycle to increase productivity of milk products. However, there is scope for policy to focus on creating diversity in local livelihoods so that reliance on the labor intensive livelihood can be balanced with other sources of income without migrating from the area. Moreover, such diversity will provide a buffer to accommodate for any reverse migration, as observed in many localities of South Asia during Pandemic. Local livelihood options have to be designed such that the tradition of yak herding can be managed as a profitable option without too much reliance.