# A generic model to assess sustainability impact of resource management plans in multiple regulatory contexts

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**Abstract.** Management of the renewable natural resources in Madagascar is gradually being transferred to the local communities. However, these local communities are struggling to assess the consequences of the management plans they must develop and implement on ecologically, economically and socially sustainable grounds. From this Malagasy case, we propose, from a law anthropology perspective, a generic model, called MIRANA, that allows taking into account law pluralism in the analysis of the impact on sustainability of agents' behaviors submitted to concurrent normative orders within multiple layered territories. From a regulatory perspective, we will describe the representations of institutions and norms, and how they are enforced by control/sanction strategies. From an individual perspective, we will describe how an agent deals with a multiplicity of normative and incentive structures. Additionally, individual behaviors are specified as a combination of subsistence economy, market economy and contractual relations.

## 1 Introduction

The MIRANA[1] model has been developed to simulate the impact of various management plans on the ecological, economical and social sustainability in a multi-institutional context in a broad sense (territorial administrations, natural parks, customary communities, etc.). In [3, p. 43], sustainable development is defined as follows: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The natural environment plays an important role because the definition entails that the usage of the resources the environment provides should not exceed the renewal capacity (ecological sustainability), while maintaining the livelihood of the current and future generations (economical and social sustainability). The usage of the resources plays a central role as it depends both on the practices (the technological dimension), and on the resource access regulations (the normative dimension). Considering the technological dimension as constant, we will mainly focus on the normative dimension. More precisely, the aim is to

explore how the introduction of norms (zones, quotas, controls and sanctions) and economical tools (taxes, permits, incentives), impacts the sustainability of a target system on a territorial basis. The impact on the sustainability will be evaluated at the ecological level by the evolution of the exploited species populations, and at the economical and social level by the level of needs satisfaction and/or illegal actions. This model has been applied on the contractualized management of the forests by base communities (VOI for Vondron'Olona Ofotony in malagasy). Therefore the norms and related impact will be considered at the base community level.

To design MIRANA, we had to develop a conceptual model that relies on a fundamental distinction between on one hand the studied system described with its actors, its resources (including spatial and spatialized) and the processes and actions which are taken place therein, and on the other hand their analysis in legal terms as subjects of law (physical or moral persons), of objects of law (for example, properties, deliverables, etc.) and activities (to use, to exploit, to sell, etc.). The heterogeneity of the actors and the multiplicity of the institutions to take into account, brought us to multiply the legal terminologies as as much points of view there are identified actor categories and institutions[2].

[4] in his book on the construction of social reality distinguishes between the regulative norms and the constitutive norms. While the regulative norms describe the rights and duties associated to the various status or roles of the actors, the constitutive rules will describe how various aspects of the reality are counted as pertaining to the categories or concepts used in the expression of the regulative norms. Therefore, an institution not only introduces rules of functioning, but also definitions in the form of a specific terminology and its definition. For example, the constitutive norms have been formalized in [5], using a contextual description logic, consequently allowing to express how a concept in a terminology can count as another concept in another terminology.

In multi-agent systems (MAS), one distinguishes the organizational approach as AGR[6] that defines the notion of groups of agents playing roles, the normative approach where one insists on the regulative norms [7] and the institutional approaches combining both norms and roles.

To represent resource management plans in a multiple regulatory context and its impact on individual behaviors, possibly leading to sustainable development, we propose a two-level description. In the first level, we use the notion of institution as a set of norms covering both the constitutive and regulatory norms. This proposition is an extension of [5] in which the notion of role and territory is naturally represented using contextual ontologies. In the second level, we propose to use the notion of agent to represent both the actors on which the norms apply, and the collective actors associated to each institution who implement the normative constraints. The norms are taken into account both at the individual level by constraining how the activities are planned and carried out, and at the collective level through various mechanisms of control, sanctions and incentives.

We well first introduce our definitions and formalization of institutions and norms. Then, we will describe the agent structure, illustrated by concrete behavioral implementations. Finally, we conclude.

## 2 Institutions and norms

We understand the notion of institution as a set of legal, practice or custom norms. This set can be recognized as such by the people on which they apply or exist only from a scientist point of view. This definition of institution is used in particular by [8]. The way these norms are used is part of the individual agents definition. The way these norms are enforced is reified as an agent endowed with the collective goals of the associated institution. This collective agent will be described in the next section. In this section we will introduce the norms we want to represent and thereafter its formal account.

### 2.1 Representation of norms

We are going to reuse the distinction between constitutive and regulative norms as proposed in [4]. Concerning the constitutive norms, we want, for example, be able to express that:

1. "Eucalyptus counts as a vegetal specie" reflecting a classification by a forester or ecologist;
2. "Eucalyptus counts as timber" understood as a relation between the concept of Eucalyptus from the point of view of the forester and the concept of timber from the point of view of a carpenter;
3. "This tree is (counts as) my property" that expresses a property relationship defined between two individuals (here an objet and an agent). This definition associates rights on this tree (to sell, to destroy, to use, etc...) through additional regulative norms;
4. "Paul is (counts-as) a license holder' that associates an individual (Paul) to a concept (license holder) endowing him with a number of rights (in this case to sell its harvest or production). In the same way, "This area is (counts as) a protected zone" expresses an association between an individual (a geographic entity) and a concept (protected zone).

One recognizes the usual structures of the ontologies or description logics, i.e. the concepts (eucalyptus, vegetal species, license holder, etc.) structured by taxonomic (vegetal specie is more general than Eucalyptus) and semantical relationships (to be the property of), and the individuals (this tree, Paul, this area) categorized (instances of concepts) linked among them (for example, an area is included into another). However, the taxonomic, semantical relationships, the links and categorization are contextual: the eucalyptus can be a vegetal specie only for the ecologist, Paul is a license holder or this area is a protected zone relative to a given institution. Finally, these relationships can be defined across contexts; the Eucalyptus from the point of view of the ecologist is considered as

fuel wood from the point of view of the coal-man, this area from the point of view of a surveyor is considered as a protected zone from the point of view of an institution (for example, the natural park administration). The most important is the lack of difference between putting an individual (Paul, this area) into a contextually defined category (license holder, protected zone) and attributing a role (the role of license holder, the role of protected zone) in this context. Thus "Paul is a license holder" and "this area is a protected zone" are of the same nature. [9] provides a detailed analysis of the various meaning of "counting-as" in a context, namely the classificatory meaning, proper classification and being constitutive. An analysis of "counting-as" is described as well in [7] but from the point of view of a unique institution. However, in each of those cases, the analysis relies only on the concepts but not the individuals, enabling to account for the first two cases but not the last ones. In [9, 7], it is therefore not possible to account for the notion of role under the form of a contextual categorization as we propose.

The regulative norms are usually specified using deontic operators (permission, obligation, prohibition). Thus, Moise+[10] is focused on the distribution of tasks in an organization with three specifications: the structural specification defining the roles, the functional specification defining a hierarchy of goals and missions, and a deontic specification linking missions to roles. [11] with AMELIA specifies the electronic institutions that impose protocols of interactions among agents defined in deontic forms. A version more sophisticated is proposed in OPERA [12]. In a different way, [7] formalizes the norms by violation criteria, the violation being deductively constructed. Indeed, the regulative norms raise the question of their control. In MAS software engineering, the norms are considered as specifications of high level and are enforced directly in the design of the agents and their interactions. In this case, the deduction of a violation becomes a kind of program proof. Nevertheless, in open multi-agent systems, the case of agents that do not abide with the norms either intentionally or accidentally has to be taken into account[12]. [13] proposes a mechanism of punishments and rewards, which requires the agent to reason on the advantages and disadvantages to obey or not to the norms.

MIRANA has the intent to model the actual functioning of the institutional structures. In Law, for a norm to come into effect, one must foresee a control function that can be systematic or not and possibly leading to a violation record (the police function) and a sanction system in case of such a record (the penal function). In order to do it, we have separated the norm expression from its implementations. Thus a hunting quota can be enforced by a control strategy or by the distribution of licenses. Given the variety of implementations, we were brought to reify each institution by an agent having the status of a moral person and the role of manager of the associated institution. Therefore, we distinguish the institution as as structure, from the agent who manages it. We are now going to present our proposition to represent and implement the constitutive and regulative norms.

### 2.2 The formalization

We are then going to formalize what precedes by using the contextual ontologies for the constitutive norms, and deontic forms for the regulative norms. Therefore, each institution $i \in I_{SMA}$ is defined as follows:

**Definition 1.** *The specification of an institution $i$ is a pair $DI_i = \langle O_i, N_i \rangle$ where:*

- *$O_i$ is an ontology;*
- *$N_i$ is a set of regulative norms .*

Having a family of institutions, we obtain a corresponding family of contextual ontologies. We will describe the ontologies and the regulative norms in turn.

**Contextual ontologies and constitutive norms** To account for the constitutive norms, we equip ourself with a family of ontologies $O_i$. Each ontology is defined on a language $\mathbb{L}_i = \langle \mathbb{C}_i, \mathbb{P}_i, \mathbb{O}_i, \mathbb{I}_i \rangle$ where:

- $\mathbb{C}_i$ is a set of concept names;
- $\mathbb{P}_i$ is a set of relation names[1];
- $\mathbb{O}_i$ is a set of individual (or object) names;
- $\mathbb{I}_i$ is a set of ontology names.

This definition is usual but the introduction of ontology names to be able to internally refer to other ontologies. To account for the specificity of MAS, we propose to decompose the set $\mathbb{C}_i$ of concepts into four disjoint sets:

- $ARole_i$ for the concepts of agent;
- $RRole_i$ for the concepts of objects (or individuals);
- $Act_i$ for the concepts of activities;
- $Loc_i$ for the concepts of places.

The derived concepts are built by the usual constructors: $\neg c$, $c_1 \sqcup c_2$, $c_1 \sqcap c_2$, $\forall r.c$, $\exists r.c$, $i{:}c$ where $c, c_1, c_2$ are the concepts, $r \in \mathbb{P}_i$ and $i \in \mathbb{I}_i$. $i{:}c$ denotes the concept $c$ in the ontology $i$ and allows denoting the concepts defined in other ontologies. We impose that the set of derived concepts for the agents, objects, activities and places are disjoint.

Finally, $c_1 \doteq c_2$ and $c_1 \sqsubseteq c_2$ are the terminological axioms for definition and subsumption. Notice that if $c_1, c_2 \in Loc_i$, $c_1 \sqcup c_2$, $c_1 \sqcap c_2$ and $c_1 \sqsubseteq c_2$ have the usual sense of geometrical intersection, union and inclusion. We are now in the position to formulate the first two cases:

- "Eucalyptus counts as a vegetal specie" is expressed as $Eucalyptus \sqsubseteq VegetalSpecie$ in the ontology (the mental universe) $O_{forester}$;

[1] In description logics, they are called roles but we will not use this term to not confuse with the roles in the organizational sense.

– "Eucalyptus counts as timber" is expressed as $Eucalyptus \sqsubseteq j{:}Timber$ where $j \in \mathbb{I}_{forester}$ is the name of the carpenter's ontology from the point of view of the forester, or complementarily, $i{:}Eucalyptus \sqsubseteq Timber$, $i$ being the name of the ontology of the forester from the point of view of the carpenter.

The forester can know that the eucalyptus is timber without the carpenter knowing it, or vice versa. Notice that it is always necessary to mention in which ontology (from which point of view) the axiom is expressed because the denotation is strictly contextual. Thus, we obtain the expressivity of [5]. However, we have added the locality of ontology names. Consequently, an ontology may not be able to designate another ontology and therefore might not know the corresponding concepts.

In the same way, we decompose the set $\mathbb{O}_i$ of individuals within:

– $A_i$ the set of agent names;
– $R_i$ the set of object names;
– $P_i$ the set of activity names;
– $L_i$ the set of place names.

The corresponding assertional axioms (or assertions) are $c(o)$ and $r(o_1, o_2)$ where $c \in \mathbb{C}_i$, $r \in \mathbb{P}_i$ or of the form $i{:}r$, and $o, o_1, o_2 \in \mathbb{O}_i$ or of the form $i{:}o$, where $i \in \mathbb{I}_i$. $i{:}o$ denotes an individual $o$ in the ontology $i$ and allows denoting the individuals as named within another ontology. It is the same for the relations. In $\mathbb{P}_i$, we define en particular a relationship *position* between a place and an individual allowing to situate an agent or an object in the space.

We can now express the last two examples:

– "This tree counts as my property" in $O_{owner}$ can be translated by $i : property(tree_{27}, I)$ where $i$ is the name of the ontology of the institution in which the notion of property is defined, $tree_{27}$ is the name used by the owner to denote the mentioned tree and $I$ is the name used by the owner to designate himself (and of course himself is different for each agent).
– in the same way, one can express "Paul counts as a license holder" by $i : LicenseHolder(Paul)$.

We see in the last example that the notion of role in the organizational sense, being for an agent or an object, is naturally expressed using contextual categorizations.

The introduction of the place as particular objects allows us naturally to introduce the roles of space areas. Thus an expression as $i{:}ProtectedZone(area_7)$ allows to categorize the place $area_7$ as a protected zone from the point of view of $i$. In geography, it is commonly admitted that a territory is defined as a socially appropriated area. Intuitively, we propose to account for this definition by saying that an ontology $O$ is the expression of a socially or individually constituted point of view, and then that the set of places categorized by using the concepts of $O$ constitutes his territory. The following definition formulates this intuitive description.

**Definition 2.** *The set of places $c_i{:}l_j$ mentioned in the assertions of the form $\langle concept\rangle(c_i{:}l_j)$ of the ontology $O_{c_1}$ is called the* territory *of $c_1$.*

The figure 1 illustrates some territories in our application. The park administration, customary lineage and VOI correspond to institution territories. In this case, the park administration and the lineage do not need to decompose the area into subareas. For the lineage, it could be a sacred, forbidden zone. The VOI defines protected zones, cropping zones, etc.. Notice the introduction of territories from the point of view of agents as well. Hence, the villagers only consider the roads between the villages. The ecologist is not an agent within the model, although he defines the notion of habitat to account for flora and fauna dynamics.

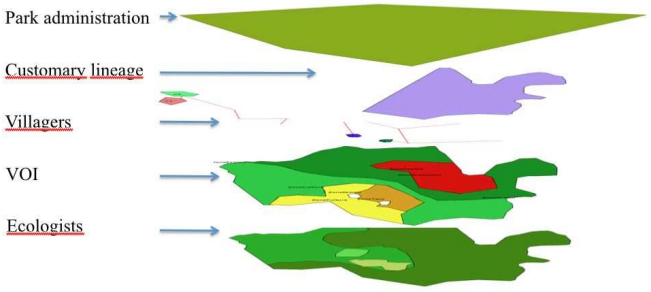



**Fig. 1.** The various territories.

Finally, we define an ontology as a triple $O_i = \langle \mathbb{L}_i, \mathbb{T}_i, \mathbb{C}_i\rangle$ where $\mathbb{L}_i$ is its language, $\mathbb{T}_i$ is the set of terminological axioms and $\mathbb{A}_i$ is the set of its assertions.

The semantics of a family of ontologies $O_i$ is defined by giving a family $M$ of local interpretations[2] $\Delta_i = \langle \mathcal{A}_i, \mathcal{R}_i, \mathcal{P}_i, \mathcal{L}_i, \pi_i\rangle$ where:

- $\mathcal{A}_i$ is a set of agents;
- $\mathcal{R}_i$ is a set of objects;
- $\mathcal{P}_i$ is a set of activities;
- $\mathcal{L}_i$ is a set of places endowed with a topology;
- $\pi_i$ is the semantical function defined as follows:
  - $\pi_i(c \in ARole_i) \subseteq \mathcal{A}_i$
  - $\pi_i(c \in RRole_i) \subseteq \mathcal{R}_i$
  - $\pi_i(c \in Act_i) \subseteq \mathcal{P}_i$
  - $\pi_i(c \in Loc_i) \subseteq \mathcal{L}_i$
  - $\pi_i(r \in \mathbb{P}_i) \subseteq \mathbb{O}_i \times \mathbb{O}_i$
  - $\pi_i(o \in A_i) \in \mathcal{A}_i$
  - $\pi_i(o \in R_i) \in \mathcal{R}_i$
  - $\pi_i(o \in P_i) \in \mathcal{P}_i$

[2] It is mainly this locality that grounds the contextual feature of these ontologies.

- $\pi_i(o \in L_i) \in \mathcal{L}_i$
- $\pi_i(i \in \mathbb{I}_i) \in M$
- $\pi_i(\neg c) = \{x \in \mathbb{O}_i | \neg(x \in \pi_i(c))\}$
- $\pi_i(c_1 \sqcup c_2) = \{x \in \mathbb{O}_i | x \in \pi_i(c_1) \vee x \in \pi_i(c_2)\}$
- $\pi_i(c_1 \sqcap c_2) = \{x \in \mathbb{O}_i | x \in \pi_i(c_1) \wedge x \in \pi_i(c_2)\}$
- $\pi_i(\exists r.c) = \{x \in \mathbb{O}_i | \exists y, \langle x, y\rangle \in \pi_i(r)\}$
- $\pi_i(\forall r.c) = \{x \in \mathbb{O}_i | \forall y, \langle x, y\rangle \in \pi_i(r)\}$
- $\pi_i(i{:}c) = \pi_j(c) \cap \mathcal{O}_i$ where $\pi_i(i) = \Delta_j$

The last definition allows defining the semantics of a reference to the expression within another ontology. It depends on the possibility to actually designate that ontology ($\pi_i(i) \neq \bot$) and to share, at least partially, the domain of discourse. For the spatial dimension, we put forward, in addition to the topology on $\mathcal{L}_i$,the semantics of the position relationship: $\pi_i(position) \subseteq (\mathcal{R}_i \cup \mathcal{A}_i) \times \mathcal{L}_i$ that gives the position of the objects and agents.

Finally, the interpretation $\Delta_i$ is a model of the ontology $O_i$ under the following conditions:

- $\Delta_i \models c_1 \doteq c_2$ if and only if $\pi_i(c_1) = \pi_i(c_2)$;
- $\Delta_i \models c_1 \sqsubseteq c_2$ if and only if $\pi_i(c_1) \subseteq \pi_i(c_2)$;
- $\Delta_i \models c(o)$ if and only if $\pi_i(o) \in \pi_i(c)$;
- $\Delta_i \models r(o_1, o_2)$ if and only if $\langle \pi_i(o_1), \pi_i(o_2)\rangle \in \pi_i(r)$;

This definition is stated differently than in [5] where the semantics of an axiom is given by the set of its possible models. It is easy to see that it is equivalent.

**The regulative norms** A regulative norm is expressed in the language $\mathbb{L}_i$ of $O_i$ and of the form $\langle ar_i, mod, act_i, or_i, l_i\rangle$ where:

- $ar_i \in ARole_i$ is an agent category (role),
- $mod$ is a deontic modality (obligation, permission, prohibition),
- $act_i \in Act_i$ is an activity category,
- $or_i \in RRole_i$ is an object category (role) on which the activity applies,
- $l_i \in Loc_i$ is a place role,

A regulative norm states that an agent considered as playing a given agent role ($r_i$) has the obligation, permission or prohibition to realize the activity $act_i$ on the objects playing a given object role ($r_j$) in a place having the role $l_i$. Remind that having a role is equivalent to be contextually categorized as such. For example, given the concepts of $User$ ($User \in ARole_i$) and of $Thing$ ($Thing \in RRole_i$), as well as the activity $ToUse$ ($ToUse \in Act_i$), one can define the norm $\langle User, permission, ToUse, Thing, Territory\rangle$. It expresses that a user has the permission to use a thing all the time on the territory. The name $Territory$ is used instead of "everywhere" because an institution is assumed to be authoritative only on its associated territory. We will see in what follows how to represent that a particular agent plays the role of $User$, a particular object plays the role of $Thing$ and that, therefore, the norm applies. To simplify, we do not

consider conditional norms nor temporal restrictions even if this last extension is taken into account, at least partially, in our implementation.

The natural order on the deontic modalities (obligation > permission > prohibition), as well as the subsumption relation $\sqsubseteq$ induces an order on the norms as given by the following definition:

**Definition 3.** *$\langle r_i, mod, act_i, r_j, l\rangle \leq \langle r'_i, mod', act'_i, r'_j, l'\rangle$ if and only if $r_i \sqsubseteq r'_i, mod < mod', act_i \sqsubseteq act'_i, , r_j \sqsubseteq r'_j and l \sqsubseteq l'$.*

Given that $\sqsubseteq$ is a partial order, $\leq$ also is a partial order. This definition is very important to compute the rights to do something somewhere. Intuitively, if we take a set of norms, all the minimal elements of this partial order define the norms that are actually applicable on the activities of the agent. However, they can contradict each other.

## 3 Agents

Each agent $a \in A_{SMA}$ is defined in the following way:

**Definition 4.** *The specification of an agent $a$ is a pair $DA_a = \langle O_a, G_a\rangle$ where:*

- *$O_a$ is an ontology specifying the beliefs of the agent;*
- *$G_a$ is a set of goals expressed in the language $\mathbb{L}_a$ of $O_a$, as a list of assertions to make true.*

This very general definition of goal is enough to express the needs $access(I, \langle Rice, 100kg\rangle)$ as well as the physical $position(house, l_{34})$ or institutional $ProtectedZone(l_{56})$ goals.

The institutions $\mathbb{I}_a$ are those known to the agent. The affiliation is expressed by an agent counting as playing a given role in the institution. A minima, he is member, a role that subsumes all the others $r$ ($\forall r, r \sqsubseteq Membre$). Thus an agent is member of an institution $i$ is expressed by $i : Member(I)$ (formally, $I$ is the category $Member$ of the institution $i$). [5] is forced to add a particular predicate $rea(a, r)$ to express that an agent $a$ plays a role $r$. In our formalism, the assertions of an ontology is sufficient. Moreover, this assertion can be only in the institution (only the institution knows that the agent is member), or only in the agent (the agent believes that it has a role in the institution), or in both.

The set of institutions $M$ of which the agent is member, and the territories in which the agent is situated, specify the set of applicable norms in terms of obligation, permission or prohibition to realize a given activity on a given object category. To account for it, we have to define formally the conditions under which a norm $\langle ar_i, mod, act_i, or_i, l_i, q_i\rangle$ of an institution $i$ is applicable. There are two possibilities:

- the norm is applicable because the agent plays a role in the associated institution;
- the norm is applicable because the agent is situated on a territory regulated by an institution.

The following definitions allow accounting for these two cases from the point of view of the agent and from the point of view of the institution.

**Definition 5.** *A norm* $\langle ar_i, mod, act_i, or_i, l_i \rangle$ *of an institution* $i$ *is* applicable *from the point of view of the agent* $a$ *if and only if:*

- $i \in \mathbb{I}_a$ *therefore* $a$ *knows the institution* $i$*;*
- *we can deduce from the axioms of* $O_a$ *that:*
  - $ar_j(I)$ *and* $ar_j \sqsubseteq i{:}ar_i$*;*
  - $a$ *knows at least one activity* $act_j \sqsubseteq i{:}act_i$*;*
  - $a$ *knows at least a category of resource* $or_j \sqsubseteq i{:}or_i$*;*
  - $position(I, l)$ *and* $l \sqsubseteq i{:}l_i$*.*

We here assume that $a$ knows something if it exists a name in its language $\mathbb{L}_a$ to designate it.

**Definition 6.** *A norm* $\langle ar_i, mod, act_i, or_i, l_i \rangle$ *of an institution* $i$ *is* applicable *for an agent* $a$ *from the point of view of the institution* $i$ *if and only if:*

- $a \in A_i$ *therefore* $i$ *knows the agent* $a$*;*
- *one can deduce from the axioms of* $O_i$ *that:*
  - $ar_i(a)$*;*
  - $a$ *knows at least one activity* $act_j \sqsubseteq i{:}act_i$*;*
  - $a$ *knows at least a category of resource* $or_j \sqsubseteq i{:}or_i$*;*
  - $position(a, l)$ *and* $l \sqsubseteq l_i$*.*

Being applicable from the point of view of an agent, respectively from an institution, does not mean that it will be actually applied. Indeed, an agent may not honor it and an institution, as an agent, may not control it nor apply any sanction for it.

We will now describe in more detail the behavior of the households, respectively the VOI in MIRANA in order to illustrate the use of the proposed formalism.

### 3.1 The households

The households are characterized by an available workforce and a set of annual needs ($\subset G_{household}$). These needs include quantities of alimentation, finance, firewood (for cooking and heating), construction wood, medicinal plants and so on. Each year, each household plans its activities and executes them (see figure 2).

An household starts its cycle by selling all or part of his workforce by asking contracts ("contract request" in figure 2) to the VOI. The planning is thereafter composed of three phases:

1. If the contract request is accepted ("get request"), he receives one or more contracts ("contracts") for lumber jacking, planting or surveillance in order to detect possible norm violations. He has consequently to plan the related activities and evaluate the remaining workforce. The objective is to sell his workforce to possibly financially cover its needs;

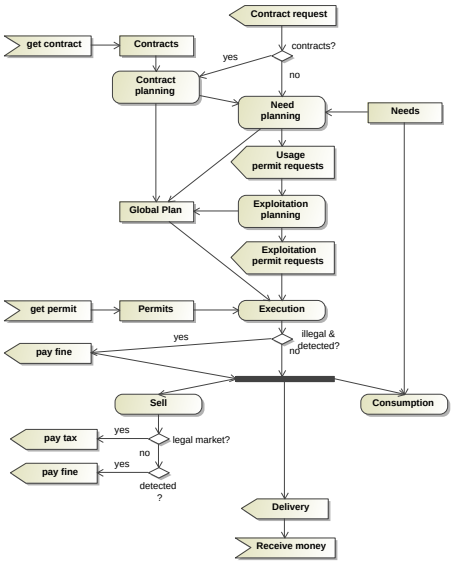



**Fig. 2.** The household behavior activity diagram.

2. Then, he plans his needs up to its available workforce. The usage permits regulate the satisfaction of the needs. Therefore he asks for such permits up to the necessary quantities of resources. The objective is to fulfill his needs;
3. Then, if some workforce remains, he plans the production of goods to sell on the market. Here also, the exploitation permits regulate the production and, consequently, are requested for. Here, the objective is to maximize his income.

The three phases produce sequences of actions to perform. These actions are added to a global household's plan ("global plan"). Notice that the behavior of the households does not reduce only to income optimization because we take into account two additional important dimensions of human behavior: i) The possibility of selling one's workforce although some optimization could be performed on the choice of contract; 2) The auto-consumption that is not based on optimization but on satisfaction only.

After this planning phase, the planned actions will be executed and the results will be delivered to the employer, consumed or sold depending on whether they were produced for the contracts, for satisfying the needs or for selling. The employee gets paid on delivery and the production sold on the legal market is submitted to a tax. At the end of year, every resource that has not be delivered to the employer or consumed is converted to money by being legally or illegally sold, and constitutes the annual financial result of the household.

We will now describe the regulation of the households' activities by the institutions. However, beforehand, we will make three remarks:

1. Each contract constitutes itself a small institution with limited duration (1 year in our simulations). Each contract defines the role of employer and employee with the associated norms in terms of delivery of goods or services, and payment. In our case, the contracts are made with the VOI who delegates the role of license holder for lumber jacking and the role of police for surveillance only to its members;
2. A part of the regulation is externally achieved by a control mechanism. The households in charge of surveillance dedicate a part of their time to monitor the actions of others. If a violation is observed, a fine is applied and the resulting resources are confiscated and given to the VOI.
3. Each household in its decision mechanism internally achieves the other part of the regulation. The result depends on whether the household is legalist or not and will be described hereafter.

At the planning level, each activity has to take place in a certain place ($\in L_{household}$). Therefore, part of the planning phase consists in choosing a place to carry out the activity. The place to be chosen depends on whether the household is legalist or not. If the household is legalist, the activity can only take place on a place where it is authorized from the points of view of all the defined institutions. This authorization depends on the norms applicable to the corresponding territories or zones that overlay upon it. If the household is not legalist, he may consider doing it on places that are not allowed from the point of view of one or more institutions. Notice that the norms can be equally be seen as constraints or resources for action.

At the execution level, the execution of the planned actions to satisfy the needs depends on the usage permit from the VOI. If the permit is not granted and the household is legalist, the corresponding action will not be executed, otherwise it will be illegally performed. In the same way, the execution of planned actions for commercial production depends on the exploitation permit from the VOI and follows the same rule. If the action is illegal and the violation is detected, a fine has to be paid and the corresponding resources are confiscated.

This behavior allows checking the impact of the imposed regulations on the financial results (economic sustainability) and the households' satisfaction (social sustainability). If all the households are strictly legalists, the level of satisfaction of the annual needs will be a good indicator of the sustainability of the regulations. If none of the households is legalist, the number of violations (detected or not) will also constitute a good indicator for the pressure imposed by the regulations. Another indicator could be the relative importance of the goods sold on the formal or informal market.

### 3.2 The VOI

The VOI has the objective, through its associated institution to guarantee a sustainable use of the renewable resources on its territory. As a stakeholder and moral person, the VOI is in charge of implementing the norms of the institution. This implementation of the norms relies on a number of tools:

- The granting of lumber jacking contracts and exploitation licenses to implement the exploitation quotas (the quota is assumed to be defined on the basis of the resources renewal speed);
- The granting of usage licenses to implement the usage quotas;
- The grants for plantation to compensate the forestry resource losses, and consequently to restore the ecosystem;
- The grants for intensification of the cultivation to increase the crop productivity and possibly reduce the footprint on the ecosystem;
- The granting of surveillance contracts to implement the norm compliance by the households.

Finally, the VOI ensures his own financial sustainability by gathering the fines and taxes, as well as by selling the contracted production and the confiscated goods on the market.

This behavior is summarized in the figure 3 where no sequential order is given to the activities because most of them are triggered by the arrival of the requests, or the order is not important.

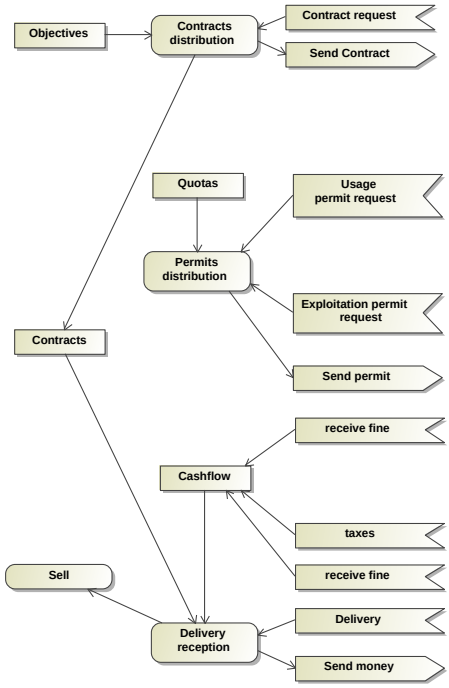



**Fig. 3.** The VOI behavior activity diagram.

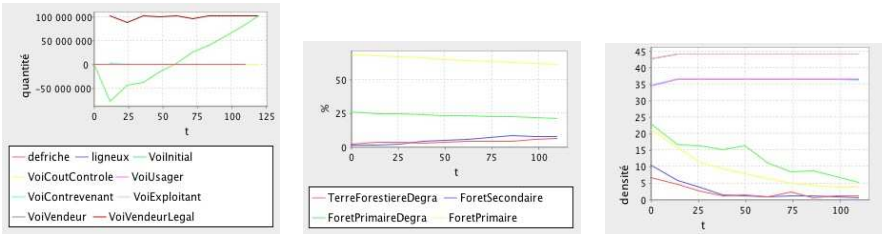
At this level, it is possible to parameterize the regulation policies by the institution norms, including the quotas and the implementation policy and to

assess the feasibility of the management plan. Therefore, we are globally able to assess the impact of the management plan on the ecological sustainability by indicators on the ecosystem itself, the economic sustainability of the households and of the VOI, and the social sustainability of the households.

Regarding the VOI economic sustainability, the costs include the surveillance and lumber jacking salaries, and the plantation and intensification incentives, while the revenues include the taxes (both for the permits and on the market sales), the fines, and the timber (both from production and confiscation) sales on the market.

### 3.3 Some results

We do not have the place to show extensive experiments, but the figure 4 illustrates some simulation results over twelve years (120 months) with non-legalist households and only a small fraction of the area with full conservation. The figure 4 a) shows the VOI financial results. The red line represents the tax incomes that are relatively constant over time, producing an increasing net income (green line). The initial negative result is due to the payment of the first salaries. The figure 4 b) shows the evolution of the habitats in percentage of the total surface. There is only a slow erosion of the primary forest. If the degraded land increases, there is similar growth of the secondary forest. The simulation on 60 years (tree growth cycle duration) shows some recovery of the primary forest. However, the figure 4 c) shows that if we look at the tree species, some are more exploited than others.




(a) VOI financial results (b) Habitat evolution (c) Tree species evolution

**Fig. 4.** Some results.

## 4 Conclusion

To tackle the sustainability impact of resource management plans in a multiple regulatory context, we have proposed a two-level description. In the first level, we have proposed the notion of institution as a set of norms covering the constitutive norms, the regulatory norms as well as the role structure, using in particular the

contextual ontologies. In the second level, we have proposed to use the notion of agent to represent both the actors on which the norms apply, and the collective actors associated to each institution who implement the normative constraints. As a result, we have shown that the proposed formalization of institutions allows accounting for the multiplicity of legal interpretations necessary to understand the regulations interplay. We also showed the possibility to naturally account for a multiplicity of territories. Finally we have illustrated how the formalism allows expressing the agent account of a multiplicity of regulative structures in its planning and execution mechanism.

The dynamics has been globally defined and the generic specification of the account of norms at the agent level remains to be described. We have, among others, dissociated the institution as a structure from the agent implementing the collective objectives through control strategies of norms and the non-regulatory management methods (incentives, taxes, etc.) that remain to be formally specified. The use of contextual ontologies for the constitutive norms paves the way to a reflection on common knowledge that also remains to be defined.

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