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Understanding Environmental Issues Using System Dynamics Methods. Pressure on Natural Resources in Southern Madagascar

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Abstract

The tropical dry forest in Androy, southern Madagascar, is threatened with disappearance by many activities. We can see in the literature and government documents the fact that the rural population is little concerned by natural resources conservation. To debate this complicated subject, multidisciplinary approach allows us to understand the different dynamics. This paper explains deforestation as a central concern among several factors causing environmental degradation in Androy. To do this, we use a system dynamics methodology for analyzing interlinks and causal relations between socio-economic and environmental variables. Deforestation is driven by many interacting factors such as a limited suite of recurrent core variables, of which the most evident would be socio-economic conditions, populations' growth and climate. Taking this into account, simulations of a socio-economic-environmental model is conducted.

Key Words: Androy, Dry forest, Natural resources, System dynamics method, Multidisciplinary.

Résumé

La forêt sèche tropicale de l'Androy, extrême sud de Madagascar, est menacée de l'extinction par plusieurs sources de perturbation. Nous pourrions voir dans quelques littératures et des documents gouvernementaux l'affirmation que la population rurale ne se soucie pas de conservation de ressources naturelles. Au regard de ce sujet, la gestion durable du secteur forestier rentre dans un système complexe et multidisciplinaire. Cet article explique la déforestation comme un point central de plusieurs facteurs qui causent les problèmes environnementaux dans Androy. Ce faisant, la dynamique des systèmes est la méthode utilisée pour analyser les relations causales entre des variables socio-économiques et environnementales. Plusieurs facteurs s'entremêlent dans le problème de la déforestation dont les plus évidents seraient des facteurs socio-économiques, démographiques et climatiques. Dans ce sens, une simulation sera effectuée en considérant le pôle social, économique et environnemental.

Mots clés : Androy, Forêt sèche, Ressources naturelles, Méthode de la dynamique des systèmes, Multidisciplinaire.

1 Introduction

Throughout history, demand for timber, forest products and agricultural land have had a negative effect on the world's forest resources. Such forest loss is the result of many pressures, acting in various combinations in different geographical locations (Geist and Lambin, 2002).

In this paper, we are interested in tropical dry forest and open woodlands. According to (FRA, 2005), only about seven percent of the Earth's dry land, are covered by tropical dry forest, with all of the forests of the southern part of Madagascar belonging to this zone. Dry forest in Madagascar is fragile because of its high levels of species endemism with the *flora* and *fauna* having come to form part of a unique ecosystem thanks to the island's isolation. There are a wide range of endemic species and 48% of the genera of plants are unique in the island (Koechlin, 1972). The "spiny forest region" is also listed as one of the 200 most important ecoregions (Olson et al., 2002). In 1970, ten years after gaining independence from French colonization, the Malagasy forests, particularly in Androy were becoming increasingly depleted due to *hatsake* (slash and burn), *ororaketa* (cactus burning for cattle herding), timber harvest and charcoal production (Sussman et al., 1994; Sussman et al., 2003; Fanokoa, 2007).

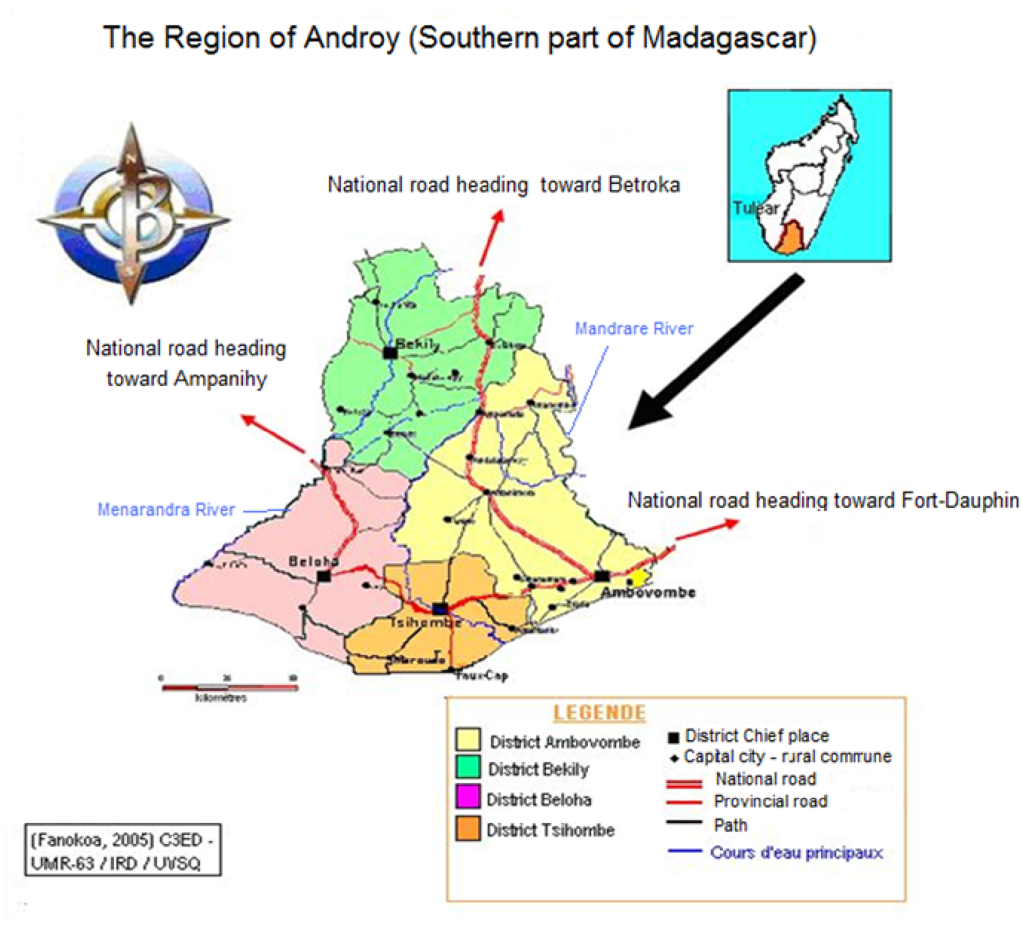

Figure 1: Study zone – The region of Androy

The study zone is situated south of the tropic of Capricorn between 24° and 26° South and 44° and 47° East. The area is bordered by the Mandrare and Menarandra rivers (Figure 1). Climate is semi-arid, with average annual precipitation varying from 35 centimetres on the south-western coast to 70 centimetres toward the north. Irregular rainfall makes the region subject to cyclic drought. Androy's forest is characterized by *xerophilous* bush, dominated by species of endemic plant families: the *Didiereaceae* and the *Euphorbiaceae.*

During recent decades, despite the recognition of the priority status of the forests little research was carried out on the forest cover changes in the region. Official protected areas are also few[1] and the region itself is forgotten (Elmqvist, 2004). Despite this lack of official protection, customary laws and taboos which play an important role in the local society are institutional factors which make a great contribution to protecting the forest patches in this region.

In the Androy region, clan is the basis of traditional socio-political organization. Each clan has its size, area, wealth, and ritual. The Tandroy have a social differentiation which is based on the territory, ancestry and wealth. The zebu is the central point of Tandroy culture and the animal plays a role in different practices and beliefs such as funerary cults, maleficent (indigenous spirits), benign (foreigner spirits), sacred efficacy, taboo (unspoken words or what is left unsaid), moral blame (largely determining prosperity and power). Zebus represent a tool of communication between God and human being (Fanokoa, 2007). The cattle supplies meat, milk and leather as well. Possessing significant numbers of zebu determines status and wealth which symbolizes a distinction of superiority within the societies. Hence, everybody endeavours as much as possible to have an impressive number of livestock (Fanokoa, 2007).

Accordingly, the Tandroy population are pastoralists, cultivators and they gather natural products. Over the last decade, the population has gradually seen a degradation of traditional beliefs due to miserable economic situation in the region (Fanokoa, 2007).

The increase of conversion of the forest areas into pasture and agricultural land is an evident problem in Androy. This happens because property right on forest land is not well defined i.e. the first who chops the trees is the owner of the patch of land. This insecure tenure system encourages farmers to practice *hatsake* activities in which they plant principally maize, manioc, sweet potatoes legumes, groundnuts, *paraky gasy* (Malagasy tobacco) and cucurbits. Land from *hatsake* practice is cultivated for an average of three to five years before the soil fertility is reduced to a point where it no longer becomes.

In this paper, our contribution is to identify core variables involves dynamically in the deforestation system and to study the behaviour of socio-economic and environmental system in the region by using system dynamic (SD) approach. This methodology could be applicable in several types of policy design (Forrester, 1961; Coyle, 1974).

The paper is structured as follows: Section 2 described the model including three subsections: firstly the causal loop diagram (CLD) is described, then the stocks and flows model are presented, illustrating the three steps of the model. Firstly the characterization of economic growth, the second step describes sustainable model and the third explains the social model. The results are shown at the end of each sub-model. The third section of the paper presents the conclusion.

2 The model

2.1 CLD

SD provides capabilities to follow and recognize the cause-and-effect mechanisms between the component parts of the system over time. This approach improves hopefully the behavior of stakeholders by examining the interrelationship between parameters and flows, material information, through the corporate structure. Basically the technique consists of the construction of a diagram indicating all the important relevant relationships in the system.

Sterman (2000) argues that SD attempts to model the structure of a system, including its feedback loops and dynamic relationships over time, in order to capture the behavior that it produces. Our model will be built with the software Ventana systems Inc. (VENSIM).

CLD is an essential instrument to show the feedback structure within the subsystems. The source hypothesis of dynamics can be identified. In Figure 2, arrow shows the causal links or causal influence among

[1] ... Angavo; Ambanisarika; Vohimena; Vohipary; Cap Sainte Marie...

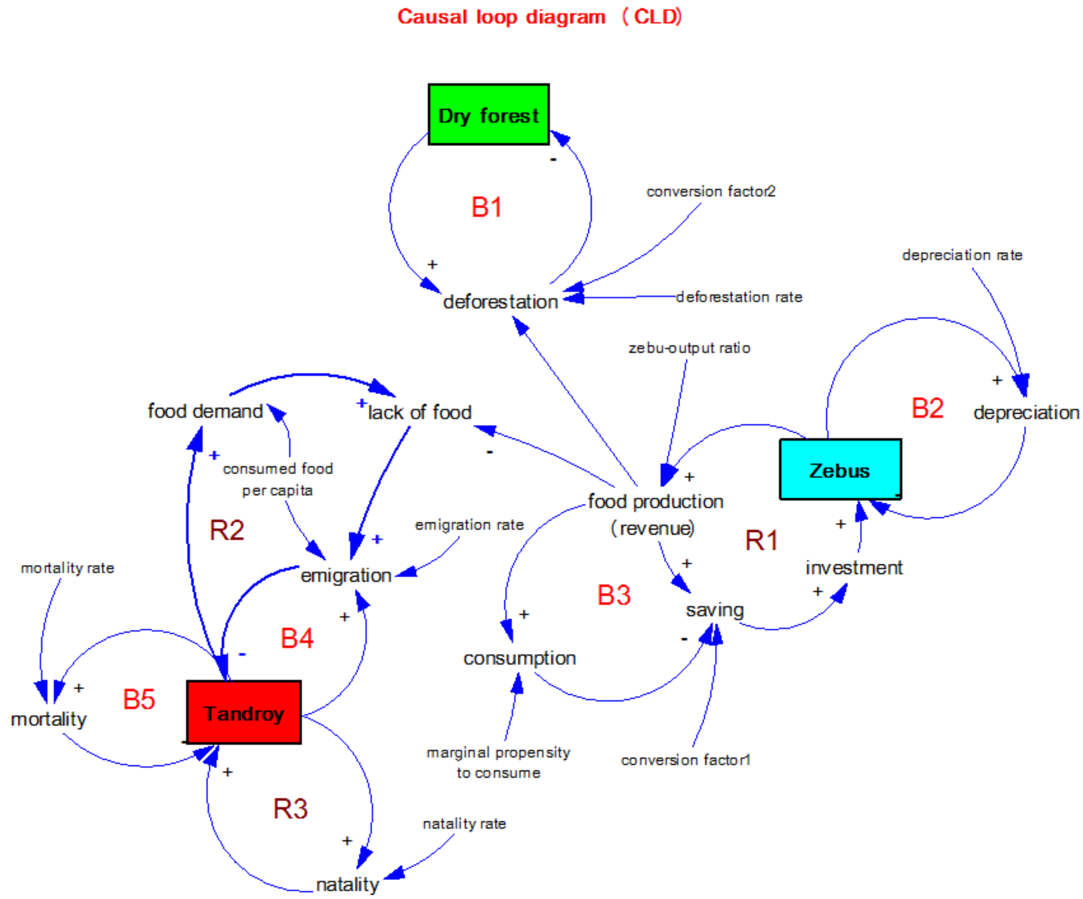

Figure 2: Causal loop diagram – CLP

variables. Negative (−) and positive (+) polarities denote how dependant variable changes when the independent variable modifies. Feedback loops (reinforcing: R or (+) and balancing: B or (−)) can also be identified in CLDs by those polarity signs.

The function Y is dependent variable and X is independent variable. In case of accumulation, Figure 2 can mathematically be expressed as follows:

$$\frac{\partial X}{\partial Y} < 0, \qquad Y = \int_{t_0}^{t} (-X_1 + ...)ds + Y(t_0)$$
$$\frac{\partial X}{\partial Y} > 0, \qquad Y = \int_{t_0}^{t} (X_1 + ...)ds + Y(t_0)$$

Description of the loops: Qualitative design of the model

This model incorporates the full range of issues which is involved in sustainable development of Androy region. In other words, the economic model will be added with the social dimensions (population, birth, death, emigration) and natural resources (dry forest resource stock, depletion and effect of agriculture production system. The general concept is illustrated in Figure 2. The whole system has 3-state variables, 11-auxilliary variables, 11 constants (initial values) and 7 loops (2 reinforcing loops and 5 balancing loops). All variables influence each other.

Loop B1 is the deforestation loop. The increase of deforestation has a negative impact on stock of dry forest. Polarities (negative and positive) result a negative feedback loop or balancing loop in Figure 2.

Loops $B2$, $R1$ and $B3$ influence directly between them in the economic pillar. The growth of food production is desired which has a positive impact of the growth of zebus. In fact, Macroeconomics looks at the total output of a nation and the way the nation allocates its limited resources of land, labor and capital in an attempt to maximize production levels and promote trade and growth for future generations. In Androy, the economic output is equivalent to a total revenue which is also equivalent to consumption plus savings or/and consumption plus investment. *Loop* $B3$ is the depreciation loop. Zebu is a tangible depreciable property of which her depreciation depends on the stock of physical capital. The sign of the loop is negative, i.e. balancing loop. Livestock depreciation begins when the livestock reaches the age of maturity (in Androy $Age > 8$). It is possible to determine an annual depreciation by the difference between the cost of the zebu and its salvage value and divided by the zebu useful life.

Loops $R2$, $B4$, $B5$ and $B3$ illustrate the system of population growth. By reinforcing loop $R3$, population itself raises which is explained by growth of natality. Whereas balancing $B3$ and $B4$ plays a counterweight to $R3$ because they decrease the population stock by emigration and mortality. For the latest decades net migration has been mainly negative *i.e.*, emigration in Androy is greater than immigration (Fanokoa, 2007). By loop $B4$, Tandroy should emigrate due to lack of food. In fact, the population growth will need more and more foods in loop $R2$. Tandroy population increases *hatsake* activity (i), to have more food production for solving problems of provisions security; and (ii) for saving.

2.2 Stocks and flows model

In the SD theory, stock and flow diagrams are essential. SD describes firstly all state variables of the system, and then it generates information upon which both actions and decisions are founded. In Figure 3, stock represents a black box which can be viewed solely in terms of its input, output and transfer characteristics without any knowledge of its internal workings. Stocks produce delays by accumulating the difference between regulator inflow to a process and its outflow. Information or material is obtained from source and outflow towards the sink. Source and sink are inexhaustible. The stock and flow diagram shows relationships among variables which have the potential to change over time.

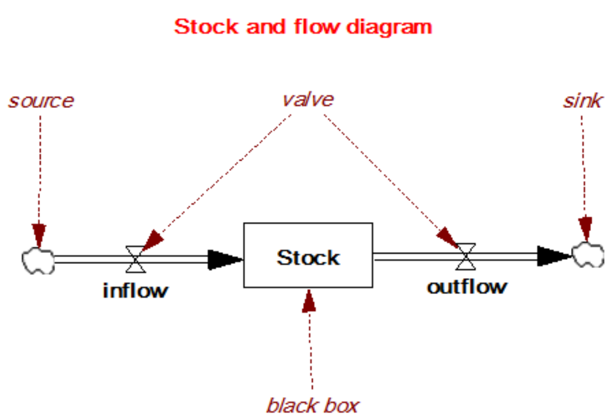

Figure 3: Stock and flow diagram (1)

Stock and flow are mathematically represented in following equations:

Differential form: $\frac{d(stock)}{dt} = \{inflow(t) - outflow(t)\}$.

Integral form: $Stock(t) = \int_{t_0}^{t} \{inflow(s) - outflow(s)\}\, ds + [Stock(t_0)]$.

Characteristics of the stock

According to Sterman (2000), (i) Stock characterizes the state of the system in which many variables depend on the current value of stocks. (ii) Stock guarantees memory and inertia in systems since it can accumulate past events. Its content can change only through an inflow and outflow. (*iii*) Stock generates delay which is defined as a process whose output lags behind its input. The difference between input and output gives a stock. In case of modeling perception delays as a stock, any material flow cannot be involved in it. (*iv*) Stock divides rate of flows and generates disequilibrium dynamics. The behavior of inflow and outflow differs each other, because of the presence of the stock (level) and the decision process that governs those both flows. The stock itself does not change in equilibrium. The derivative of stock in SD is considered as exogenous variables and non-linear function.

State variables

Three principal state variables are expressed in the model to explain the sustainability of development poles in Androy: zebu as a physical capital K, Tandroy population L and forest resources F. The model will be portrayed in 3 steps of dynamic sub-model with a discrete time. In each sub-model, the following matters will be described: (*i*) equations of sub-model, (*ii*) flow and stock diagram, (*iii*) steady state equilibrium (SSE) and (*iv*) result of simulation.

2.2.1 1st step: Simple economic growth model

We adopt a simple macroeconomic growth model developed in the late 1940s. The model is applied in development economics to explain the growth rate of economy in terms of the level of saving and the productivity of investment *i.e.* the capital output ratio. In other words, the model underlines an economic prosperity and growth that occurs through a reinforcing process where capital is accumulated. Consider five simple behaviour relationships:

$$K(t+1) = K(t) + I(t) \tag{1}$$

where $K(t+1)$ is the physical capital stock or (the zebu), $K(t)$ is the initial physical capital stock, and $I(t)$ is the investment of zebu per year. Equation (1) shows a capital accumulation where stock of zebu is increased by the amount of investment.

$$Y(t) = \frac{1}{\kappa} * K(t) \tag{2}$$

The production function in (2) is illustrated by the production or output $Y(t)$ which is produced only by the stock of zebu obtained from the production of food and from the immigrated Tandroy. In Androy, the surplus of food will be immediately converted in zebu; and κ represents the capital-output ratio measured by number of zebu per unit of food per year.

$$C(t) = c * Y(t) \tag{3}$$

The equation (3) is very familiar in macroeconomic consumption function. Where C is consumption and c is marginal propensity to consume (MPC).

$$S(t) = Y(t) - C(t) \tag{4}$$

In (4) portion of disposable food (not consumed) is accumulated or invested directly in zebu.

$$I(t) = S(t) \tag{5}$$

$$I(t) = \varphi * S(t) \tag{6}$$

In (5), the equilibrium can be achieved by equating investment I with saving S; otherwise output would not be exhausted completely or in a state of shortage. For the unit conformity, saving S in equation (6) is multiplied by a convertion factor φ. This latter ensures a food unit of saving S to a zebu unit of capital investment. In other word, the needed unit here is unit of zebu per food dimension.

SD modeling requires a precise specification of each variable as defined in the five equations above for allowing us to build easily a model. Regarding the proportion of the number of five equations and the five unknown variables, the economic growth model becomes consistent.

Steady state equilibrium of capital accumulation

With SD, determining steady state (SS) is also very essential because in SS, stocks are in standstill, and at the same time, the net flows value turn into zero, *i.e.* there is no growth.

Stock and flow relation

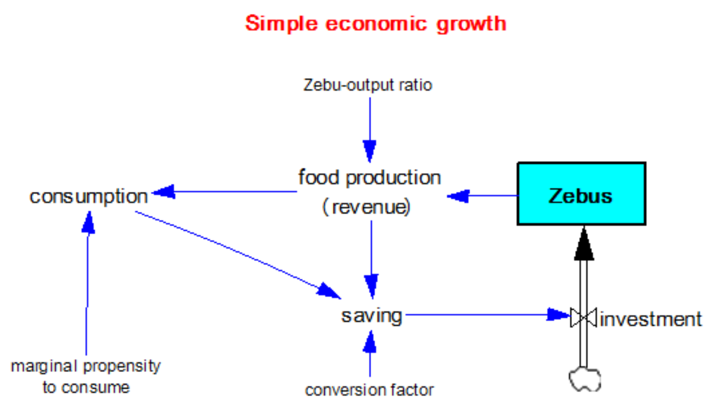

Figure 4: Stock and flow diagram(2)

Table of growth path

Year	Zebus	Revenue	Consumption	Investment
2001	290000	268519	233611	6981.48
2002	292900	274983	239235	7149.55
2003	295829	281603	244994	7321.67
2004	298787	288382	250892	7497.93
2005	301775	295325	256932	7678.44
2006	304793	302434	263118	7863.29
2007	307841	309715	269452	8052.59
2008	310919	317171	275939	8246.45
2009	314028	324807	282582	8444.98
2010	317169	332626	289385	8648.28
2011	320340	340634	296352	8856.48
2012	323544	348834	303486	9069.69
2013	326779	357232	310792	9288.04
2014	330047	365832	318274	9511.64
2015	333348	374639	325936	9740.62
2016	336681	383658	333783	9975.12
2017	340048	392895	341818	10215.3
2018	343448	402353	350047	10461.2
2019	346883	412039	358474	10713
2020	350352	421959	367104	10970.9

Proposition 1 *SSE of the capital accumulation is reached in $K(t+1) = K(t)$ but SS is analitically reached, assuming a single equation of capital accumulation which is given by:*

$$K(t+1) = K(t)\left[\frac{\kappa - c + 1}{\kappa}\right] \tag{7}$$

Proof. See Appendix. □

Assume the whole revenue is consumed. This circumstance results that neither saving nor investment is available. This can be numerically explained by $S^{SS} = I^{SS} = 0$ and MPC is equal to unitary. SS equilibrium is reached at $K^{SS} = 290,000$ and $C^{SS} = 233,611$.

Simulation 1

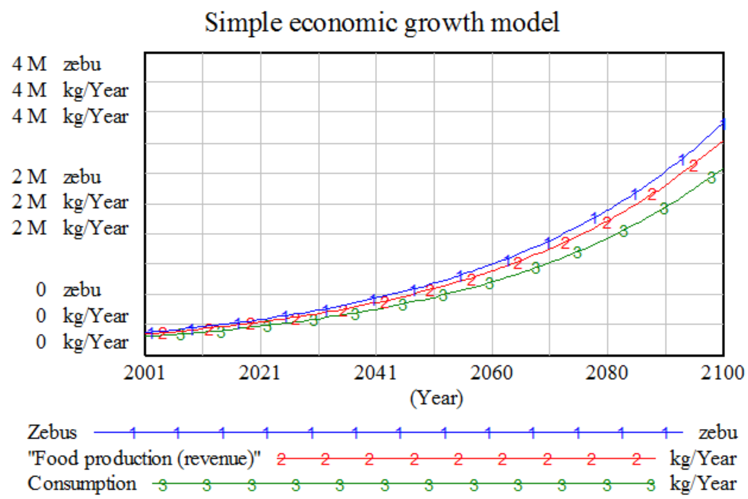

Figure 5: Simulation 1

The growth path is shown in Figure 5. Recall that the relative increase in personal spending *(consumption)* that comes with an increase in disposable income is known as MPC. The latter indicates the portion of additional income that is used for consumption expenditures. In simulation 1, the growth path is set by $c = 0.87$, means that 13% of the revenue is saved for the investment in zebus. The infinity growth of the capital, revenue, consumption and investment is at the rate of 2.4% for MPC equal to 0.87.

2.2.2 2nd step: Sustainable model

Let us develop the model by introducing capital depreciation and forest resources:

$$K(t+1) = K(t) + I(t) - D(t) \quad (8)$$

$$D(t) = \rho * K(t) \quad (9)$$

where ρ is a depreciation rate of livestock per year and the inequality $I(t) - D(t) \geq 0$ should be satisfied.

In modern economy, depreciation has been widely known as machines, cars, homes, etc., but what about zebu? It can obviously happen that livestock can be depreciated as long as they are used for breeding. By definition depreciation is the depletion of capital assets in equation (8) where $I(t)$ represents a gross investment and $D(t)$ is the depreciated zebu per year . However, we assume that breeding animal in Androy can be depreciated, no taking into account raising cost such, for exampe, expense items (grass, plant, medicine...); these are negligible.

Proposition 2 *As seen in precedent proposition, SS is analogically reached at $K(t+1) = K(t)$ or $I(t) = D(t)$, hence the equation of the model is reduced as:*

$$K(t+1) = K(t) * \left[\frac{(1-c) + (1-\rho)\kappa}{\kappa}\right] \quad (10)$$

A marginal propensity to consume becomes less than one, which implies that the portion of production $Y(t)$ has to be saved to replace the capital depreciation.

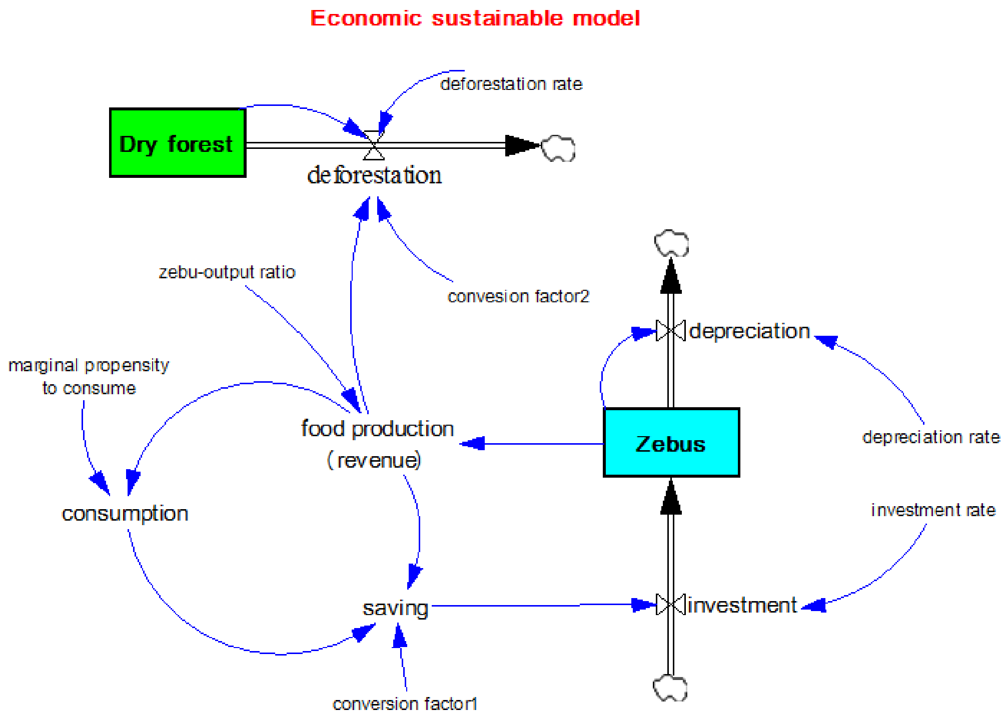

Figure 6: Stock and flow diagram (3)

Proof. See Appendix. □

Thus, from (10), SS can be expressed as follows:

$$1 - c^{ss} = \kappa^{ss}\rho^{ss} \tag{11}$$

Let us grow out the economy of the SS after introducing the forest resource; that is the growth of zebus as $K(t+1) > K(t)$ and the following condition has to be captured: (1) enhences the productivity: the zebus-output ratio $\kappa < \kappa^{ss}$; (2) improves the quality of livestocks : $\rho < \rho^{ss}$ or (3) enhences the level of saving and investment or diminishes the level of consumption such as $c < c^{ss}$.

In previous economic growth model, zebus depreciate, and for maintaining the current level of production/output, some portion of revenue has to be saved in order to replace $D(t)$. If zebu's depreciation rate is high, the portion of revenue has to be saved at the same cost of consumption. Thus, Tandroy population overuses natural resources to maintain the sustainability of their economy. However, the economy reproduction process creates an environmental crisis.[2] The sustainable issue should be called to mind and this leads to the famous definition of the Brudtland commission of sustainability. This definition is a kind of fashionable reference for sustainable development that meets the need of the present without the ability of future generations to meet their own needs (WCED, 1987). In this sense, an environment pillar will be integrated in the next model.

Simulation 2.1

As illustrated in Figure 7, the zebus keep growing from the starting time of simulation until 2100. Numerically, we consider the previous case (3) and we set $\rho = 0.032$. As shown in Figure 7 $K_{2001} = 290,000$

[2]At present time Tandroy population depend principally on the forest resources for reproduction (agriculture, breeding, different economic activities...).

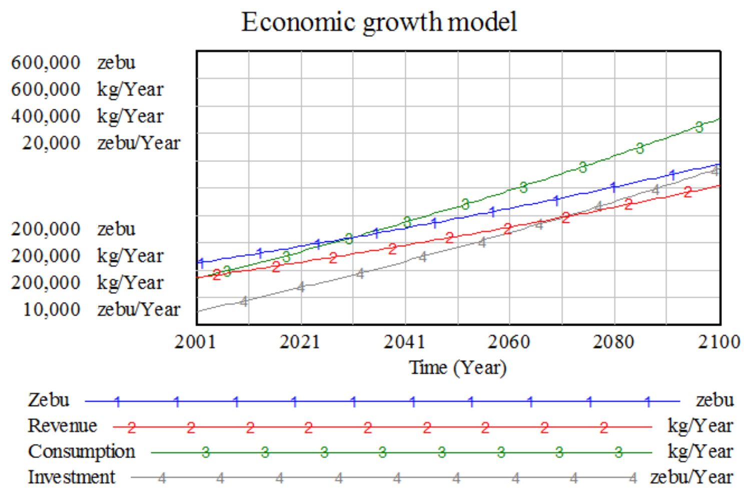

Figure 7: Simulation 2.1

to $K_{2100} = 313,510$. During the century the average growth of zebus has a rate forecast of 0.41%. and for food production increases from $Y_{2001} = 268519$ to $Y_{2100} = 412039$. Nevertheless, we want to see wether such growth can be sustainable?

Forest resources

The condition in (8) presumes an availability of natural resources to be integrated in the model which is represented by the forest resources in the following equation:

$$F(t+1) = F(t) - \Delta F(t). \tag{12}$$

Equation (12) shows forest depletion dynamic due to *hatsake* and *ororaketa* for food production $Y(t)$. $F(t)$ represents an initial forest area at time t, and $\Delta F(t)$ characterizes the deforested area which is needed for the input. In other words, deforestation is considered in this context as raw material and consequentely it will be described in the following equation:

$$\Delta F(t) = \eta * Y(t) \tag{13}$$

where, η denotes a rate of deforestation measured by the net stock of deforested area per unit of food.

SSE

To determine the SS of forest resource, we would equate $F(t+1) = F(t)$ which implies $\Delta F(t) = \eta * Y(t) = 0$. Both physical capital and forest resources are integrated in the model as state variables. However, the SS of capital accumulation is not influenced by the introduction of forest resources. Consequently, SSE of physical capital is a positive amount of production which is contradictory to the SSE of forest resource. To avoid this confusion and to make the model feasible, we skip the concept of forest SSE or we assume an availability of forest resource at any time in the Androy economy system. Hence, this availability can be written as follow: $\sum_{t=2001}^{\infty} \Delta F(t) < Y_{2001}$.

Simulation 2.2

The dry forest resource is continuously depleted even at SSE of zebus' accumulation. Deforestation attains its peak at $t = 2026$ before getting felt at the rest of simulation. This curve trend is supposed to be normal because the depletion of dry forest is considerable from $t = 2001$ to $t = 2100$: the higher the depleted forest, the lower the forest clearing, because there will not be enough forest to cut. Food production

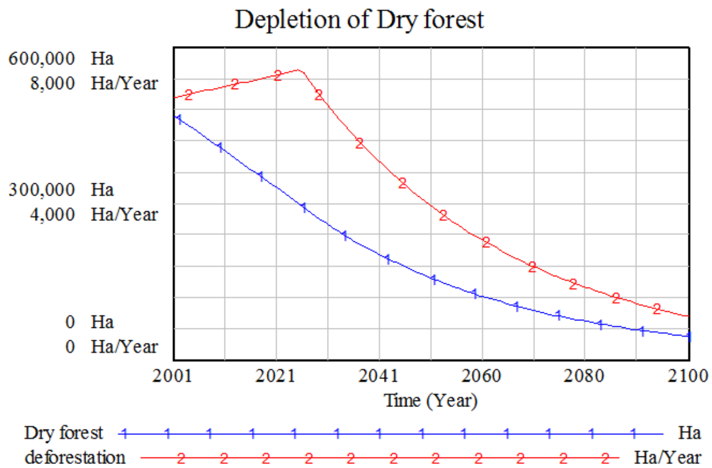

Figure 8: Simulation 2.2

and zebus grow weakly during the simulation which is contrary to the behavior of the forest loss curve. At $F_{2030} = 264,355$, half of the dry forest will remain. Long-term forest management is necessary, otherwise dry forest will be practically cleared at F_{2060}.

2.2.3 3rd step: Social model

Consider a tandroy population growth model whose size $L(t+1)$ is given by the following simple dynamic:

$$L(t+1) = (\alpha - \beta - \gamma)L(t) \tag{14}$$

where, α, β and γ are constant and denoting respectively birth, death and emigration rates and $L(t)$ represents initial population in time t. The agricultural population is defined as all persons depending for their livelihood on agriculture, hunting, fishing or forestry (FAO, 2002). Despite poverty in any nation, assume that agricultural population can provide at least a minimum amount of food in period of time for the reproduction of its population. Accordingly, the consumption function (3) will be rewritten as follows:

$$C(t) = \not{c}L(t) \tag{15}$$

where $\not{c}$ denotes a minimum amount of consumed food per person. Hence, the integration of this minimum consumption requires an adjustment of all functions which are involved with (15). Let revise a saving function S as a non-negative saving which is expressed as follows: $S(t) = Max\left\{Y(t) - C(t), 0\right\}$. The net production can be noted in (16):

$$Y(t) - D(t) - \not{c}L(t) \geq 0 \tag{16}$$

The equilibrium in (5) is revised in (17):

$$I(t) = S(t) = Y(t) - C(t) = Y(t) - \not{c}L(t) \geq D(t) \tag{17}$$

The tandroy-agricultural population represents a number of workers which is denoted by $W(t)$ and can be expressed in the following:

$$W(t) = \omega * L(t) \tag{18}$$

where, $\omega = 0.85$ is a participation ratio of tandroy workers. (18) allow us to rewrite a production function in the following expression:

$$Y(t) = Min\left\{\frac{1}{\kappa}K(t), rW(t)\right\} \tag{19}$$

where, $r = 1.1$ is an output-Tandroy worker-ratio.

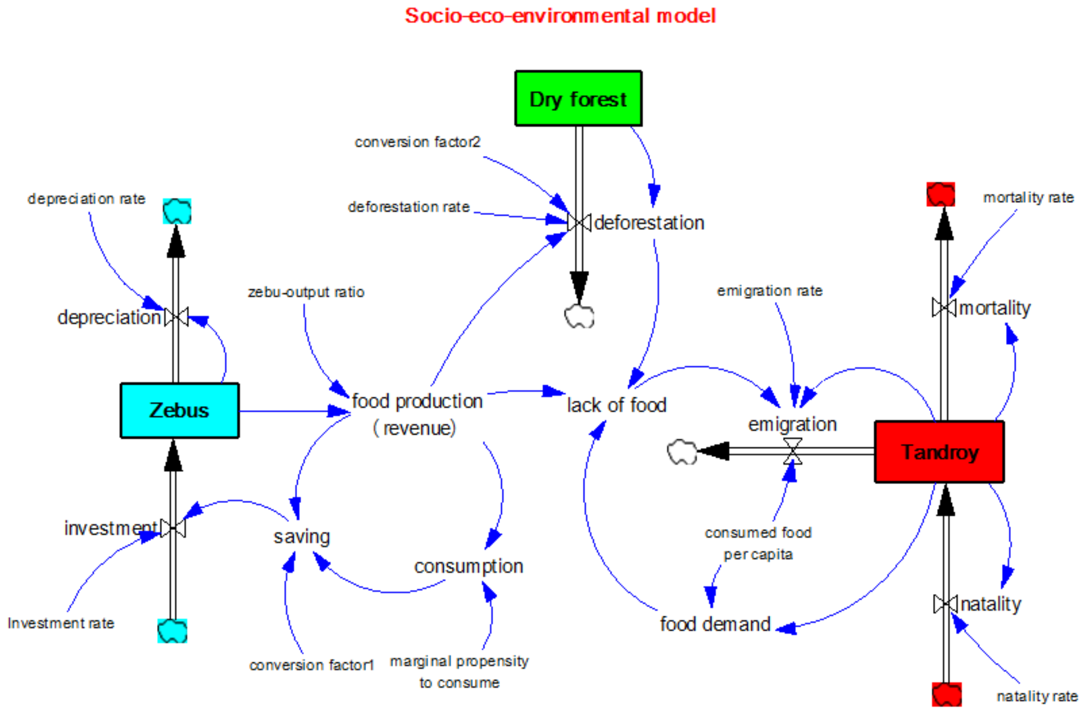

Figure 9: Stock and flow Diagram(4)

Stock and flow diagram

Steady state equilibrium of sustainable socio-economic model

Finally, the model contains three stock variables $K(t+1)$, $F(t+1)$ and $L(t+1)$. These stocks expand in nine unknown variables and nine constants which are structured in nine equations. Therefore, the consistency of the model remains. Recall that non-existence of SSE of renewable resources is mentionned. Nevertheless , the SS of population growth $L(t+1) = L(t)$ is attained when $\alpha^{ss} = \beta^{ss} + \gamma^{ss} = 0.01$. As it is seen previously, SS of zebus can be also attained for the value of constatnts $(c^{ss}, \kappa^{ss}, \rho^{ss}) = (0.87, 1.08, 0.032)$. From equation (19), two cases of SSE can be expressed :

a) "The food production" is constrained by zebus and from (2) $Y(t) = \frac{1}{\kappa} * K(t)$; this can be re-written:

$$\frac{K(t)}{L(t)} = \frac{\cancel{c}}{\frac{1}{\kappa} - \rho} = 0,87$$

For $L(t) = 548,418$, zebus have to be $K(t) = 290,000$ at SS. Thus, except the dry forest, the SSE is resumed in the following table:

K^{ss}	L^{ss}	Y^{ss}	C^{ss}	S^{ss}	I^{ss}
$290,000$	$548,418$	$252,174$	$242,339.22$	9834.78	9834.78

b) "The food production" is constrained by the labor and (18) $W(t) = \omega * L(t)$; this can be expressed:

$$\frac{K(t)}{L(t)} = \frac{\omega r - \cancel{c}}{\rho} = 1,74$$

For $L(t) = 548,418$, zebus has to be $K(t) = 290,000$ at SS. Thus, expect the that dry forest, a SSE is resumed in the following table:

K^{ss}	L^{ss}	Y^{ss}	C^{ss}	S^{ss}	I^{ss}
290, 000	548, 418	252, 174	484, 678.44	19, 669.56	19, 669.56

Simulation 3

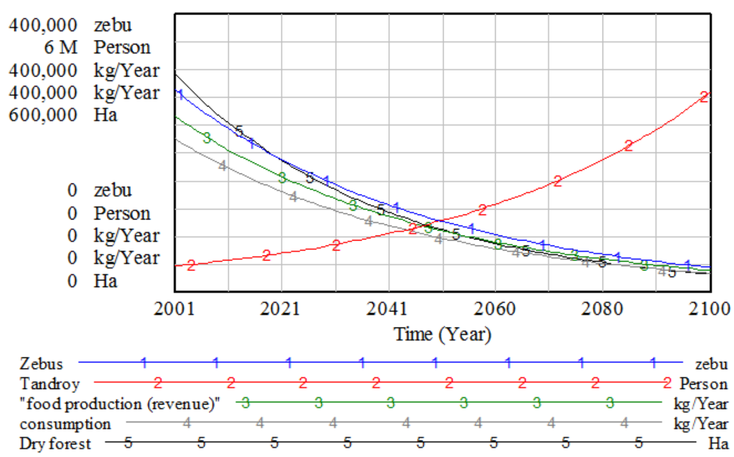

Figure 10: Simulation 3

Figure 10 illustrates the final result which is gotten from the interrelation between the three pillars. The result shows, firstly, that the dry forest in the Androy region is depleted fast and will practically disappear in $t = 2080$. This may happen because of the *ororaketa* and *hatsake*. Due to the reduction of fodder of zebus which has a tight link with the forest, zebus are reduced in number as well. However, population increases with 2.1% of rate per year. In the same case, the lack of food appears because the food production cannot cover completely the gap. Then, the consumption and the investment decline.

3 Conclusion

We described the core variables involved in the degradation of natural resources in the southern part of Madagascar. Recall that SD was the multidisciplinary approach used to describe the interrelation and/or the influence between the whole variables in the system. The behavior of those variables is shown from the initial time until the end of the simulation. The variable "*food production*" or revenue plays a principal role as decision variable upon which the future of the three pillars (environment, economy and social) depend. Tandroy use forest resource like an input (raw material) which is not sustainable neither for the growth of the economy or for the future of the dry forest *per se*.

Three extensions would be worthwhile to highlight. First, other state variables would be integrated in the model such as fertility of soil, agricultural livestock land etc. Second, it would be given as more reliable as social measurement scales (gender, education, health, etc). And lastly, other source of revenue would be deeply investigated (hunting, fishing, selling, money transfer...).

4 Appendix

4.1 Proof of Proposition 1

Decomposing (1) with respect to $K(t)$, $Y(t)$ and $C(t)$, yields

$$K(t+1) = K(t) + I(t) = K(t) + Y(t) - C(t) \tag{20}$$

Substituting in (20) leads to

$$K(t+1) = K(t)\left[1 + \frac{1-c}{\kappa}\right] \tag{21}$$

4.2 Proof of Proposition 2

Decomposing (8) with respect to $K(t)$, $Y(t)$, $C(t)$ and $D(t)$ yields

$$K(t+1) = K(t) + I(t) = K(t) + Y(t) - C(t) - D(t) \tag{22}$$

Substituting in (22) leads to

$$K(t+1) = K(t)\left[1 + \frac{1-c}{\kappa} - \rho\right] \tag{23}$$

At SS condition the following condition must be fulfilled:

$$\frac{1-c^{ss}}{\kappa^{ss}} = \rho^{ss} \tag{24}$$

and $1 - \kappa^{ss}\rho^{ss} < 1$.

4.3 Equations

29 equations are developed with VENSIM software as follows:

1) consumed food per capita = 400
   Units: kg/Year
2) consumption = marginal propensity to consume*"food production (revenue)"
   Units: kg/Year
3) conversion factor1=0.2
   Units: zebu/kg
4) conversion factor2=1.08
   Units: 1/kg
5) deforestation = MIN(deforestation rate*Dry forest, "food production (revenue)"*conversion factor2)
   Units: Ha/Year
6) deforestation rate=0.0251
   Units: Dmnl
7) depreciation = Zebus*depreciation rate
   Units: zebu/Year
8) depreciation rate=0.055
   Units: 1/Year
9) Dry forest= INTEG (deforestation,469019)
   Units: Ha
   The dry forest area in the year 2001 is choosen as an intial condition of simulation.
10) emigration = Tandroy*emigration rate/(consumed food per capita-lack of food)
    Units: Person/Year
11) emigration rate = 0.005
    Units: 1/Year
    Current migration in the region is 0.005 (Fanokoa, 2007).
12) FINAL TIME = 2100
    Units: Year
    The final time for the simulation.

13) food demand = consumed food per capita*Tandroy
Units: kg/Year
14) "food production (revenue)"=Zebus/"zebu-output ratio"
Units: kg/Year
15) INITIAL TIME = 2001
Units: Year
The initial time for the simulation.
16) investment=saving*Investment rate
Units: zebu/Year
17) Investment rate = 1.5
Units: Dmnl
18) lack of food = MIN(food demand-"food production (revenue)", deforestation)
Units: kg/Year
19) marginal propensity to consume=0.87
Units: Dmnl
20) mortality = Tandroy*mortality rate
Units: Person/Year
21) mortality rate = 0.005
U*nits: 1/Year*
Average mortality rate hase been computed using the same source (RM, 2003) and in the same manner as with "average natality rate".
22) natality =Tandroy*natality rate
Units: Person/Year
23) natality rate = 0.026
Units: 1/Year
The natality rate of the Tandroy is measured in childbirths per person and year. We compute "Average natality rate" using the data from RM(2003) for the four main districts in the Region in year 2005.
24) SAVEPER = TIME STEP
Units: Year [0,?]
The frequency with which output is stored.
25) saving = conversion factor1*("food production (revenue)"-consumption)
Units: zebu/Year
26) Tandroy = INTEG (natality-(emigration+mortality),548418)
Units: Person
We take as reference of initial population in the 2001
27) TIME STEP = 1
Units: Year [0,?]
The time step for the simulation.
28) "zebu-output ratio" = 1.15
Units: zebu/(kg/Year)
29) Zebus = INTEG (investment-depreciation,290000)
Units: zebu

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