Supporting policymakers in designing agricultural policy instruments: A participatory approach with a regional bioeconomic model in La Réunion (France)

Marie Dupré, Jean-Marc Blazy, Thierry Michels, Pierre-Yves Le Gal

Title: **Supporting policymakers in designing agricultural policy instruments: a case study in La Réunion (France)**

Marie Dupré [a*], Jean-Marc Blazy[b], Thierry Michels[a], Pierre-Yves Le Gal[c]

[a] (1) CIRAD, UPR HORTSYS, 97455 Saint-Pierre Cedex (La Réunion), France

(2) HORTSYS, Univ Montpellier, CIRAD, Montpellier, France

thierry.michels@cirad.fr

[b] INRA, UR1321 ASTRO Agrosystèmes Tropicaux, F-97170 Petit-Bourg (Guadeloupe), France

jean-marc.blazy@inrae.fr

[c] (1) CIRAD, UMR Innovation, F-34398 Montpellier, France

(2) Innovation, Univ Montpellier, CIRAD, INRA, Institut Agro, Montpellier, France

pierre-yves.le_gal@cirad.fr

* Corresponding author: mariedupre92@gmail.com

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Title

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Abstract

Bioeconomic models make it possible to assess *ex-ante* the consequences of public interventions in the agriculture sector. Yet since policymakers rarely participate in their design or use, these models are often too complex or do not address their questions. This article describes the implementation of a nine-step participatory modelling process involving regional policymakers, and analyses the contribution of this process to the cross-brainstorming between policymakers and researchers. In the preliminary stage, researchers develop a prototype bioeconomic model which links the farm level, where trade-offs between productions are considered, with the regional level, where the balance between production and consumption per product is considered. Public actors are then mobilised to identify issues and characterise the scenarios that can be used to explore the questions selected. The scenarios are simulated with the bioeconomic model, which evolves depending on the needs, and the outputs are discussed with the public actors. The method was applied in La Réunion (France) on the design and assessment of aid mechanisms related to the development of organic farming. The results showed (i) which farms convert to organic farming according to aid amounts, (ii) how local demand per product is satisfied and (iii) what are the amounts of the ensuing budgets for subsidies. The approach proved to be relevant for exchanging knowledge between public actors and researchers, regarding in particular innovative farming systems, farm diversity and multi-criteria evaluation of policy choices. The simulated scenarios offered powerful support for discussions about market evolutions and environmental challenges. These results indicate that transparent modelling tools and long-term partnerships with policymakers are required to implement such an approach at the regional scale.

Key words

Participatory modelling; Exploratory scenarios; Optimization; Organic farming; Farm typology

1. Introduction

More sustainable farming practices are being introduced in response to the threat posed to food security worldwide by global changes such as climate change and biodiversity loss (De Schutter, 2012; Tubiello et al., 2015). Government authorities have diverse instruments at their disposal to encourage stakeholders in the agriculture sector to change their practices. These instruments can be positive, such as subsidies (e.g., price support, payments coupled or not with production), or restrictive, such as taxes and regulations (Carpentier et al., 2015). In addition to the cost of their implementation, another drawback is that they can be a source of tension between stakeholders by running counter to some of their objectives. These instruments also must adapt to rapid changes in their operational contexts induced by, for example, technical innovations, competition from foreign markets, health crises and demands from consumers and the general public. The research community is consequently faced with the critical task of offering public actors a means to assess *ex-ante* the potential effects of their agricultural policies (Van Ittersum and Brouwer, 2010). The term 'public actor' is used here to refer both to policymakers and the public technical services staff in charge of providing input for policy decisions.

Modelling has been used to explore the possible consequences of policy changes (Pacini et al., 2004; Louhichi et al., 2010) and to facilitate the design of new agriculture policies (Semaan et al., 2007). Bioeconomic optimisation models frequently have been used to evaluate the behaviour of farmers confronting new contexts (Janssen and Van Ittersum, 2007). These models render it possible to identify the modelled agents' potential reactions and their actions on the system being modelled through the simulation of scenarios characterised by economic, regulatory, social and environmental elements (Leenhardt et al., 2012).

The design and use of these models are supervised by researchers and rarely involve policymakers (Falconer and Hodge, 2001; Rozman et al., 2013). When the latter are involved, this involvement and the lessons learned by the participants are rarely analysed (Reed, 2008). Nonetheless, this participatory dimension involving researchers, non-researchers and modelling tools has been developed (Voinov and Bousquet, 2010), notably in the agriculture sector to support farmers and technicians in the design of new farming systems and the agriculture policies facilitating their adoption (Pissonnier et al., 2017; Lacombe et al., 2018). Although these approaches are often proposed to national and supranational policymakers, they are rarely used at the local level, where public actors nonetheless have complex decisions to make regarding the design of specific policies and the adaptation of national policies (Uthes et al., 2010).

Participatory modelling literature has highlighted significant challenges to involving public actors. A preliminary condition is to find the right amount of solicitation adapted to the participants' time, skills and reachability (Basco-Carrera et al, 2017). In that respect, local policymakers may be more reachable than national or international ones. In the water sector, Hare (2011) notes the low use of many models designed to support policymakers. He advocates that models should better fit policymakers' needs and be kept as simple as possible to be understandable by their targeted stakeholders. Moreover, these models should help policymakers by precisely taking into account farm heterogeneity, and farm-level results should not be aggregated (Carpentier et al, 2015). Policymakers also need models which consider cross-relations between farming systems and food markets (Van Ittersum et al., 2008). Based on the modelling and simulation of various agricultural policy scenarios, they can evaluate *ex-ante* the various options regarding the objectives pursued at farm and regional levels. This anticipation of agricultural land use changes should enable public actors to better optimize land use policy and to plan sustainable transitions. These considerations make the regional level relevant to precisely take into account both the diversity of farms and the evolution of consumers' demand when using participatory modelling with policymakers.

This study aims to investigate the three points that were highlighted above: (1) involving stakeholders in the definition and analysis of new agricultural policies at a local regional scale; (2) taking into account simultaneously the diversity of agricultural production systems and local marketing channels and their relationships; and (3) formalizing a generic methodological framework to involve policymakers in the design of an understandable model addressing their questions.

This article shows how such a participatory process can be implemented with public actors, and presents the results obtained with regard to insights into the design of aid policies. It is based on the use of a regional optimisation model named ENTICIP (EvaluatioN at Territory scale of the Interactions between Consumption, public Interventions and farming Production) in an island setting where the sustainability of agriculture is a key issue (La Réunion, France). After presenting the process and its underlying model, two sets of questions are used to illustrate their implementation. The first, proposed by the public actors, concerned the short-term development of two fruit crops following a health crisis; the second, proposed by the researchers, concerned the medium-term development of these same crops to meet an increasing demand for products produced through organic farming (OF). The lessons learned by the various participants during the process are then discussed, as well as the advantages and disadvantages of the method and the ENTICIP model.

2. Materials and methods

2.1. The support process

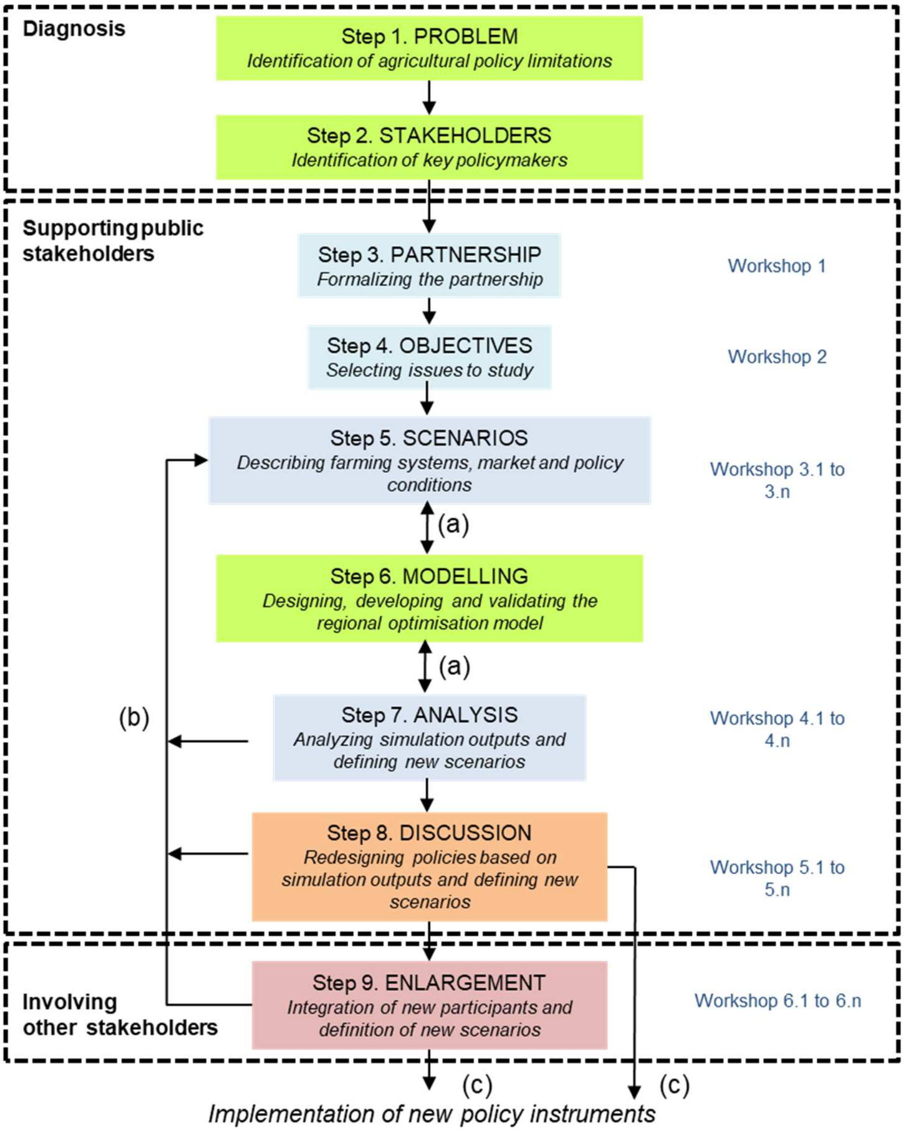
2.1.1. The nine steps of the participatory process

The process used in the case study has eight steps; a ninth can be added to integrate new participants in addition to public actors (Fig. 1). The first two 'preparatory' steps aim to frame the direction given to the process and are managed by the researchers. The first step is to identify the overall issue for which the process will be implemented. This issue may be related to environmental, economic or food security objectives for which existing policy instruments appear poorly adapted. It is accompanied by the design of an initial version of the model intended to address the issue identified. The second step aims to identify the public actors who, by virtue of their mandate and the instruments and funding at their disposal, are best equipped to act and interact with researchers regarding the issue identified.

The next steps are based on a series of workshops gathering researchers and public actors. The first workshop (step 3) serves to formalise the actors' commitment to implementing a participatory process around the issue identified. On this occasion, the model designed in step 1 is presented to participants (objectives, overall structure, input and output variables). The second workshop (step 4) consists of choosing the questions that the actors wish to explore using the participatory approach and that researchers feel capable of addressing given their fields of interest and skills.

The ensuing workshops are devoted to the selection and characterisation of scenarios (step 5). After a preliminary analysis of the simulation results, the model outputs are formatted (step 7) to adapt the presentation of results to stakeholders' expectations (Leenhardt et al., 2010). Building and assessing scenarios render it possible to explore combinations of economic and political levers, objectives, and technical options that differ from an initial situation (Van Ittersum et al., 2008). This key stage of the process is preferably undertaken with the technical staff of public institutions and not with elected officials because it is time-consuming and requires precise technical knowledge. This also helps to limit the risk of tension between stakeholders regarding the choices to be made (Delmotte et al., 2016a). The loop between step 5 and step 7 provides the core information nurturing discussions between the researchers and the technical staff regarding the scenarios' configurations and outputs. It can be the subject of numerous iterations according to the needs, contributions and reactions expressed by the technical staff. It also contributes to the process of designing, developing and validating the model (step 6).

Once steps 5 and 7 have produced scenarios that the technical actors find interesting, step 8 is initiated. This consists of presenting and discussing these outputs with policymakers. The latter can decide to integrate them into practical action or to request new scenarios, with (step 9) or without the involvement of additional professional stakeholders (farmers, cooperatives, manufacturers) or stakeholders from civil society (consumer associations, citizens). These choices may relaunch the process from step 5 and lead ultimately to the effective implementation of new policy instruments.



(a) The modelling process is based on and feeds discussions between researchers and stakeholders.

(b) Additional iterations are carried out as long as the stakeholders involved in the process are interested.

(c) Whether this last step takes place depends on technical, economic, social and economic conditions

Figure 1. Steps of the participatory modelling process with the gradual integration of policy actors. Green: research team alone; Blue: integration of technical services staff; Orange: integration of policymakers; Pink: integration of other stakeholders (farmers, cooperatives, processors, consumers).

2.1.2. The core model of the process: ENTICIP

Overall structure of the model

The general structure of ENTICIP is inspired by the multi-scale structure of the SEAMLESS framework designed to assess the sustainability of agricultural systems in the European Union (Van Ittersum et al., 2008). In SEAMLESS-IF, farming systems models (FSSIM) are linked with a food supply-demand simulation model (SEAMCAP) and an econometric meta-model (EXPAMOD). Comparatively, ENTICIP is a regional two-scale model which aims to be both understandable to non-modelling stakeholders while addressing cross-scale considerations. It renders it possible to assess the effects of a regional agriculture aid policy on (i) farm incomes according to the type of farm, and (ii) the supply levels of local markets targeted by this policy.

To achieve this, it is organised into two sequentially linked levels, namely the individual farm and the production and consumption area (PCA), with each level being the subject of an optimisation calculation (Fig. 3). The PCA corresponds to all of the farms supplying the commodities studied on a given territory and all of their markets. As a result of this per product approach, one frequently used in public policy, existing farms are represented in a simplified manner using the concept of the production unit (PU). Only the commodities studied are considered, as well as the surface area and workforce of the farm dedicated to these commodities. The PU takes into consideration farmers' individual objectives and constraints, notably in terms of economic profitability. It corresponds to a farm type on which the first optimisation is implemented. This optimisation provides the optimal distribution of land resources between the commodities studied.

The PCA consists of different PUs that are linked to market segments which they respectively supply (Fig. 2). Each PU optimised in the preceding step is represented *n* times in the PCA, with the *n* values for the different PUs considered the object of a second optimisation. The aim is to assess the optimal regional distribution of PUs that would enable consumer demand to be met by considering the following phenomenon: competition between farmers marketing their production within the same market segment, possible changes in market segments (increase or decrease in volumes or prices), and policy objectives set at the corresponding territorial level. Concretely, this second optimisation assumes the existence of processes for young farmers to establish themselves and the transfer of existing farms from one PU to another.

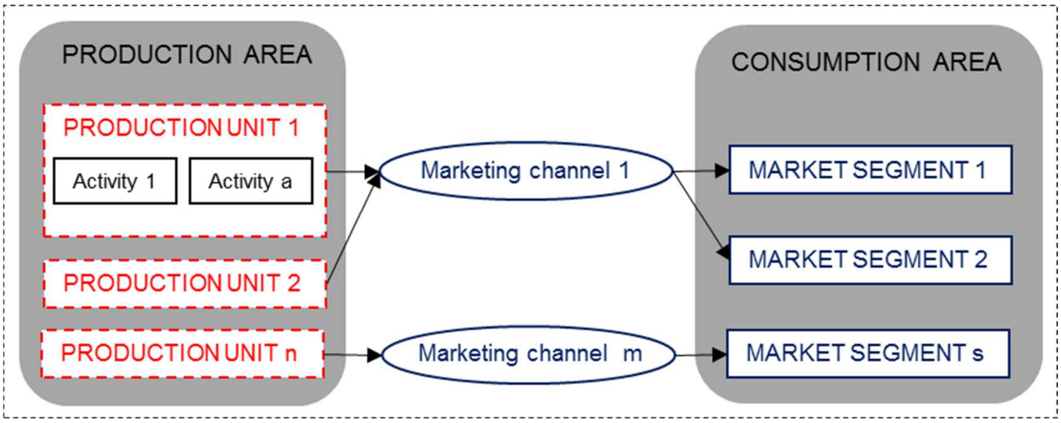


Figure 2. Illustration of a PCA including diverse producers (production units) linked via their main marketing channel to diverse market segments.

Optimisation at the PU level

For each PU described in the territory studied, ENTICIP calculates the optimal distribution of available surface areas between the farming activities studied, enabling the gross margin of the PU to be maximized under its own constraints. Each activity is characterised by the species cultivated and its mode of production. This is defined by technical coefficients per hectare, including monthly workload, input costs, yield (distinguishing between the yield of premium quality products and the yield of products with defects), and environmental indicators adapted to the issue being addressed. These indicators are chosen by the user of the model based on the risky practices and alternative practices modelled, and on the request of participants. Livestock activities can be described by the areas allocated to fodder crops and pastures, to which are added the resources consumed by animals (inputs and workforce) and the production of meat and dairy products. Each activity is associated with (i) a geographic zone to consider the effects of the natural environment on yields according to farming practices, and (ii) a marketing channel with a corresponding selling price, quality criteria and subsidies received for the product considered.

The choice of the PU's activities is determined by the model according to constraints that are internal (area, labour force) and external (geographic area, marketing channels allowing or banning certain activities), and which influence the potential agriculture productions and their performance, as well as the farmer's specific objectives, such as retaining permanent employees. Calculations are made for an entire year, but the labour constraint is assessed monthly by limiting the workload to the available work time. Activities with a crop cycle longer than one year are characterised by the average per month (work time) or per year (production, gross margin) over the entire cycle. Details of the set of equations used in the model are presented in Supplementary Material 1. Once these calculations are made, each optimised PU is characterised by the areas allocated for the activities chosen and all of the resulting indicators: gross margin, marketable volumes by market segment and the environmental indicators selected.

Optimisation at the PCA level

The second level of optimisation works from a representation of the PCA made up of the optimised PUs established at the first level (Fig. 3). It calculates the optimal distribution of farms of each PU type that would enable the total gross margin to be maximized at the PCA level while meeting the maximum marketable volumes for each market segment on the PCA. A market segment corresponds to a commodity produced by the activities studied, its possible certification (organic), the way it is marketed and its final destination. Other constraints may be set according to the scenarios, for example, a maximum cultivable area at the scale of the production area, or an environmental impact threshold that may not be surpassed (Sup. Mat. 2, Sup. Mat. 3).

Several indicators are calculated based on the optimum found, such as the total gross margin, total volumes per market segment, environmental indicators aggregated at the PCA level, and the total aid amounts distributed. The outputs then can be analysed and discussed by looking at the expansion or shrinking of PUs and market segments depending on the aid policy considered, as well as market dynamics (changes in product selling prices introduced into the model).

A scenario thus consists of a description, for each of the selected commodities, of the different possible PUs with their possible farming activities, the market context and the aid mechanism being explored. ENTICIP is coded using GAMS (General Algebraic Modelling System) language with GAMS software (Base Module, version 24.8.3) and uses a Mixed Integer Nonlinear Programming solver (Bonmin solver).

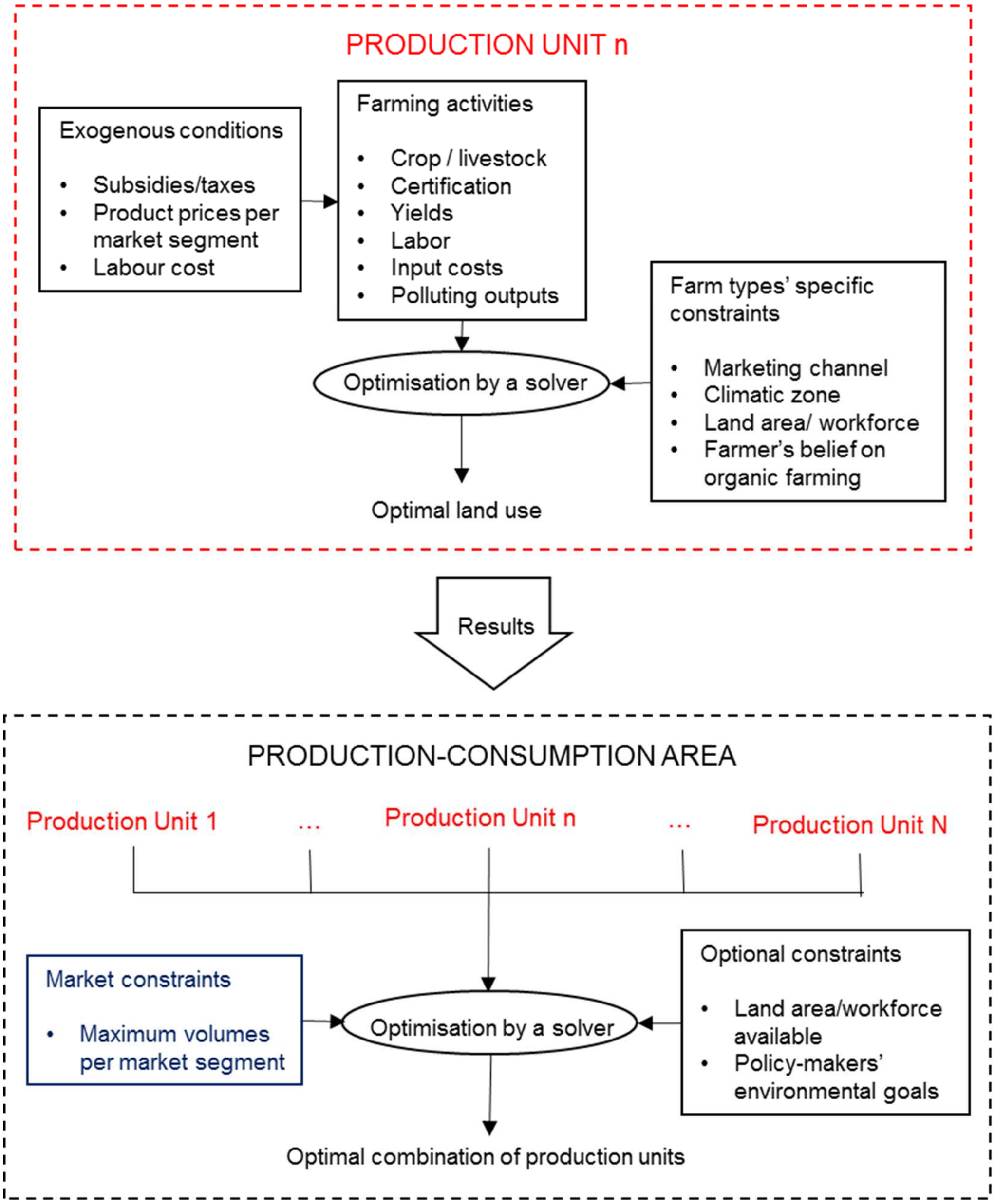


Figure 3. Structure of ENTICIP based on two optimisation levels, the Production Unit (PU) and the Production and Consumption Area (PCA).

2.2. A context conducive to the implementation of the approach

The approach was implemented on fruit crops in La Réunion (2,512 km²; 21° 06′ 52″ South, 55° 31′ 57″ East) for three reasons: the accessibility of public actors, past interactions with agriculture research organisations represented locally on the island, and sound knowledge of these value chains based on research (Dupré et al., 2017). As an outermost region of the

European Union, La Réunion benefits from public funds that are a significant source of leverage for local agriculture policy action through the implementation of a package of aid subsidies. Fruit crop subsidies were identified during the first step of the process (see Supplementary Material 7 for their amounts at the time of the study). The *Programme d'Options Spécifiques à l'Eloignement et à l'Insularité* (programmes of options specific to remote and insular areas, henceforth referred to in the text by the French acronym, POSEI) is the main mechanism. These coupled subsidies provide direct assistance to producers who are members of a cooperative, per ton of fruit delivered regardless of the type of outlet (fresh local markets, export, processing). Decoupled subsidies are also available as producers can enter into European contracts known as agri-environment-climate measures (AECM), independent of their marketing channel. They receive direct payments per hectare if they commit to implementing more environmentally friendly practices for crops eligible under the contract. Subsidies for maintaining OF (referred to here with the French acronym, MAB) is a second type of voluntary contract that is proposed by the French government.

3. Results: Application to fruit production in La Réunion

3.1. Initiating the participatory process

The first step of the process in La Réunion was based on a previous study at the farm level which identified a potential to improve the public aid mechanism in order to encourage agroecological practices (Dupré et al., 2017; Dupré et al., 2020).

Then, Step 2 of the process made it possible to identify the key actors in the design of local agriculture policies. They belong to the *Conseil Départemental*, the provincial council in charge of submitting to the European Union agriculture policy initiatives for La Réunion and of managing funding. Previously, these actors mainly relied on various experts' opinions when designing new forms of assistance. However, these opinions were limited by the experts' fields of expertise and could become a source of conflict of interest between the institutions which they represented. The council actors declared that they were interested in our proposal of an approach integrating a participatory modelling process. To reduce demands on the main policymaker (the elected official sitting on the *Conseil Départemental* in charge of the agricultural sector), steps 3 to 7 were conducted with the official's technical team over the course of four workshops. A summary of these steps was presented to the policymaker during a fifth workshop (step 8). Due to time constraints related to the funding of the research team, the first workshop was held in May 2017 and the fifth in July 2018. The remainder of the process (step 9 and the possible implementation of new subsidies) could not be achieved within the framework of the study.

3.2. Choice of questions addressed (step 4)

The scenario development process focused on two of the participants' concerns corresponding to different time horizons. The first examined potential subsidies to encourage farmers to reorient their farming systems in response to a pressing health crisis while developing a commodity that would be in high demand on the market. La Réunion island had been affected by an epidemic of

Huang Long Bing (HLB), a bacterium responsible for destroying citrus orchards. It was therefore necessary to consider uprooting the orchards affected and discuss the kind of replacement crops that could be recommended to citrus farmers in order to remediate the soil. For the scenarios, the decision was made to include tangor as the crop to be uprooted and pineapple as its replacement. Tangor is a citrus variety found across the territory and one which already had been studied by researchers (Dupré et al., 2017). Policymakers were in effect seeking to encourage the development of the pineapple crop to respond to growth in export and processing markets *via* the plantation support mechanisms under consideration. This choice led the researchers to collect data on the local pineapple value chain.

The second question concerned medium-term changes leading to more agroecological farming systems on La Réunion island. This concern was addressed by the researchers, who examined the market and support conditions that would enable a move from niche productions to a massive shift on the part of farmers towards agroecological practices. The public actors were interested in the question due to its links to environmental issues facing the island, such as pesticide pollution in runoff water. However, due to the difficulty in integrating the wide range of practices possible, a joint decision was taken to refocus the exploratory work on OF. Compared to products produced using agroecological practices that do not bear a recognisable label, organic products are better defined in terms of regulations, and have a clearly identifiable market. The public actors furthermore considered that the local market would grow sharply in the years to come. The same fruit crops (pineapples and tangor) used for the first question were chosen, both in the interest of limiting the number of references needed, and due to their importance in the local fruit sector.

3.3. Configuration of ENTICP according to the scenarios explored (step 6)

The framework offered by ENTICIP was used to characterise the scenarios. A range of activities were identified based on the possible combinations between two cultivated species (tangor and pineapple), two modes of production (conventional and organic), two natural areas (below and above 400 m) and five marketing channels (direct sale, retailers, cooperatives for the local market, cooperatives for processing, and, for pineapples alone, cooperatives for the export market). Each activity has a specific agronomic (yield), economic (gross margin) and environmental (seven assessment indicators for practices) performance. The at-risk practices considered were the use of synthetic pesticides and fertilisers, deep tillage and mulching with non-biodegradable plastic. The alternative practices considered were the use of pesticides and organic fertilisers bearing the AB label (the French OF certification label). Working from knowledge gained through surveys, data in the literature and workshops with local experts, 36 activities were described by the researchers (Sup. Mat. 4-5-6.). The public technical team did not modify either their definition or their description as they did not have any technical references that contradicted the contents.

In contrast, both researchers and the technical team contributed improvements to the definition and description of the PUs. This process resulted in a segmentation of the PCA into 18 PUs representing the diversity of the farms (Table 1). It was based on five factors guiding farmers' production and practice choices which had been identified by the researchers during preliminary surveys, namely: the land and labour resources available to the PU, which take the form of constraints in the model; the altitudinal location, which determines the natural flowering of the pineapple and the use or not of a floral inducer (prohibited in OF); the sales channel on which the purchase price of the product depends (only one channel per PU to be chosen from the five modes possible); the producer's attitude towards risk, approximated by the possibility or not of hiring permanent staff to reduce labour constraints; and the producer's primary objective (economic or environmental). When the priority is economic, OF activities are only chosen if they are more profitable than conventional activities ("Optional" mode in Table 1). In contrast, when the priority is environmental, OF activities are mandatory. This limited number of factors and modes was chosen so that the model outputs would be clear and admissible for policymakers for operational purposes. Policymakers can in effect only consider known administrative criteria, notably farm location and size, reported workforce, main marketing channel and adherence to an environmental charter as in OF.

At the request of the technical team, model outputs were adapted to their needs and work habits. The amount of all aid provided annually was added together and brought back to the hectare farmed. Within this package of aid, a distinction was made between current forms of assistance under budget constraints and the new forms of aid envisioned. This enabled the technical team to validate the financial feasibility of the mechanism studied, and to increase their confidence in the model's outputs because they could compare simulation results with orders of magnitude that they already knew.

Table 1. Characterisation of the 18 PUs in the initial situation.

PU code[1]	Farm type	Land area (ha)	Risk aversion[2]	Workforce (h/month)	Organic farming label[3]	Marketing channel
DA_1 / DA_2	**A**lternative	1	High	Max : 100	Yes	**Di**rect selling
DT_1 / DT_2	**T**raditionnal	1	"	Max : 125	Optional	**Di**rect selling
RS_1 / RS_2	**S**tandard	2	"	Max : 200	Optional	**R**etailers
CS_1 / CS_2	"	2	"	"	"	**C**ooperative (local market)
PS_1 / PS_2	"	2	"	"	"	**P**rocessing
ES_1 / ES_2	"	2	"	"	"	**E**xport
CL_1 / CL_2	**L**arge	4	Low	Min : 85	Optional	**C**ooperative (local market)
PL_1 / PL_2	"	4	"	"	"	**P**rocessing
EL_1 / EL_2	"	4	"	"	"	**E**xport

[1] First letter: Marketing channel (see in bold); 2nd letter: Farm type (see in bold); $_1$: localisation < 400 m; $_2$: localisation > 400 m
[2] High = Limitation to family workforce; Low = Employment of external workers
[3] Optional = Economic priority; Yes = Environmental priority

The validity of this representation and of the model was assessed by comparing the initial situation of the two crops on the island with a simulation of the same context of aid and markets (Sup. Mat. 7-8.). The estimates of the volumes marketed in the initial situation were derived from the research team's surveys and official data. The percentage of absolute deviation (PAD) was used to check the correspondence between the simulated outputs and real-life estimates by market segment (Janssen and Van Ittersum, 2007; Kanellopoulos et al., 2010) (Eq. 1). When a PAD is less than 20% for all of the market segments (Table 2), the model is estimated to be satisfactory (Chopin et al., 2015; Ridier et al., 2013).

$$PAD_m = 100 * (Vol\_Obs_m - \sum_{u=1}^{n} (N_u * Vol_{u,m})) \div Vol\_Obs_m \quad \text{Eq.1}$$

Where:
Vol_Obsm: volume sold estimated by market segment *m*
N_u: number of farms of each PU *u*
$VOL_{u,m}$ *:* volume sold per type *u* PU in the market segment *m* after simulation
Table 2. Validation of the model with the percentage of absolute deviation (PAD) between the simulated production and estimated volumes per market segment of the initial situation

Market[1]			Estimated volume (t)	Simulated volume (t)	PAD (%)
Tangor	Direct selling	Conventional	100	94	5.8
		Organic	34	30	12.6
	Retailers		900	879	2.3
	Cooperative (local market)		118	99	16.5
	Processing		150	133	11.2
Pineapple	Direct selling	Conventional	325	321	1.2
		Organic	17	14	18
	Retailers		2925	2890	1.2
	Cooperative (local market)		550	547	0.5
	Processing		600	559	6.8
	Export		2100	2082	0.9

[1]All of the markets only sell products from conventional farming except "Direct selling"

3.4. Description of scenarios (step 5)

In parallel with this configuration and validation process, the scenarios corresponding to the two questions addressed were described, particularly in terms of the aid mechanism to be simulated.

Scenario 1: develop pineapple production in response to the tangor health crisis

At the start of the process, the public actors had considered an aid mechanism aiming to develop pineapple production to replace the citrus orchards affected by HLB. Subsidies for planting pineapples were set at 7,500 €/ha in conventional production and 9,000 €/ha in organic production (Table 3), based on experts' estimates of conventional pineapple farming production costs, and assuming that organic production would face additional costs. The request expressed by the public actors consisted of using ENTICIP to assess *ex-ante* the advantages of this choice to substitute pineapples in the place of tangor at the scale of La Réunion island.

As this mechanism was to be set up in the months following the study, assumptions regarding the short-term evolution of the context were discussed and implemented in the model. The first hypothesis consisted of defining a new zone where tangor activities were excluded from all PUs due to the HLB virus. The size of the zone was set at 45 ha based on the knowledge of a local HLB expert. This third zone led to the addition of nine PUs to the scenario based on the PUs defined in Table 1.

The second hypothesis was that in the short term, the organic market would remain a niche market characterised by high prices and direct sales as the sole marketing channel (Sup. Mat. 8.). Based on their information about market demand, the participating technicians formulated the third hypothesis that the maximum volumes absorbed by processing and export markets would increase in the short term.

Scenario 2: develop organic farming for a mass pineapple and tangor market

At the start of the process, the technical team considered how to encourage a conversion to OF through an increase of existing subsidies, the size of which remained to be determined. Scenario 2 was therefore designed to explore the effects of such an increase on activities chosen by the PUs and resulting revenues by varying the amount of additional aid given (Table 3) rather than by reducing the aid given to conventional farming. The technical team felt that some farmers' representatives would find the latter option unacceptable.

Rather than sticking with the current situation, where OF is a niche market, the decision was made to examine a transition to a mass organic market characterised by selling prices lower than the current prices of organic products and higher volumes demanded in all of the marketing channels. The simulations were made by considering a situation that stabilised in the medium-term once the farm conversion and market structuration processes related to the shift to OF had been completed. In the absence of a local benchmark, the selling prices of organic commodities in such a context were proposed by the research team based on an analysis of the literature (Graciot et al., 2015; Yiridoe et al., 2007). As in scenario 1, the market segments remained unchanged but the maximum volumes that they could absorb increased.

Table 3. Description of the technical, policy, and economic changes introduced in the two scenarios studied.

	Initial situation	Scenario 1	Scenario 2
Representation of production area	18 PUs (Table 1)	Additional zone without tangor due to HLB contamination *(+9 PUs)*[1]	Idem initial situation
Aid mechanisms	POSEI subsidies AECM subsidies MAB subsidies	Added support for planting pineapple (*conventional: 7,500 €/ha, organic: 9,000 €/ha*)	Increase in MAB subsidy (*different amounts tested from 900 to 11,700 €/ha with an increment of 900 €/ ha)*
Market			
Selling price	Bonus for OF in direct sales *(+40%)*	Idem initial situation	Bonus for OF in all marketing channels *(+15 to 25% depending on visual quality*)

Total volume per segment	Increase in OF for direct sales (*substitution up to 33% of the volume in conventional*)	Increase for all processing *(+200%)* and export *(+50%)* market segments	Increase in OF for all marketing channels (*substitution up to 50% of conventional volumes*) + Increase for all processing *(+200%)* and export *(+50%)* market segments

[1] Corresponding to 9 PUs per zone, as defined in Table 1.

3.5. Analysis of the simulated scenarios' outputs (step 7)

Scenario 1: validate the relevance of the aid mechanism and assess its budget
The aid mechanism implemented would allow a 14% increase in pineapple production island-wide, and the percentage of demand (about 9,000 t/year) covered would increase from 70% (initial situation) to 80%. This increase mainly would benefit organic pineapples, which would cover 38 ha of the 45 ha of the "HLB" area targeted. The budget required for the new pineapple plantations would be €376,000.

The participants appreciated being able to obtain a quantitative estimate to compare with the funds that the *Conseil Départemental* had at its disposal to fund the aid mechanism. They pointed out in particular that the increase in the size of the POSEI subsidies distributed that was foreseen in the scenario could potentially be impeded by the reduction in the forecast budget allocated to POSEI aid for La Réunion.

Scenario 2: calibrate the aid system with an integrated, multi-level assessment
A MAB subsidy of 3,600 €/ha would be required for areas under OF to achieve the 15% threshold corresponding to the national policy objective (Figure 4). This amount would require a 2,700 €/ha increase in the MAB subsidy compared to the amount in the initial situation. The change of surface area would come from the conversion to OF of farms belonging to the RS_2 PU; these farms are located at altitudes of over 400 m and market through retailers. The farms convert all of their production area to OF by replacing conventional tangor with organic pineapples, which are more economically attractive than organic tangor or conventional pineapple once subsidies are included (Table 4).

The other PUs only shift to OF when MAB amounts are much higher (Figure 4). PUs in zone 1 cannot cultivate organic pineapples because they are located at an altitude of under 400 m, therefore they would need to use a floral inducer, which is prohibited in OF. Organic tangor farming is possible in this area but it is significantly less profitable than pineapple production. This is why RS_1 only converts to tangor OF once the MAB subsidy is equal to 6,300 €/ha. Among the PUs in zone 2, those in direct sales (DT_2) only convert after the amount is 7,200 €/ha because this marketing channel offers prices far above those received via retailers, which renders it possible to compensate for the reduced earnings due to lower yields in OF. PUs in cooperatives (CS_1 to ES_2) benefit from POSEI subsidies, which increase the economic attractiveness of conventional compared to OF because this aid is proportional to tonnage. They therefore only convert to OF if MAB subsidies are high. Large PUs (CL_1 to EL_2) convert to OF only for high MAB subsidies, higher than those triggering the conversion in standard PUs in the same marketing channel. Indeed, the fluctuating demand for labour in organic pineapple farming over the year renders it difficult to maintain a steady workload for their permanent employees.

This differentiated switchover of PUs to OF depending on the proposed MAB subsidy means that the coverage of demand envisaged in scenario 2 in the different market segments (Table 3) is only effective once the amount is very high, which is incompatible with the resources that the *Conseil Départemental* has at its disposal (Figure 5).

Table 4. Comparison of organic farming (OF) and conventional activities gross margins (€/ha/year) including the current OF subsidy (900 €/ha) in zone 2 according to crop and marketing channels.

Marketing channel	Conv. pineapple	OF pineapple	Conv. tangor	OF tangor
Retailers	12 291	10 230	12 002	6 613
Direct selling	23 258	17 662	23 702	14 508

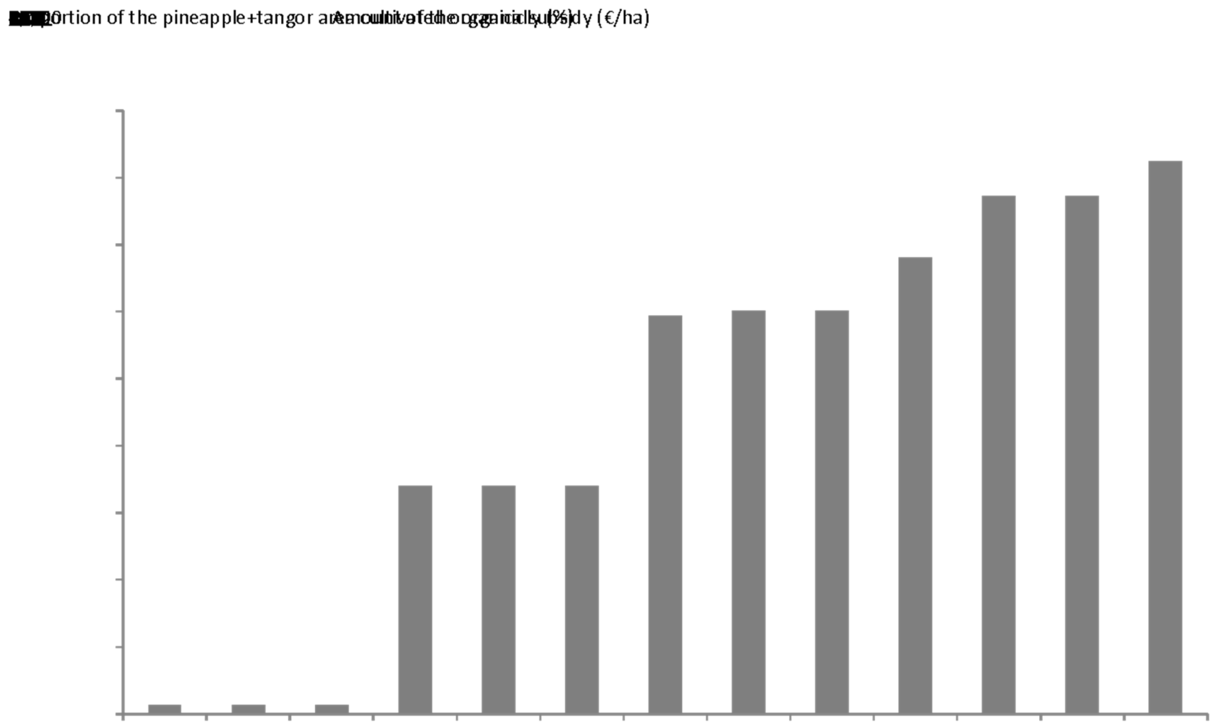


Figure 4. Change in the proportion of area cultivated organically (pineapple + tangor) according to the amount of organic subsidy (each increment = 900 €/ha). PU codes (see Table 1) are positioned on the graph above the amount which triggers their switch to OF. CL1, PL1 and EL1 switch to OF for amounts superior to 14,000 €/ha. The increase at 9,000 €/ha corresponds to an increase of the number of farms and the area per farm in some PUs which have already moved to OF.

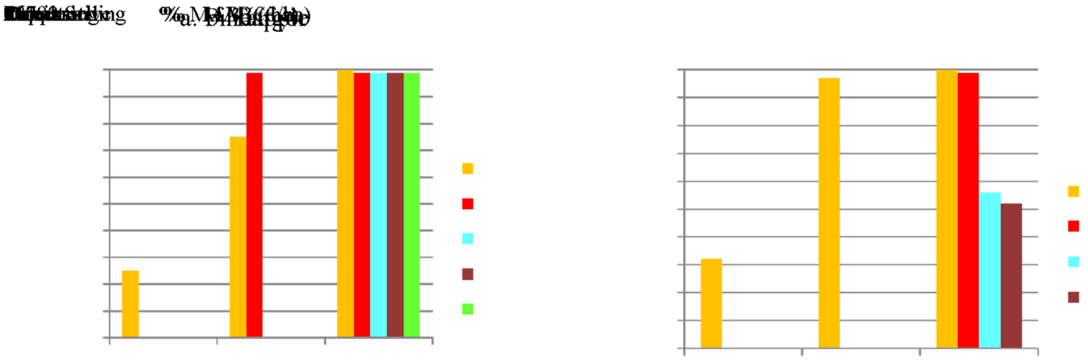


Figure 5. Proportions of total organic demand covered by local organic products according to the market segment and three simulated MAB subsidy amounts (initial, "15% of cultivated area under OF" objective, "maximization of the area cultivated under OF" objective).

These results were complemented by the calculation of a set of social and environmental indicators proposed by the researchers (Table 5). They highlight that the choice of the subsidy amount would require a compromise between the economic, social and environmental performance expected from the aid mechanism. Overall, the better the environmental performance, the greater are the size of the public subsidies. Local optimums appear for certain indicators: for example, the number of permanent employees is higher with MAB subsidies of 3,600 €/ha than 11,700 €/ha because the conversion of large areas under pineapple to OF results in a less evenly distributed workload over the year. This is unfavourable for the retention of permanent employees, but does favour seasonal work.

Table 5. Multi-criteria evaluation of Scenario 2 according to two MAB amounts.

	Initial situation	Scenario 2 *with* *MAB = 3600 €/ha*	Scenario 2 *with* *MAB = 11700 €/ha*
Environmental			
OF area (% of total area)	2	34	83
Herbicide treatments (nb/ha)	2.7	2.0	0.6
Intensive soil tillage (% of total area)	37	42	18
Social			
Permanent farm workers (number)	83	129	97
Occasional farm workers (maximal number)	110	152	200

Economic			
Public funding			
Total amount (k€/year)	693	1870	6621
% of subsidies in total gross margin	14	25	55

3.6. Discussion of outputs with the local policymaker (step 8)

These outputs were first presented to the technical team. At the latter's request, the results were then presented to the local policymaker due to their potential to contribute to the *Conseil Départemental*'s discussions on agriculture support policy. How the model and scenarios operated was explained to this elected official, who was interested in the overall approach. He found the precise typology of farms and their link to markets relevant and informative. In particular, he had thought that the development of OF generally took place through direct sales although other marketing channels could be considered.

In the light of all of the results presented, the local policymaker wished to broaden the group of participants to include key economic players in these fruit sectors, the reasons varying depending on the scenario. For scenario 1, the objective would be to discuss simulation outputs, or even define new scenarios, before moving on to a more operational stage requiring professionals to comply with the support mechanism explored and the underlying policy plan. For scenario 2, the objective of expanding the participants would be to gather as much knowledge as possible on the organic tangor and pineapple sectors (production and marketing) for which information was lacking. Due to a lack of time, this move to step 9 of the process could not take place within the framework of the study.

4. Discussion

4.1. Improving the design of agriculture policies through participatory modelling

The use of the ENTICIP model improved three components of the process intended to support the design of agriculture policy. First, the technical and economic framework for technicians and policymakers, initially made up of standard conventional production operational sequences, were enriched by references on organic operational sequences, selling prices and regional production volumes, and by hypotheses regarding the evolution of these data for OF. The research team played an information sharing role by collecting technical data from various sources (literature, local technical trials and farmers' experiments) to synthesise this into operational data for public actors and data useful for the configuration of the model used. This exchange of knowledge and information between those involved in the process, one that takes place around the description of scenarios to be simulated, is one of the contributions often highlighted in this type of interaction (Gisclard et al., 2015; Chantre et al., 2016). In countries where quantitative data on local contexts and especially on local markets are not easily available, this participative step of data collection is essential. Shared estimations validated by stakeholders can be used in ENTICIP as has been done in La Réunion for informal marketing channels.

Participatory modelling took into account the diversity of farmers' contexts of action by combining the administrative view of farm categories based on structural criteria with the factors determining the choice of practices identified by the researchers. This combination was reflected in a compromise between an overly simplified vision of this diversity and a typology that would be too complex to use in the model due to being based on qualitative criteria such as the farms' strategic orientations. The compromise was expressed through the concept of the PU, leading researchers to translate their scientific knowledge into entities that could be described in the model while at the same time reflecting the reality on the ground experienced by public actors. For their part, the latter modified how they perceived the diversity of the territory's farms. Taking into account this diversity enables the nature of subsidies and their amounts to be better adapted to the types of farms best suited to meet the objectives sought (Sipiläinen and Huhtala, 2013). The typology tool consequently must be used and adapted with public actors in the light of the issue and territory concerned (Girard et al., 2008).

Lastly, the approach enabled public actors to obtain a quantitative *ex-ante* assessment at the level on which they work, namely the production and consumption area on the scale of the island. One of the major concerns expressed by these public actors, namely the coverage of consumer demand for different products and market segments, has been taken into account with data that the actors can easily compare against their own knowledge and values. This possibility offered by ENTICIP differs from studies assessing the effect of policies only at the farm level (Falconer and Hodge, 2001), or only at the regional level without providing information on transformations within farms (Acosta-Alba et al., 2012). ENTICIP makes it possible to envision the effects of an aid mechanism that is both aggregated at the scale of a territory and individualised by major farm type (Van Ittersum et al., 2008; Herrero et al., 2014).

4.2. Implementing a participatory approach with public actors

The exercise carried out in La Réunion shows that it is possible for researchers to engage in a public policy design support process alongside concerned public actors on the condition that researchers arouse the interest of, and obtain support from, the latter parties. From this perspective, ENTICIP has proven to be a core part of the mechanism insofar as its design has made it possible to tackle a variety of issues, including both current concerns of public actors (health crisis) and questions raised by researchers (development of OF in connection with an agroecological transition dynamic) (Sterk et al., 2006). Nevertheless, differences between the points of view of public actors and researchers concerning the questions to be addressed and the time horizons to be considered could be a source of tension in such an approach (Van Ittersum et al., 2004). This was circumvented here by the fact that the move towards OF was seen as an answer to both the short and medium-term questions.

The nine-step process designed in this study differs from other participatory modelling approaches in that only policymakers and scientists are involved during the first steps and scenario development. The enlargement to other stakeholders is an optional last step which is left to the policymakers' appreciation according to the results obtained during the first steps and the need to discuss them with a broader audience. This design was successful to limit conflicts between participants that could slow down the process, an issue pointed out in a participatory modelling process carried out in the Camargue region of France (Delmotte et al., 2016a).

Time management intended to reduce the frequency by which actors are solicited also proved to be key to maintaining their interest (Walz et al., 2007). The elected policymaker was only solicited once, following four meetings with his technical team which enabled the proper formalisation of the results presented to him. In comparison, 20 participatory workshops were organized during the collaborative modelling process described in Basco-Carrera et al. (2017).

In La Réunion the researchers' intervention framework was limited by the duration of the funding for the study. It did not permit the final step in the process to be carried out, namely that in which the arena of discussion is broadened to other stakeholders. From this perspective, the organisation of research in projects that rarely last more than four years could prove to be a constraint given the operating pace of non-researcher actors, who are driven by other factors such as availability and urgency. In long-term projects, participant turnover can be a problem. This issue was faced in La Réunion when some technical services staff left and certain steps had to be started over with the arrival of new participants. Uncertainty linked to local elections can also be a major limitation to the effectiveness of the approach.

This participatory process remained unfinished as major stakeholders, in particular farmers, did not design or evaluate the scenarios. Although the diversity of local farmers resources, constraints and aspirations was surveyed in a previous in-depth study (Dupré et al., 2017; Dupré et al., 2020), discussions between their representatives and local policymakers would have enriched the policymakers' understanding of the local context and their evaluation of the various options simulated. On the other hand, by specifically supporting policymakers, this approach relaxed the political pressure during the process and helped the policymakers to gain a general and holistic vision of the issues addressed.

4.3. Future development of the model

ENTICIP was designed to meet several objectives: (i) to be capable of addressing a variety of public policy-related questions concerning the same range of production activities, rendering it possible to reduce the time required for its configuration, which is often high in a modelling process (Janssen and Van Ittersum, 2007); (ii) to provide an acceptable compromise between this versatility and the quality of the representations provided by the model on different issues (Affholder et al., 2012); and (iii) to provide a representation of reality that can be understood and shared by actors so that model outputs feeding discussions are based on grounds that they all understand (Jakeman et al., 2006; Voinov and Bousquet, 2010). On this basis, the choice was made to limit the number of input variables and their conditions and to clarify as clearly as possible the relationships between the values entered and the simulation outputs.

Several phenomena were not therefore modelled in the jointly built scenarios. Differences in farmers' risk aversion were greatly simplified by only considering their impact through constraints on the workforce rather than by defining a coefficient of aversion and characterising the variability of yields and selling prices of activities in the calculation of expected returns (Van Ittersum et al., 2008). The quantification of risk aversion coefficients, which are specific to each type of farmer, requires significant experimental work (Charness et al., 2013). Furthermore, data on the variability of yields and selling prices are not always available, particularly in an exploratory situation such as that of this study.

Unlike some dynamic models, ENTICIP also does not consider variations in yields linked to previous effects in rotations (Dogliotti et al., 2005) or to the immature stages of perennial crops (Cittadini et al., 2008). The small number of activities described in the scenarios is another important simplification compared to many models used to assess agriculture policies (Chopin et al., 2015; Liang et al., 2018). This simplification can prove to be a hindrance for users wishing to integrate a larger range of alternative activities in the choices of farmers (Delmotte et al., 2016b). However, it enables interactions between fewer activities to be highlighted and reduces the quantity of reference needed to be collected.

The assessment provided by ENTICIP was oriented strongly by economic considerations. Yet the nature of the issues addressed calls for a more rounded consideration of environmental and social dimensions in the search for compromise solutions at the heart of the design of agro-environmental policies (Uthes et al., 2010). Such an integrated assessment could be possible using multi-objective optimisation techniques developed, for example, with the MODAM system (Sattler et al., 2010), but there is a risk that this would be too complex for a participatory approach. An alternative would be to combine the use of ENTICIP with life cycle analysis (LCA) methods, which would enable a precise environmental assessment of farming practices with the inclusion of marketing channels (Acosta-Alba et al., 2012).

Conclusion

The approach implemented in this study, one that uses a regional optimisation model, integrating both “farm” and “production-consumption basin” levels, made it possible to provide interested public actors with quantified data on the consequences of potential subsidy systems (case of the HLB crisis) and to explore a more distant future (case of mass market organic production). Thanks to the dual levels integrated into ENTICIP, policymakers can obtain an *ex-ante* quantitative assessment at the policy scale of a territory. Simulation is then an efficient tool to support the design of agricultural land use policies as *in vivo* experiments could be difficult and risky to conduct at the regional scale. Although all of the steps could not be completed due to a lack of time, this process demonstrated the feasibility of, and the contributions enabled by, participatory modelling that involves policymakers and their technical teams. The exchange of knowledge that takes place between participants when building the scenarios improves the design of agricultural land use policies by including the specificities of local contexts. The process can also provide policymakers with typologies of farms that grasp their diversity at the regional level. The spatial heterogeneity can also be described and taken into account in the policy design. The strength of the process is to offer a simple model that renders it possible to address diverse, short and long-term issues. However, this experience in La Réunion shows that the participatory modelling process needs to be planned to take place over a period of at least three years. Longer interactions will enable the involvement of local stakeholders suggested by policymakers to guarantee the acceptance and success of the newly designed policies. As scientists and policymakers may hold different visions of farm diversity, public actors should be involved as early as the stage of categorizing farm types on the territory. Future research should aim to use the entire methodological process in other contexts, up to the final steps of integrating farmers’ representatives and all stakeholders who could be impacted by agricultural policies (e.g., distributors, agro-industries, consumers and local residents). In that enlargement, scientists should play a role of facilitators between policy makers and local stakeholders, assuming their involvement is not limited by short-term funding. New scenario developments will then require evolutions of the ENTICIP model, such as modelling of investment dynamics or risk aversion.

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