Macroeconomic view of sustainability of dry forest in Androy region. A system dynamics approach

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Abstract

The Tandroy communities do not cease to practice slash and burn agriculture to satisfy their subsistence needs. To get rid of the spines, before feeding their zebu, peasants burn the cactus cladodes *(omputia)* and the mozotse *(euphorbia stenoclada)* vegetation. Despite these techniques, the performance of the agriculture and the breeding of zebu are successful only for a brief period. Nevertheless, in long term, these practices are unsustainable vis-à-vis the ecological pressure on the neighboring dry forest. These activities may lead to greater risk of socioeconomic disasters on both local and global scales in the near future. In this paper, we report the concept of a methodological framework for integrating the subjects of system of thinking and system dynamics and confront it with the Tandroy macroeconomic view, accordingly. Thus, we analyze the effect of both interlinks and causal relations between socioeconomic and environmental variables in Androy.

Keywords: *Androy, Dry forest, Madagascar, Macroeconomic view, Natural stocks, Slush and burn agriculture, System dynamics, Tandroy, Zebu.*

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 in Androy Madagascar. According to (FRA, 2005), only about seven percent of the Earth's dry land, are covered by tropical dry forest and all of the forests in the southern part of Madagascar belong to this zone. Dry forest in Madagascar is fragile because of its high level of plant endemism, with 48% of the genera and 95% of the species endemic (Koechlin, 1972). Flora and fauna in Madagascar is extremely popular as the island home for some of the most unique and rare species of the world (WWF, 2011). The "spiny forest region" is also listed as one of the 200 most important eco-regions (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 (Fanokoa, 2007; Sussman *et al.,* 1994; Sussman *et al*., 2003).

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 centimeters on the southwestern coast to 70 centimeters 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 has 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 supply 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 endeavors as much as possible to have an impressive number of livestock (Fanokoa, 2007).

The Tandroy populations are pastoralists, cultivators and gatherers. Over the last decade, the population has more doubled in the last 30 years and the combined effect of an increasing population and of reluctance to change their traditional lifestyle and production system has led to great ecological pressure on the dry forest.

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

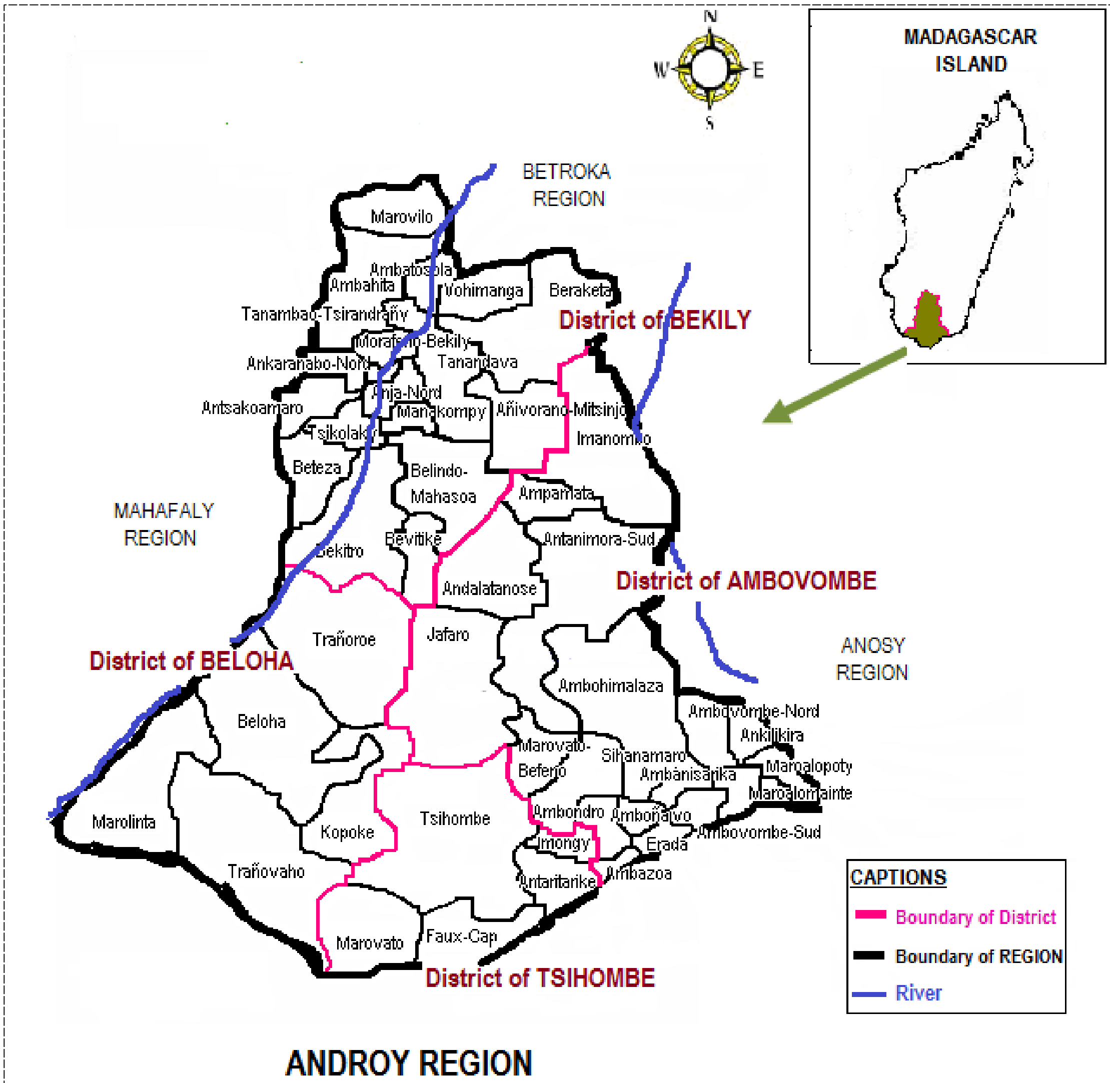


Figure 1: Study zone – The region of Androy

As both human and cattle populations are increased, *hatsake* and *ororaketa* activities require increasing agricultural land (Fanokoa, 2007; Andrés-Domenech, *et al*, 2011). The increase of conversion of the forest areas into pasture and agricultural land is an evident problem in Androy. This happens because the 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 the *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 involved dynamically in the deforestation system and to study the behavior of socio-economic and environmental system in the region by using system dynamics (SD) approach. The main objective is to identify and to understand the impact of the Tandroy socio-economic activities on environment.

The reminder of the paper is structured as follows: in section 2, we model the interaction between three natural stocks (Zebu, dry forest and Tandroy population). The causal loop diagram (CLD) will be developed, then the stocks and the flows model will be presented, illustrating the three steps of the model: the characterization of (1) zebu's stock, (2) stock of dry forest in area unit and (3) growth of Tandroy population. The results will be shown at the end of each sub-model. Subsequently, section 3 concludes.

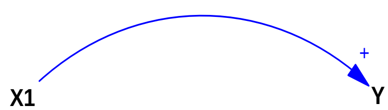
2 The model

2.1 CLD

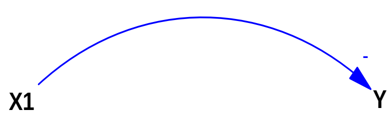
We use the VENSIM to write the entire model. Moreover, SD provides capabilities to follow and recognize cause-and-effect mechanisms between the component parts of the system over time. This approach improves the behavior of stakeholders by examining the interrelationship between parameters and flows, 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. What's more CLDs characterize major feedback mechanisms, which reinforce (positive feedback loop (R) or (+)) or counteract (negative feedback loop (B) or (-)) a given change in a system variable (Sterman, 2000). CLD is an essential instrument to show the feedback structure within the subsystems. The source hypothesis of dynamics can be identified. Besides, CLD consists of variables connected by arrows denoting causal influence (named causal links) among variables and then the formal definitions are summarized as follows.

Given a function Y dependent on x independent variables, the diagram:



can be mathematically expressed as: $\frac{\partial Y}{\partial X_1} > 0 \quad or \quad Y = \int_{t_0}^{t}(X_1 + \cdots)ds + Y(t_0)$ in the case of accmulations.
On the contrary, the following relationship:



represents: $\frac{\partial Y}{\partial X_1} < 0 \quad or \quad Y = \int_{t_0}^{t}(-X_1 + \cdots)ds + Y(t_0)$ in the case of accumulations.

In *figure 2*, arrows show the causal links or causal influence among variables.

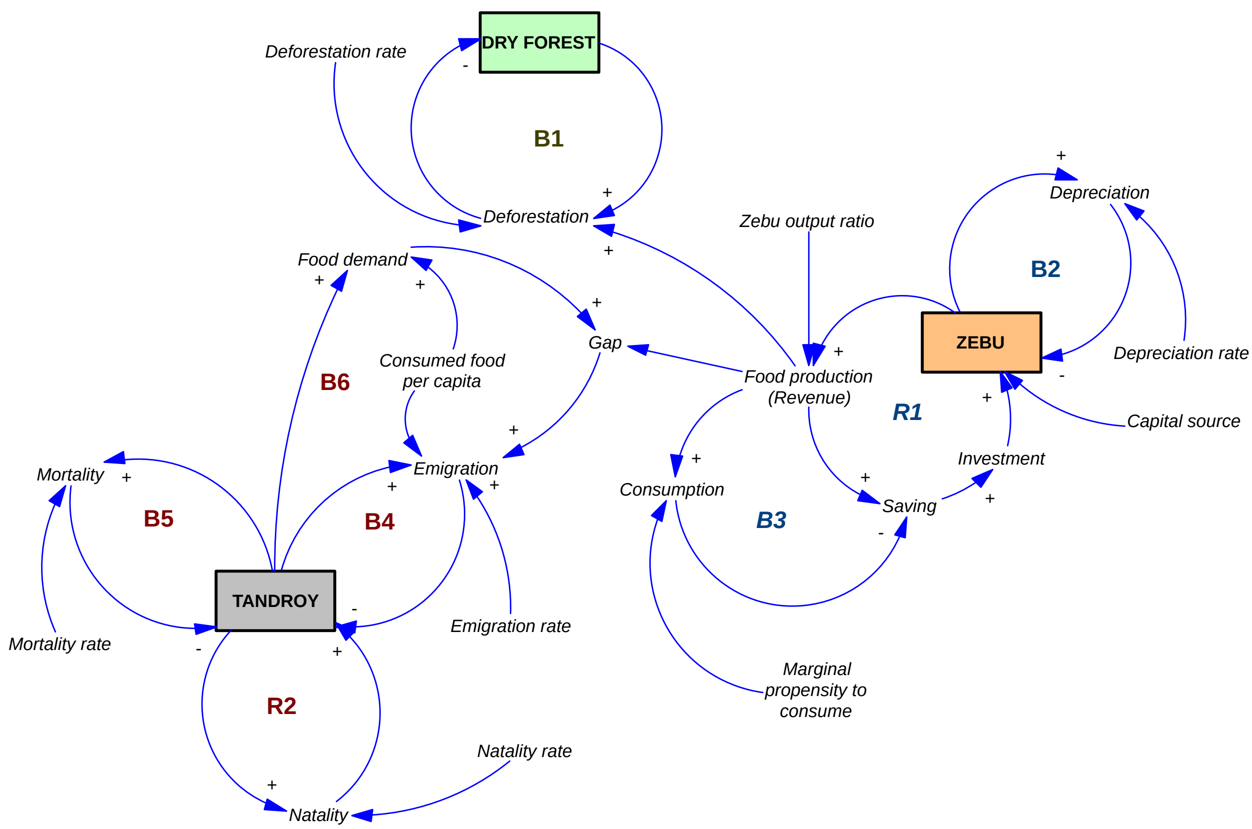


Figure-2: Causal loop diagram (CLD)

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. The baseline descriptive model consists of three blocs of subsystems of natural stocks namely economic structure (the accumulation of zebu as a capital), social dimension (population, birth, death, emigration) and natural resources (dry forest resource stock, its depletion and effect of agriculture production system). *Figure* 2 describes the whole system, in which it has 3-state variables, 11-auxilliary variables, 11 constants (initial values) and 7 loops (2 reinforcing loops and 6 balancing loops). All variables influence each other.

(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 (R1), (B2) and (B3) influence directly between them in the economic pillar. The growth of food production is desired which has a positive impact on the growth of zebus. In fact, macroeconomic model 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 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 zebu itself. The sign of the loop is negative, i.e. balancing loop. The livestock depreciation begins when the livestock reaches the age of maturity [in Androy $Depreciated\ Age_{zebu} > 8\ Years$] (Fanokoa, 2007). 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 (B6) illustrate the system of population growth. The reinforcing loop (R2), population itself grows, which is explained by birth growth. However, the loops (B4), (B5) and (B6) play a counterweight to (R2) because emigration and mortality, decrease the stock of population. For the latest decades net migration has been mainly negative i.e., emigration in Androy is greater than immigration (Fanokoa, 2007). By the loop (B4), most of Tandroy has to migrate due to lack of food (Gap). In fact, the population growth by loop (R2), would need more and more foods. CLD in *figure 2* shows roughly that the Tandroy performs the *hatsake* activity for two reasons: (1), to have more food production for solving problems of food security; and (2) to spare.

2.2 Stocks and flows

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 materials are 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. Several textbooks such as (Sterman, 2000), (Yamaguchi, 2014) and others give more detail about building system dynamics blocks. In *figure 4*: The stock, the flow, the variable and the arrow information are interconnected as system dynamics bloc.

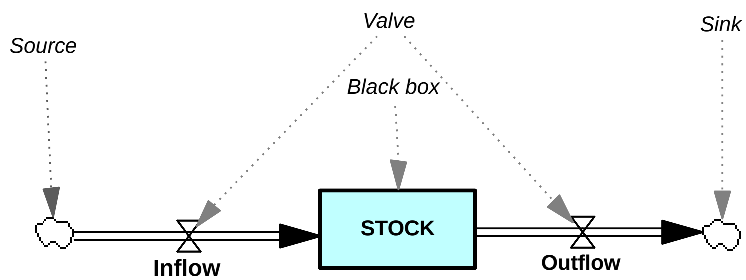


Figure 3: Stock and Flow diagram (1)

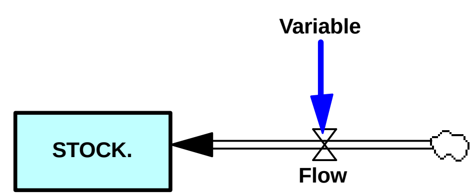


Figure 4: Langage of System Dynamics

Stock and flow are mathematically represented as follows:

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 (natural stocks) are expressed in the model to explain the sustainability of development poles in Androy: zebu 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 macroeconomic 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 (Yamaguchi, 2001). In other words, the model underlines an economic prosperity and growth that occurs through a reinforcing process where capital is accumulated. Assume that capital depreciation is not considering in this first step. Consider five simple behavior relationships:

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

where $K_z(t+1)$ is the capital stock from the zebu, $K_z(t)$ is the initial 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.

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

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 conversion 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 six 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 (SSE) of zebu accumulation

With SD, determining steady state (SS) is also very essential because 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

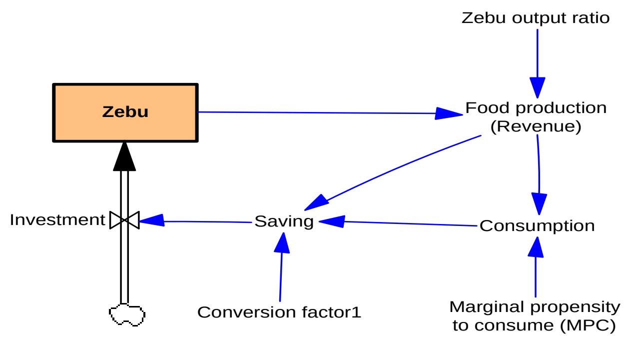


Figure 5: Stock and Flow diagram (2)
ECONOMIC GROWTH

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

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

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 1. SS equilibrium is reached at $K_z^{ss} = 290000$ and $C^{ss} = 233611$.

Simulation 1

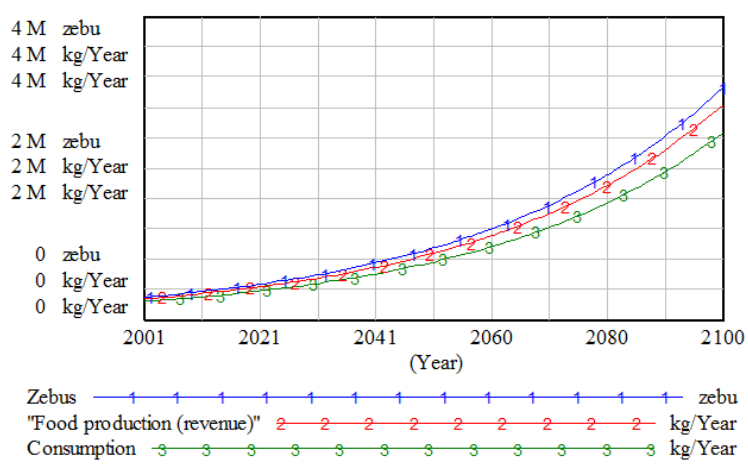


Figure 5: Simulation 1 – Simple economic growth model

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:

$$K_z(t+1) = K_z(t) + I(t) - D(t) \tag{8}$$

$$D(t) = \rho * K_z(t) \tag{9}$$

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 example, expense items (grass, plant, medicine...); these are negligible.

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

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

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.

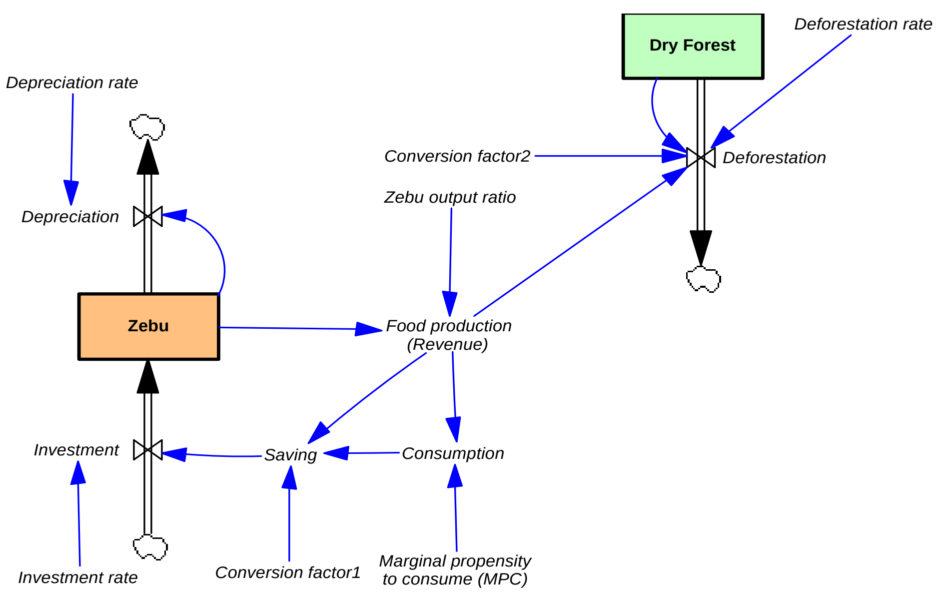


Figure 6 : Stock and Flow diagram (3)
Economic sustainable model

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 $K_z(t+1>Kzt$ and the following condition has to be captured: *(1)* enhances the productivity: the zebus-output ratio $\kappa < \kappa^{ss}$; *(2)* improves the quality of livestock : $\rho < \rho^{ss}$ or *(3)* enhances 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 famous 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 zebu keeps 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* $K_{z(2001)} = 290\ 000$.

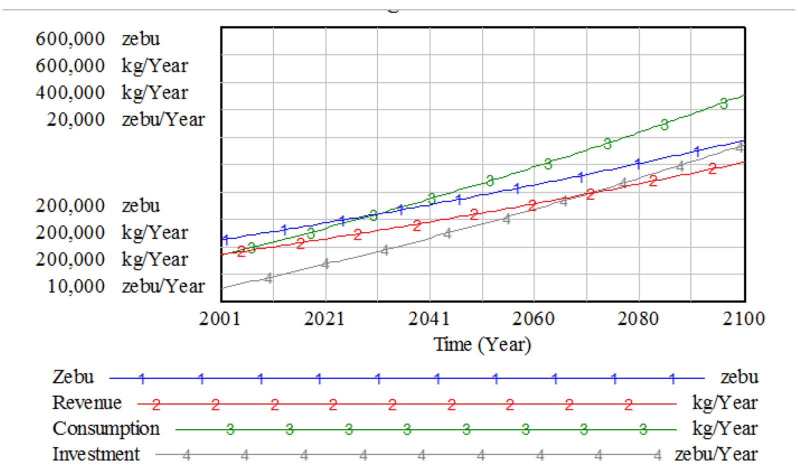


Figure 7: Simulation 2.1 – Economic growth model

to $K_{z2100} = 313510$. 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 whether such growth can be sustainable?

Dry forest resources

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

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 consequently 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 zebu 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 zebu 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

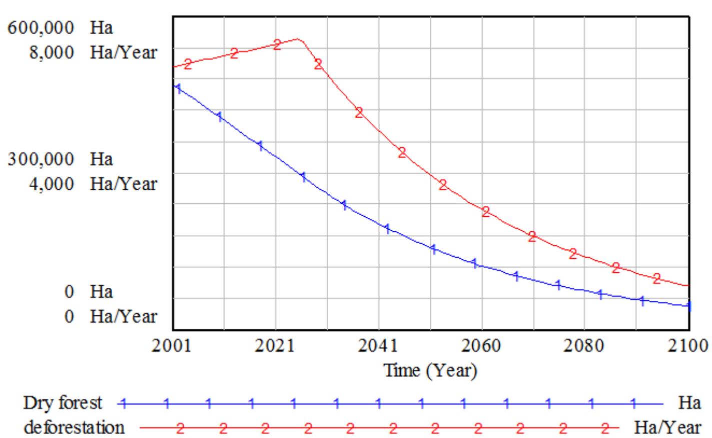


Figure 8: Simulation 2.2 – Depletion of dry forest

and zebus grow weakly during the simulation which is contrary to the behavior of the forest loss curve. At $F_{2030} = 264355$, half of the dry forest will remain. Long-term forest management is necessary; otherwise dry forest will be practically cleared at F_{2026}.

2.2.3 3rd step: Tandroy population 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:

$$C(t) = \psi L(t) \tag{15}$$

where ψ 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: $S(t) = Max\{Y(t) - C(t), 0\}$. The net production can be noted in (16):

$$Y(t) - D(t) - \psi L(t) \geq 0 \tag{16}$$

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

$$I(t) = S(t) = Y(t) - C(t) = Y(t) - \psi(t) \geq D(t) \tag{17}$$

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) allows us to rewrite a production function in the following expression:

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

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

Stock and flow diagram SSE of sustainable socio-economic model

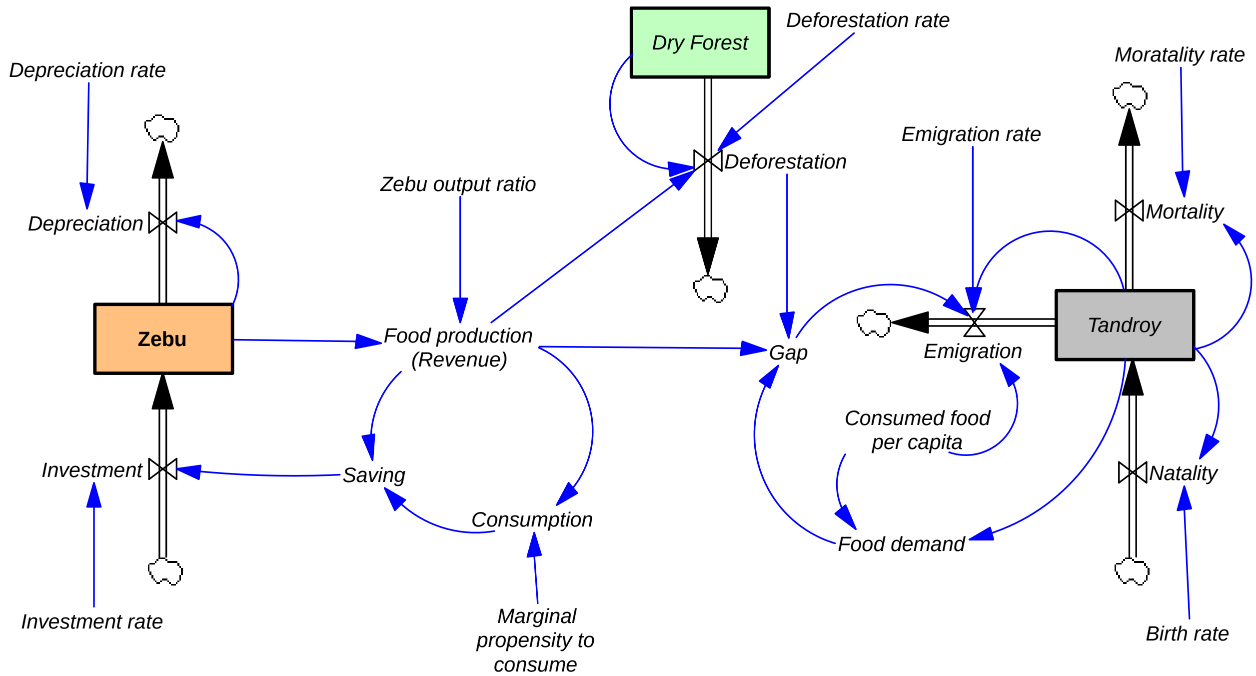
Lastly, the model contains three stock variables $K_z(t+1)$, $F(t + 1)$ and $L(t + 1)$. These stocks expand in nine unknown variables and nine constants, which are structured in nine equations. Therefore, the consistency of the model remains. Recall that non-existence of SSE of renewable resources is mentioned. 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 constants $(c^{ss}, \kappa^{ss}, \rho^{ss}) = (0.87, 1.08, 0.032)$. From equation (19), two cases of SSE can be expressed:

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

$$\frac{K_z(t)}{L(t)} = \frac{\psi}{\frac{1}{\kappa} - \rho} = 0.87$$

For $L(t) = 548418$, zebus have to be $K_z(t) = 290000$ at SS. Thus, except the dry forest, the SSE is resumed in the following table:

K_z^{ss}	L^{ss}	Y^{ss}	C^{ss}	S^{ss}	I^{ss}
290000	548418	252174	242339.22	9834.78	9834.78



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

$$\frac{K_z(t)}{L(t)} = \frac{\omega r - \psi}{\rho} = 1.74$$

For $L(t)\ =\ 548418$, zebus has to be $K_z(t) = 290000$ at SS. Thus, expect the that dry forest, a SSE is presented in the following table:

K_z^{ss}	L^{ss}	Y^{ss}	C^{ss}	S^{ss}	I^{ss}
290000	548418	252174	484678.44	19669.56	19669.56

Simulation 3

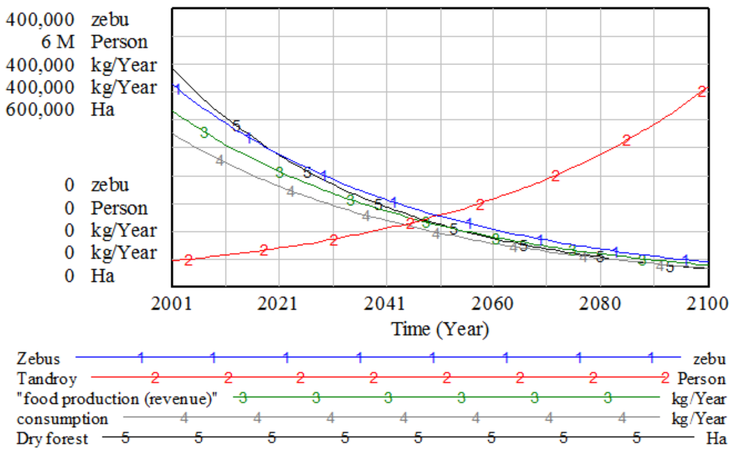


Figure 10: Simulation 3

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 identified the core variables that play an important role in the whole model. The model showed that the economic and productive system in Androy is not sustainable. The Tandroy need to lower heir birth rate. The growing of the population puts pressure on dry forest resource. As forest is open access resource, the deforestation rate is harmful of the sustainability of forest resource.

The variable "food production" or revenue plays a principal role as decision variable upon which the future of the three pillars (environment, economy and population) depends. Tandroy uses forest resource like an input (raw material), which is too costly to control or to monitor, then it maybe necessary to strengthen afforestation by means of public program to counterbalance the deforestation damage and to stabilize the forest surface area.

As the land cannot provide enough revenues for the current population and for feeding the cattle, then the sustainability cannot be guaranteed. A number of changes that may revert the situation, either on the demand consumption side or on supply side. To ensure a sustainable development for the current population is to lower per capita consumption in the region by roughly 30% with respect to the currents levels.

Clearance arises due to mix of lack of forest law and the poverty. Then, to spare the dry forest, it is necessary to reduce the consumption rate but on contrary the deforestation issue may aggravate or population raises persist overtime.

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 $K_z(t), Y(t)$ and $C(t)$, yields

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

Substituting in (20) leads to

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

4.2 Proof of Proposition 2

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

Substituting in (22) leads to

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

At SS condition the following condition must be fulfilled:

$$\frac{1-c^{ss}}{\kappa^{ss}} \text{ and } 1 - \kappa^{ss}\rho^{ss} < 1 \tag{24}$$

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