

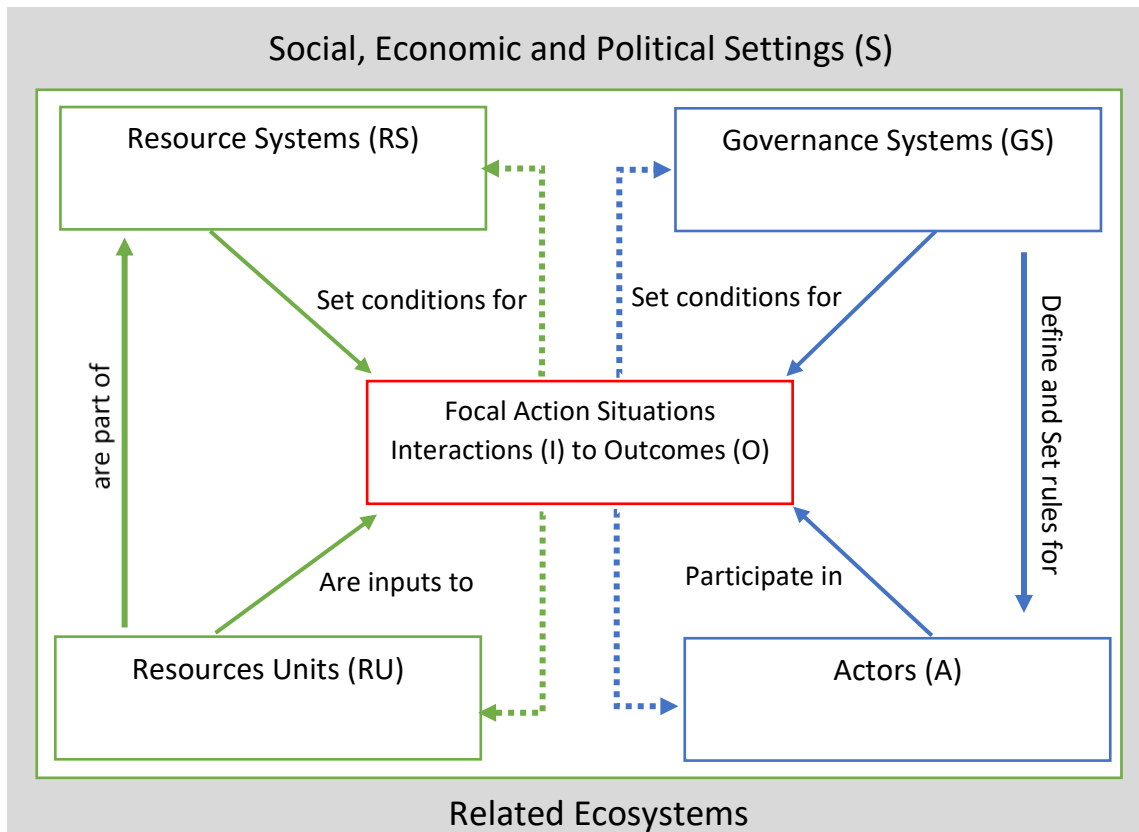
Supporting Information - Integration of Resilience Markers framework into Social-Ecological System: Case Study of Agriculture in Dadeldhura, Nepal

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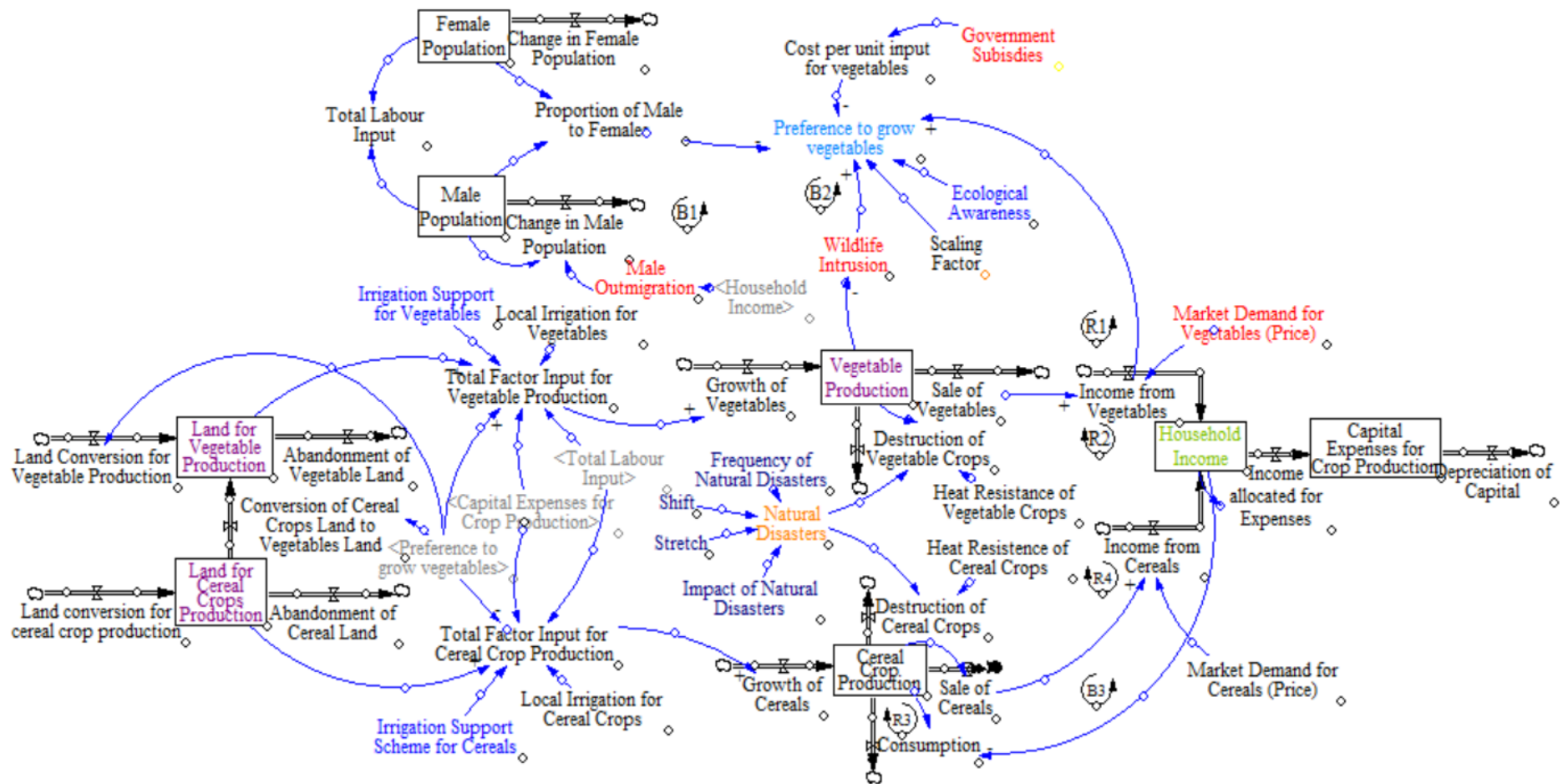
Appendix S1. SES framework

The figure below SES framework, the lines in bold (-) represent a direct link between two variables and the dotted lines (...) represents a feedback link, illustrating how different systems and their actors interact with one another under social, economic and political settings.



SES framework adapted from (Ostrom, 2009)

Appendix S2. Full Stock Flow Diagram modelled in Vensim.



Appendix S3. Documentation of parameters, equations and variables used in our SFD created in Vensim software.

(01) Abandonment of Cereal Land=

10

Units: ha

(02) Abandonment of Vegetable Land=

10

Units: ha

(03) Capital Expenses for Crop Production= INTEG (

Income allocated for Expenses-Depreciation of Capital,

1000)

Units: NPR

(04) Cereal Crop Production= INTEG (

0.1*(Growth of Cereals-Sale of Cereals-Consumption-Sale of Cereals)-Destruction of Cereal Crops

,

10000)

Units: metric tons [0.5,?]

(05) Change in Female Population=

0

Units: people/year

(06) Change in Male Population=

Male Population*Male Outmigration

Units: people/year

(07) Consumption=

0.2*Cereal Crop Production/Household Income

Units: metric tons/year

(08) Conversion of Cereal Crops Land to Vegetables Land=

Preference to grow vegetables*400

Units: ha/year

(09) Cost per unit input for vegetables=

157200*(1-Government Subsidies)

Units: NPR/ha

Average Expense: 157200 NPR per hectare

(10) Depreciation of Capital=

100000

Units: NPR/year

Assume a constant Depreciation of capital at 1000 NPR/year

(11) Destruction of Cereal Crops=

Natural Disasters*(1-Heat Resistance of Cereal Crops)

Units: metric tons

(12) Destruction of Vegetable Crops=

Natural Disasters*(1-Heat Resistance of Vegetable Crops)

Units: metric tons

(13) Ecological Awareness=

1

Units: Dmnl

(14) Female Population= INTEG (

-Change in Female Population,

1000)

Units: people

(15) FINAL TIME = 10

Units: year

The final time for the simulation.

(16) Frequency of Natural Disasters=

0

Units: Dmnl [0,10]

(17) Government Subsidies=

0.6

Units: Dmnl

Average government subsidy is 60%

(18) Growth of Cereals=

IF THEN ELSE(Total Factor Input for Cereal Crop Production >=0 , Total Factor Input for Cereal Crop Production

, 0)

Units: metric tons/year [0,?]

(19) Growth of Vegetables=

IF THEN ELSE(Total Factor Input for Vegetable Production >=0 , Total Factor Input for Vegetable Production

,

0)

Units: metric tons/year

(20) Heat Resistance of Vegetable Crops=

0.4

Units: **undefined**

(21) Heat Resistance of Cereal Crops=

0.8

Units: **undefined**

(22) Household Income= INTEG (

Income from Cereals+Income from Vegetables-Income allocated for Expenses

,

10000)

Units: NPR/year

(23) Impact of Natural Disasters=

19000

Units: Dmnl [0,30000]

(24) Income allocated for Expenses=

Household Income*0.5

Units: NPR/year

Assume that half of Income is allocated towards expenses for
production

(25) Income from Cereals=

Sale of Cereals*"Market Demand for Cereals (Price)"

Units: NPR/year

(26) Income from Vegetables=

Sale of Vegetables*"Market Demand for Vegetables (Price)"

Units: NPR/year

(27) INITIAL TIME = 0

Units: year

The initial time for the simulation.

(28) Irrigation Support for Vegetables=

1e-08

Units: Dmnl [-1,1]

(29) Irrigation Support Scheme for Cereals=

0

Units: Dmnl

(30) Land conversion for cereal crop production=

200

Units: ha/year

(31) Land Conversion for Vegetable Production=
 $750 * \text{Preference to grow vegetables}$

Units: ha/year

(32) Land for Cereal Crops Production= INTEG (
 $0.1 * (\text{Land conversion for cereal crop production} - \text{Abandonment of Cereal Land}$
 $- \text{Conversion of Cereal Crops Land to Vegetables Land}),$
19200)

Units: ha

(33) Land for Vegetable Production= INTEG (
 $0.1 * (\text{Land Conversion for Vegetable Production} - \text{Abandonment of Vegetable Land}$
 $+ \text{Conversion of Cereal Crops Land to Vegetables Land}$
 $),$
1800)

Units: ha

(34) Local Irrigation for Cereal Crops=
 $1e-08$

Units: Dmnl

(35) Local Irrigation for Vegetables=
 $1e-08$

Units: Dmnl

(36) Male Outmigration=
 $1e+07 / (\text{Household Income})$

Units: Dmnl

(37) Male Population= INTEG (
 $-\text{Change in Male Population},$
1000)

Units: people

(38) "Market Demand for Cereals (Price)"=

25

Units: NPR/metric tons

25 is the base price of vegetables in NPR/metric tons

(39) "Market Demand for Vegetables (Price)"=

50

Units: NPR/metric tons

The baseline price of Vegetables is 50 NPR/ metric tons

(40) Natural Disasters=

RANDOM POISSON(0, 1 ,Frequency of Natural Disasters , Shift , Stretch , 0
) *Impact of Natural Disasters

Units: metric tons

(41) Preference to grow vegetables=

IF THEN ELSE((1-EXP((-ABS(((Ecological Awareness)^(-20)*1e-20*Income from Vegetables
) / (Cost per unit input for vegetables
) / (Proportion of Male to Females
) / Wildlife Intrusion
))) / Ecological Awareness < 0.8, (1-EXP((-ABS(((Ecological Awareness)^(-20)
) *1e-20*Income from Vegetables) / (Cost per unit input for vegetables
) / (Proportion of Male to Females
) / Wildlife Intrusion
))) / Ecological Awareness , 0.8)

Units: Dmnl

Set 0.8 as the maximum preference to grow vegetables.

(42) Proportion of Male to Females=

Male Population / (Female Population)

Units: Dmnl

(43) Sale of Cereals=

$0.8 * \text{Cereal Crop Production}$

Units: metric tons/year

(44) Sale of Vegetables=

Vegetable Production

Units: metric tons/year

(45) SAVEPER =

TIME STEP

Units: year [0,?]

The frequency with which output is stored.

(46) Shift=

0

Units: Dmnl [0,1,0.01]

(47) Stretch=

1

Units: Dmnl

(48) TIME STEP = 0.0078125

Units: year [0,?]

The time step for the simulation.

(49) Total Factor Input for Cereal Crop Production=

$(\text{Local Irrigation for Cereal Crops} + \text{Irrigation Support Scheme for Cereals}$

$) * (1 - \text{Preference to grow vegetables}) * \text{Capital Expenses for Crop Production} * \text{Land for Cereal Crops Production}$

$* \text{Total Labour Input}$

Units: Dmnl

1e-08 is the scaling factor

(50) Total Factor Input for Vegetable Production=

$(\text{Irrigation Support for Vegetables} + \text{Local Irrigation for Vegetables}) * \text{Capital Expenses for Crop Production}$

*Land for Vegetable Production*Total Labour Input*ABS(Preference to grow vegetables
)

Units: Dmnl

(51) Total Labour Input=

$0.6 * (\text{Female Population} + \text{Male Population})$

Units: people

(52) Vegetable Production= INTEG (

$0.1 * (\text{Growth of Vegetables} - \text{Sale of Vegetables}) - \text{Destruction of Vegetable Crops}$

,

$+14000$)

Units: metric tons

(53) Wildlife Intrusion=

$(8 / (\text{Vegetable Production}))$

Units: 1/year

Appendix S4. Modelling of droughts using Poisson Distribution

For policy testing, we assumed that the frequency of droughts is modelled by a Poisson Distribution with a frequency k as follows:

$$P(k) = e^{-\lambda} \frac{\lambda^k}{k!}$$

where k refers to the Frequency of droughts per year and λ refers to the mean or the average number of droughts per year.

The Poisson Distribution is a discrete probability distribution that is used to determine the probability of the number of droughts occurring within a year. In Vensim, it is implemented using the RANDOM POISSON (m, x, M, h, r, s) function. The syntax and our parameters used to simulate different cases is as summarised the table below:

Table S1. Summary of Parameters used in Poisson Distribution

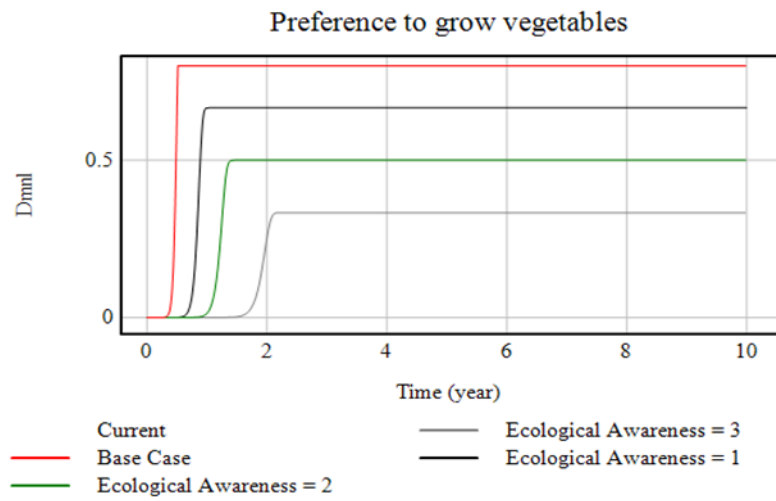
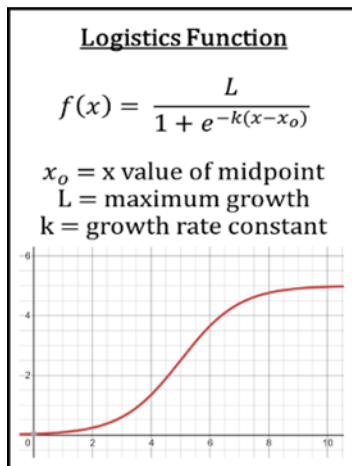
Parameters	Definition	Values used
m (min)	Minimum Value of function output	Min = 0
x (max)	Maximum Value of function output	Max = 1
M (mean)	Mean frequency (same as λ)	For Base Case, $\lambda = 0$ For Droughts only, $\lambda = 0.364$ For Climate Change, $\lambda = 0.450$
h (shift)	Indicates how much the distribution will be shifted to the right after it has been stretched	$h = 0$ (No shifting of the curve)
r (stretch)	Indicates how much the distribution will be stretched before it is shifted.	$r = 1$ (No stretch)
s (stream ID)	stream ID for the distribution by default it is equal to zero. Does not affect distribution.	$s = 0$ (by default)

Appendix S5. Tolerance of Crops to Water Shortages.

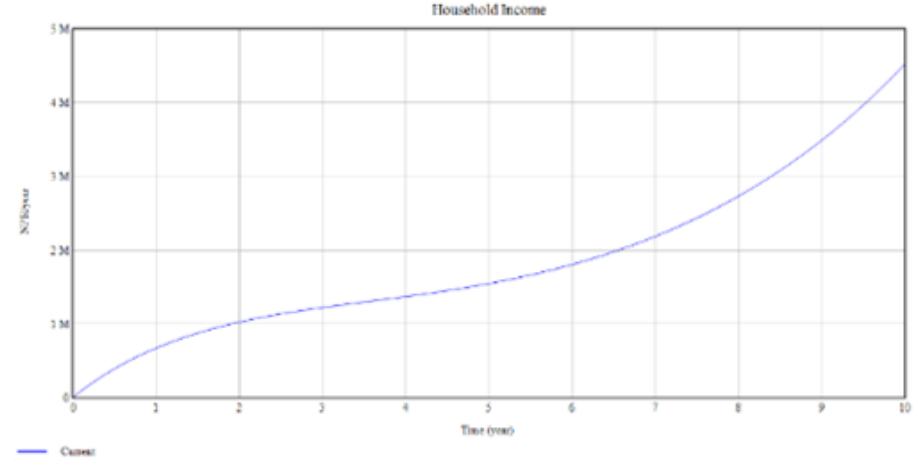
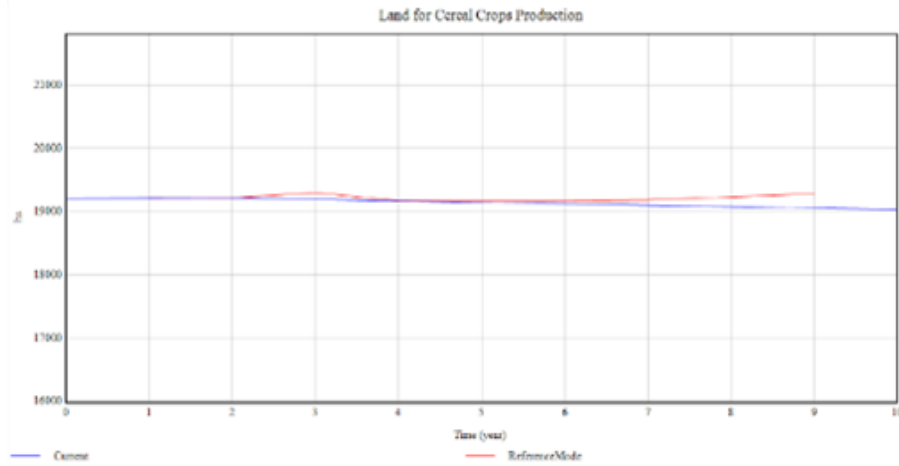
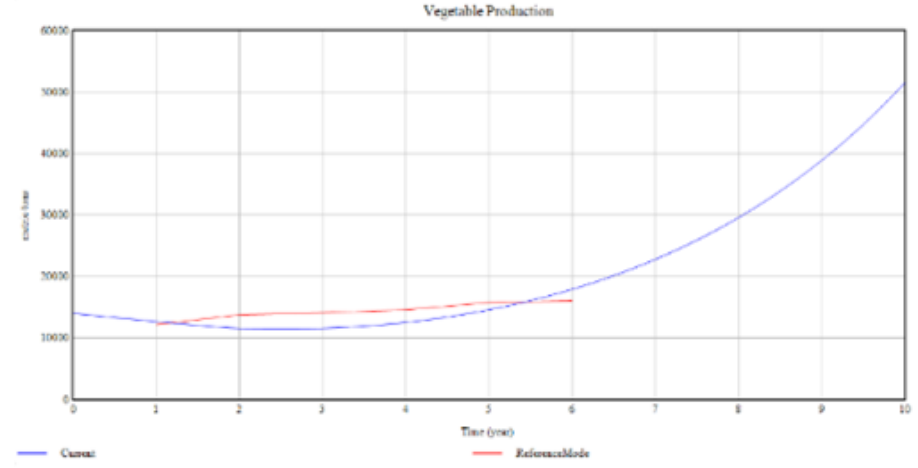
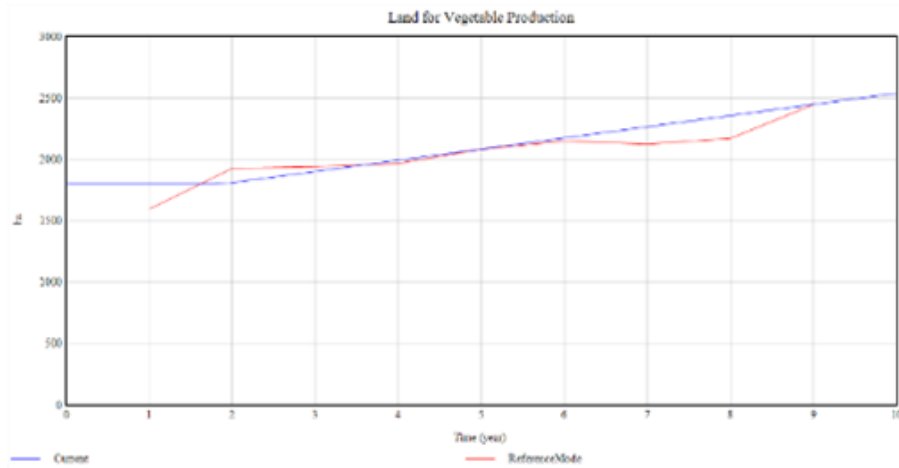
The table below (adapted from FAO (Dubois, 2011)), cereal crops accounted for in our model are highlighted in yellow, and vegetables considered in our model are highlighted in green.

Tolerance	Low	Low-Medium	Medium-High	High
Crops	cassava cotton millet pigeon pea sorghum	citrus grape groundnuts soybean sugar beet sunflower wheat	beans cabbage maize onion peas tomato watermelon	banana fresh green vegetables paddy rice potato sugarcane

Appendix S6. Modelling of preference to grow vegetables as a function of ecological awareness using a logistics function.



Appendix S7. Simulation Results showing Land for vegetable Production, Vegetable Production, Land for Cereal Crop Production, Cereal Crop Production from baseline scenarios.



References

- DUBOIS, O. 2011. *The state of the world's land and water resources for food and agriculture: managing systems at risk*, Earthscan.
- OSTROM, E. 2009. A general framework for analyzing sustainability of social-ecological systems. *Science*, 325, 419-422.