Thesis title : **Processes and territories: ecodesign of circular and resilient value chains for biomethane production**

French title : **PROcédés et TErritoires: Ecoconcevoir des filières circulaires résilientes pour la production de biomethane**

Acronyme : **PROTEE**

The project has the label Cyrcular Economy - Circulades https://circulades.univ-toulouse.fr/

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Laboratories and researchers involved in the PhD project : TBI, LEREPS, LBE

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1. *Description of the PhD project*

a. *State of the art*

Our society is facing major challenges that call for a structural review of our modes of production, organization and consumption. The reindustrialization of territories from an energy-defossilization perspective, the relocalization of activities and the circularity of the economy imply, more than ever, a paradigm shift in the scientific approach: connecting concepts from different disciplinary fields, particularly "technical" and "human".

Ensuring that value chains are viable in a local economy calls for reflection on the complete functioning of any value chain: from the availability of resources to the choice of technologies, and including the players to be involved (farmers, organizations, decision-makers, industrialists, etc.). Whether we're talking about the choice of technologies, the economic and environmental performance sought, or the durability and sustainability of these transitions, all these factors need to be assessed as far as possible ex ante, in order to guide efforts and investments in the right direction.

The process research landscape is teeming with new developments and proposals designed to replace a carbon-based industry or mitigate the effects of climate change. New processes need to be adapted and robust in the face of the many constraints of a circular economy in its territorial dimension. For example: which local energy source (solar, underground, wind, etc.)? Which technology for which scale of production? What are the water and land requirements? What degree of technological sophistication and risk is acceptable? What deposits/variability of raw materials? Etc.

Societal issues have led to the emergence of new socio-economic models grouped around the ecological economy, which, in opposition to the standard economy, considers a development space with limited resources, takes an interest in the functioning of ecosystems, and finally includes the effects of irreversibility and boundaries that must not be crossed, both in terms of resource consumption and social well-being (or ill-being).

These models promote a territorial economy that cares for the environment and the development of cooperative communities (Georgescu-Roegen, 1971). In general, work in economics has focused initially on the key role of public policy in the development of eco-innovations in energy systems and biofuels (Constantini et al., 2015). Other work, on a regional scale, focuses on the development or diversification of "green" technologies, a process that depends heavily on pre-existing capacities (technological, industrial, etc.) in the regions concerned (Santoalha and Boschma, 2021).

The generic question is how to structure a circular value chain in a given region. How do we choose the right scale for developing or implementing production units? What structural and organizational changes are needed to ensure viable socio-economic development?
Clearly, these questions require a careful characterization of what a circular economy is, what a value chain is, and what a territory is.
The aim of this project is to address some of these issues, using the production of bioenergy - biomethane - as a case study.

La question générique est de savoir comment structurer une chaîne de valeur circulaire dans une région donnée. Comment choisir la bonne échelle pour développer ou mettre en œuvre des unités de production ? Quels sont les changements structurels et organisationnels nécessaires pour assurer un développement socio-économique viable ?
Il est clair que ces questions nécessitent une caractérisation minutieuse de ce qu'est une économie circulaire, de ce qu'est une chaîne de valeur et de ce qu'est un territoire.
L'objectif de ce projet est d'aborder certaines de ces questions, en utilisant la production de bioénergie - le biométhane - comme étude de cas.

From an economic point of view, there would appear to be no profit for the farmers. What's more, this approach would encourage farmers to produce more waste to feed the biogas plant. Finally, it should be noted that the overall benefit seems to decrease when biogas is purified and resold, compared with "on-farm" use. Equipment exists for different scales, but the question is more complicated for small-scale purification processes and depending on the intended use of the biomethane (e.g. INSA Toulouse/TBI theses by David Benizri (2016) and Eliot Wantz (in progress)). Added to this is the issue of CO2 capture and recovery. Other questions arise concerning the social organization of the rural environment (Bluemling et al., 2013) around the biomethane value chain: the supply network, the distribution network, the distribution of benefits, the social limits of the system at its scale. At the local economic level, the development of methanization is studied on the basis of the relationships (often personal ties) that are forged between players to enhance the value of existing resources on a territory (crops, waste... but also players' skills, knowledge) (Gonçalves et al. 2021). These relationships can be conflictual, particularly when it comes to choosing the location for these methanization units, hence the role that local authorities and other institutional players will play, both to provide support (advice, organizational or financial), and to act as intermediaries (coordinators/mediators) between these players, in particular the agricultural and energy sectors on the one hand, and citizens on the other (Bourdin and Nadu, 2020; Bourdin et al. 2020). To conclude this succinct positioning in the state of the art, we will observe that the disciplinary approaches that have been mobilized to draft the preceding lines have never been crossed/combined in a systemic vision. To date, published studies have not considered the dynamics that drive the industry (changes in raw materials, the dynamics of economic players, technological dynamics, etc.), nor the optimal scales from the point of view of all these environmental, technical and socio-economic criteria.

b. *Objectives and methods*

As explained above, the main aim of the project is to develop a representation (modeling) of value chains on a given territory, integrating: 1) technologies (which processes, which scales), 2) channels from raw material to product and consumer, 3) resource flows (biomass, water, energy) associated with these channels, 4) economic players, their strategy and their relationships on the territory.
Modeling will make it possible to: 1) deduce indicators to characterize ex ante the strategy to be applied in the field; 2) propose eco-designed scenarios for implementing the circular economy at different scales.
An interdisciplinary approach to ecodesign is proposed, using methodologies and tools specific to process engineering, economic and social sciences, and environmental assessment.
The thesis work will be broken down into the following 5 stages.

1) Identification and characterization of existing scales of anaerobic digestion and biogas recovery. This "bibliographical" stage will enable us to identify, for different scales in the field, the type of raw material used and the equipment. Existing databases will be used to provide examples of local processes, and to document the availability of raw materials (from the commune to the département and the region) (ADEME, ORDECO). Supervision: primary TBI and secondary LEREPS.

2) Modelling of processes and value chains. The key point of this stage is the development of a generic model to simulate biogas production from any of the available feedstocks. Given the great variability in the characteristics of these feedstocks, purely phenomenological modeling is too complex. Under these conditions, the use of AI could be a good compromise. A library of process models will thus be built up for the following stages. TBI supervision.

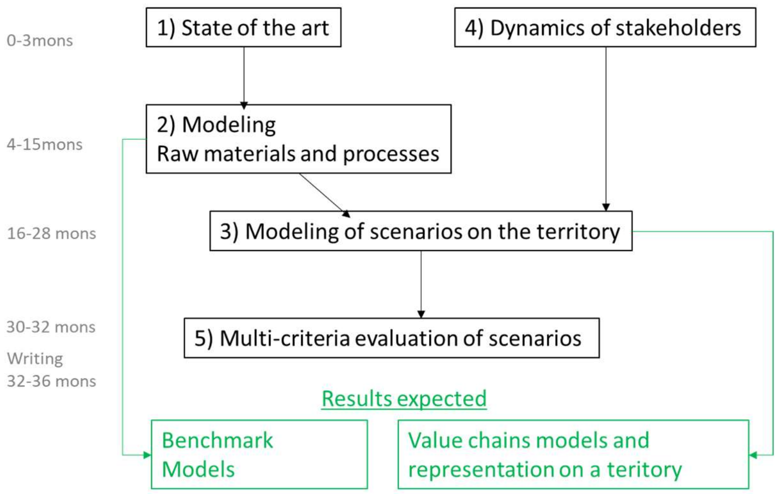
3) Modelling of the process chains and regional scenarios, by combining the different production, purification and utilization processes for biomethane and CO2. The modeling will take into account the complete cycle of flows, from the

farm to end users and final waste. The location of each player in the territory will be taken into account (GIS, natural resources, infrastructures, etc.). Parameterized models will take into account spatial variability, the scale of the installation and type of process, and the infrastructure required, to simulate different scenarios. This step will enable us to calculate material and energy balances, resources (biomass, land, water, energy) consumed, products obtained and waste and pollution created. Principal supervision TBI and secondary supervision LEREPS.

4) Local industry dynamics. Examples of local value chains will be studied in order to understand their development and organization processes, the way in which the various players coordinate at local level, and the factors (socio-economic, technical, organizational, etc.) that hinder/favor the development of these chains. The implementation of the value chains and their dynamics will be studied using experimental approaches in the field, based on semi-directive interviews with public and private players and site visits. The aim is to use qualitative information (obtained at LEREPS in parallel projects) to understand the (inter)dependencies between local players (access to the resource, technologies, value sharing, energy needs) and other players linked to the sector (public authorities, consumers, major energy groups, research centers, etc.), often operating at different scales, which will influence the decision to adopt (or not) anaerobic digestion technologies.
These analyses should make it possible to use implementation probabilities for certain technologies, which will be integrated into the scenarios modelled in point 3. Supervised by LEREPS.

5) Evaluation and analysis of simulated scenarios. The scenarios thus proposed will be evaluated using "classic" methods such as LCA for environmental impacts and economic calculations. This evaluation will be based on the scenario models developed in the previous stages and on the simulation results.
Socio-economic indicators will be proposed, based on the results of step 4), but also on the literature (e.g. Bonnet et al., 2021 proposes sustainability indicators on the scale of a département, characterizing the environment, energy, economic dynamism, social cohesion/solidarity, governance and citizenship).
The end result will be a set of quantified criteria for each scenario, as an aid to decision-making on the implementation of value chains in the region. Supervised by TBI and LEREPS.

Thesis's planning corresponds to the steps 1 to 5 described here above, and in the figure below.



The PhD student will benefit from the recognized expertise of our researchers and the data generated by projects carried out at TBI (EPUROGAS, ECOFEV, SOLIDIA, etc.), on the subject of methanization and biomethane purification. We have specialized software for process simulation and LCA.

The PhD student will benefit from the results of projects carried out within LEREPS, during 2022-2024, which combine several disciplines, including economics, management and land use planning. In particular, the results of the TRABIOG project (Trajectoires technologiques de la méthanisation et du biogaz), which aims to study the development dynamics of these technologies, in relation to their economic, industrial, institutional and spatial context (project funded by Labex SMS Structurations des Mondes Sociaux, bringing together LEREPS, LISST and UMR AGIR). The results of these projects will be processed at LEREPS prior to the thesis.

2. Potential positioning of the project in a "science with and for society" dimension

The main challenge of this project is to model circular value chains, taking into account the technologies and players involved, and integrating socio-economic concepts and the bio-physical flows of an area into the modeling of processes and value chains. This representation will enable these chains to be qualified in terms of technical, environmental, economic and social performance, and will help decision-making on their implementation in the region. For example, the question

"At what scale should anaerobic digestion be implemented?" has yet to be answered by a scientific approach. We hope to make our contribution through an interdisciplinary methodology, which could then be adapted to other sectors.
In addition to the technical aspects linked to the development of models and indicators, this thesis focuses on societal issues, with a view to providing the elements needed to guide the environmental and energy transition. Biogas production is currently very much in vogue as one of the main alternatives for the production of renewable energies, which relies heavily on on-farm methanization that enables, at the same time, energy production, effluent management and soil fertilization. Although anaerobic digestion is currently a mature technology, questions remain about the environmental and economic impacts, which vary depending on the capacity/scale of the site infrastructure and the designated use. Site design is based on the biomass that can be mobilized around the site and the size of the plot, from which the configuration and scales are defined, as well as the type of valorization and economic gain for biogas production. In this context, this thesis work will contribute to the design of economically profitable sites, bearing in mind that environmental impacts must be taken into account in the economic analysis, notably via the increase in the carbon tax. What's more, this project will highlight criteria and new practices that farmers will need to adopt in line with the agroecological and energy transition. Finally, the conclusions drawn from our project will contribute to the Occitanie region's challenge of becoming the first positive-energy region.

Practical information

The candidate should have a solid background in chemical engineering, with skills in modeling and numerical approaches. Knowledge of Python programming language is appreciated.

Localization : TBI (team SOPHYE) https://www.toulouse-biotechnology-institute.fr/

On the campus of INSA Toulouse. https://www.insa-toulouse.fr/fr/index.html

Salary 2000 €/mois (estimation)

Thesis supervisors : Pr. Ligia Barna et Dr. Carlos Robles, with the active participation of the other researchers involved in the project.

The PhD student will be enrolled in the INSA MEGEP doctoral school

Application to be sent by email (as soon as possible) to:
Dr. Carlos Robles : roblesro@insa-toulouse.fr
Pr. Ligia Barna : lbarna@insa-toulouse.fr

The application should contain the CV (resume), a motivation letter.

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