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Terrasim : An Agent-Based Simulation for systemic policy evaluation. Application to electricity mix transition.

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Abstract. We present the first steps of an Agent-Based Model aimed at evaluating policies, calibrated on national accounts, with a use case on French electricity mix transitions. It incorporates ecological, social, and economic impacts for a systemic analysis. First results highlight the challenges and feasibility of transitioning to more sustainable energy sources, and supports our general approach. Future work aims to refine the model, develop its energy sector, and details other sectors of activity.

Keywords: agent based simulation, policy evaluation, energy transition

1 Introduction and previous works

To prevent “severe, widespread and irreversible impacts globally,” scientists advise “stabilizing temperature increase to below 2°C relative to pre-industrial levels” [1]. Almost 10 years after the “Paris Climate Agreement”, current policies are still not enough to keep global warming below this objective [2]. Establishing effective policies that integrate ecological, social, and economic factors is a significant challenge. Decision-makers require tools not only to assess the objectives of their policies, but also the necessary transitions to achieve them. Energy transition is a multidimensional issue. In particular, energy and its usages in all sectors are major drivers of climate change [1]. We propose here an Agent-Based Model (ABM) calibrated on national accounts [3] and various technical reports [4, 5], measuring numerous ecological and socio-economic impact indicators, with feedback loops and systemic analysis. Using this model, we provide a systemic evaluation of French electricity mix choices and transitions.

Classical macroeconomic models - and by extension coupled economy environment - are limited and heavily criticized, mainly because they are developed around the concept of general equilibrium and utility/profit maximization [6]. New approaches are needed to model the co-evolution of environmental change and economic dynamics. The agent-based approach seems the most suitable, having demonstrated its ability to address these criticisms and reproduce many stylized facts [7]. ABM also excel in studying transitions and in integrating socio-environmental impacts [8, 9].

The Eurace@Unibi agent-based model [10] contains a complete economy, with detailed goods and labor markets, and empirically-based behaviors. In the

same vein, Lagom model [11] is the first large-scale agent-based model of a complete economy systematically calibrated on national accounts. This is one of the few models to integrate all three factors of production: labor force, physical capital and intermediate goods (e.g. raw materials). Finally, DSK [12, 13] is an agent-based model coupled economy-climate. Firms' production increases atmospheric carbon concentration, which in turn stochastically triggers economic shocks (disasters). Our work is a continuation and combination of the latter two approaches.

As mentioned in previous work [8, 14], there are many ABM focusing on energy. However, many of them lack sufficient empirical data, and they usually focus on one particular aspect (e.g. energy markets, technology dissemination) [14], or propose an over-simplification of the energy system [15]. Our final goal is to build a sufficiently detailed representation of the energy system and integrate it within a coupled economy-environment model to measure its many systemic effects and impacts.

2 Model Architecture

The model contains a population, firms, the state and an investment bank. Environmental impacts are considered both during the goods - and services - production and during consumption. We consider the following impacts : land use, greenhouse gas (GHG) emissions, particulate matter, acidification, eutrophication, and water withdrawal.

The population consumes consumption goods (CG), builds up savings and makes financial and real estate investments. They receive wages from firms, financial income, rents, various benefits and replacement incomes.

Firms produce goods - or services - specific to their activity sector. For each sector, three types of goods can be produced : CG, intermediate goods (IG), and physical capital goods (KG). IG are used to produce other goods and are destroyed in the process, e.g. raw materials. KG, are durable (≥ 1 year), e.g. machines and production infrastructure. Firms can also import and export goods. They aim to meet the demands they receive. They define the quantities to be produced on the basis of current inventories and their estimate of future demand.

Goods production requires three non-substitutable production factors : IG, KG and labor force. This is modeled by Leontieff functions, with coefficients taken from national accounts. Thus, firms can increase their production capacity by investing in more KG and hiring more employees. Conversely, they may not renew their end-of-life KG and lay off workers. Firms set the price of goods according to costs and margins.

The state collects taxes from the population and firms. In return, it pays out the various benefits and replacement incomes to the population, and subsidies to firms. The investment bank provides financing for certain firms.

In order to contain the complexity of the problem and follow an incremental design approach, the first version of the model is macroscopic. The population is

instantiated by a representative agent, and a representative firm will be instantiated for each sector of activity (producing each of the three types of goods).

This simplified version of the model makes it easier to calibrate to national accounts, and provides a sufficient model base for our first use case. These representative agents will later be broken down into a variety of heterogeneous companies and households to correctly capture economic dynamics, as many critics [6, 16] have pointed out with regard to macroeconomic approaches. We have validated our model by comparing its results with the national accounts, noting a difference of less than 5% on all indicators.

3 Case study : French Electricity Mix Transition

To test our approach and its capabilities, we chose to focus on the transition of the electricity mix. The significant greenhouse gas (GHG) emissions from energy use in France (70% of total emissions in 2018) and heavy reliance on fossil fuels (64% of final energy consumption) underscore the need for change [17, 18]. The ongoing debate about France’s electricity future and uncertainties surrounding nuclear power in Europe further motivated our selection [19, 20]. Additionally, we benefit from existing extensive studies by the French electricity grid operator RTE [18], providing a solid basis for our research.

We chose the 2018 electricity production mix as a starting point (due to the wide availability of verified data and no major disturbance due to world events). Three other mixes were tested as targets, representing the typical mixes discussed in France [18, 21].

	Nuclear	Solar	Wind	Hydro	Biomass	Fossil
2018 French Mix	71	2	5	12	2	8
RTE N03	55	12	23	9	1	0
SNBC	29	22	39	9	1	0
RTE M0	0	36	52	9	3	0

Table 1. Tested electrical production mixes in our model, by share of generation source in the yearly production. Mixes are sorted in descending order of nuclear share.

Each generation source is, for now, represented by a single firm (no competition), which also means an agent per generation source. The main goal of the electrical system is to always meet the demand, whatever the firms’ share. It must do so while following the target mix as close as possible. Because firms adapt their capacities based on demands, the electricity mix evolves naturally from the 2018 mix to the target one. Thus, if a firm’s production is limited, other firms will take its place even if they already reached their target production (for example, leaving a gas-fired power plant on because renewable energies haven’t developed fast enough).

Each mix is simulated over 50 years, starting in 2018 with the actual power plants fleet initialized. New plants construction is restricted : main parameters include construction lead times, yearly construction capacity and lifespan, all based on available sources [18, 4, 5]. Nuclear has an additional constraint : one plant is opening in 2024 (FLA3), and new constructions can only start after.

The total electricity consumption is stable, and electricity firms are aware of the target mix, and progressively build electric plants to reach this target.

Results

The 2018 French mix is no longer viable after 40 years of simulation, and will create an electricity shortage during the renewal of the nuclear generating fleet, progressively freezing all sectors of activity. The shortfall amounts to 109.1 TWh, spreading over 6 years. For comparison purposes, however, Table 2 shows this mix’s key impacts in the case where these 109.1TWh were imported.

The SNBC mix has not been achieved, wind power only reaching 9%. Increasing construction rate of wind power plants to achieve full transition is not supported by the rest of the economy: combined with renewals, the demand for physical capital creates a shortage of goods in less than 30 years.

The M0 mix is not reached either, even with increased construction capacities, but causes no economic crash. In every case, renewable power plants reach a plateau, the construction capacity becoming dedicated to the renewal of existing plants. Moreover, to compensate for the massive reduction in nuclear power, fossil fuels need to be maintained during the transition and even after, considerably increasing pollutant emissions, see Table 2.

The N03 mix can only be achieved if the rate of construction of wind power plants is increased to 4 GW/y. According to our results, this is the only mix that is achievable and viable without recourse to fossil fuels over the next 50 years, with a transition that minimizes most systemic impacts, including costs and environmental ones.

	2018	SNBC	N03	M0
GHG (Mt CO ₂ e)	20.41	2.13	1.49	12.3
water withdrawal (M m ³)	326	194	251	167
surface (M m ²)	114	177	130	208
particulate (t TSP)	253	26	18	151
eutrophication (kt N)	13.12	1.37	0.96	7.89
acidification (t Aeq)	435	45	32	261
investment cost (Md €)	303	crash	455	555
employment (k FTU)	237	crash	300	345

Table 2. Direct impacts of electricity production during the last year of simulation for each mix. These data correspond to the mix achieved in the simulation under best conditions, which may differ from the target mix. Cost is summed over the simulation, employment is averaged and includes both direct and indirect jobs. The lower values are highlighted in bold.

4 Conclusions and Future Works

The current model, despite its homogeneity, already shows promising results on the impact of various electricity mixes and their feasibility. It gives valuable insights of the cost of transition, and necessary construction rate.

We wish to extend this preliminary work in many ways : more detailed agents, detail other sectors of activity, extend electricity by adding markets and model the energy transition (including electrification and consumption habits).

References

1. IPCC: Summary for policymakers. In: P. Shukla, J. Skea, R. Slade, A.A. Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley (eds.) *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA (2022). DOI 10.1017/9781009157926.001. URL https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf
2. Ritchie, H., Rosado, P., Roser, M.: CO2 and Greenhouse Gas Emissions. *Our World in Data* (2023). URL <https://ourworldindata.org/co2-and-greenhouse-gas-emissions?insight=current-climate-policies-will-reduce-emissions-but-not-enough-to-keep-temperature-rise-below-2c#key-insights>
3. INSEE: Les comptes de la Nation en 2018 (2018). URL <https://www.insee.fr/fr/statistiques/4131436>
4. IEA: Projected costs of generating electricity 2020 (2020). URL <https://www.iea.org/reports/projected-costs-of-generating-electricity-2020>
5. UNECE: Life cycle assessment of electricity generation options. URL <https://unece.org/sed/documents/2021/10/reports/life-cycle-assessment-electricity-generation-options>
6. Haldane, A.G., Turrell, A.E.: Drawing on different disciplines: macroeconomic agent-based models. *Journal of Evolutionary Economics* **29**, 39–66 (2019). DOI 10.1007/s00191-018-0557-5
7. Lengnick, M.: Agent-based macroeconomics: A baseline model. *Journal of Economic Behavior and Organization* **86**, 102–120 (2013). DOI 10.1016/j.jebo.2012.12.021
8. Rai, V., Robinson, S.A.: Agent-based modeling of energy technology adoption: Empirical integration of social, behavioral, economic, and environmental factors. *Environmental Modelling & Software* **70**, 163–177 (2015). DOI 10.1016/j.envsoft.2015.04.014. URL <https://www.sciencedirect.com/science/article/pii/S1364815215001231>
9. Hoekstra, A., Steinbuch, M., Verbong, G.: Creating Agent-Based Energy Transition Management Models That Can Uncover Profitable Pathways to Climate Change Mitigation. *Complexity* **2017**, e1967,645 (2017). DOI 10.1155/2017/1967645. URL <https://www.hindawi.com/journals/complexity/2017/1967645/>. Publisher: Hindawi
10. Dawid, H., Gemkow, S., Harting, P., Hoog, S.V.D., Neugart, M.: Working papers in economics and management agent-based macroeconomic modeling and policy analysis: The eurace@unibi model agent-based macroeconomic modeling and policy analysis: The eurace@unibi model (2014). URL <http://ssrn.com/abstract=2384391Electroniccopyavailableat:https://ssrn.com/abstract=2384391Electroniccopyavailableat:http://ssrn.com/abstract=2384391>
11. Poledna, S., Miess, M.G., Hommes, C., Rabitsch, K.: Economic forecasting with an agent-based model. *European Economic Review* **151** (2023). DOI 10.1016/j.eurocorev.2022.104306
12. Lamperti, F., Roventini, A.: Beyond climate economics orthodoxy: impacts and policies in the agent-based integrated-assessment dsk model*. *European Journal of Economics and Economic Policies: Intervention* **19**, 357–380 (2022). DOI 10.4337/ejeep.2022.0096

13. Lamperti, F., Mandel, A., Napoletano, M., Sapio, A., Roventini, A., Balint, T., Khorenzhenko, I.: Towards agent-based integrated assessment models: examples, challenges, and future developments. *Regional Environmental Change* **19**, 747–762 (2019). DOI 10.1007/s10113-018-1287-9
14. Hansen, P., Liu, X., Morrison, G.M.: Agent-based modelling and socio-technical energy transitions: A systematic literature review. *Energy Research & Social Science* **49**, 41–52 (2019). DOI 10.1016/j.erss.2018.10.021. URL <https://www.sciencedirect.com/science/article/pii/S2214629618306418>
15. Ponta, L., Raberto, M., Teglio, A., Cincotti, S.: An Agent-based Stock-flow Consistent Model of the Sustainable Transition in the Energy Sector. *Ecological Economics* **145**, 274–300 (2018). DOI 10.1016/j.ecolecon.2017.08.022. URL <https://www.sciencedirect.com/science/article/pii/S0921800916310138>
16. Dosi, G., Roventini, A.: More is different.. and complex! the case for agent-based macroeconomics. *Journal of Evolutionary Economics* (2019). DOI 10.1007/s00191-019-00609-y
17. Ministère de la Transition écologique et de la Cohésion des territoires: Bilan énergétique de la France pour 2018 (2018). URL <https://www.statistiques.developpement-durable.gouv.fr/bilan-energetique-de-la-france-pour-2018>
18. RTE: Futurs Énergétiques 2050. URL <https://www.rte-france.com/analyses-tendances-et-prospectives/bilan-previsionnel-2050-futurs-energetiques>
19. Mouterde, P.: Le gouvernement confirme renoncer à un débat au Parlement sur les grands choix énergétiques de la France. *Le Monde.fr* (2024). URL https://www.lemonde.fr/politique/article/2024/04/11/le-gouvernement-confirme-renoncer-a-un-debat-au-parlement-sur-les-grands-choix-energetiques-de-la-france_6227282_823448.html
20. Urvoy, H.: What’s in store for Europe’s nuclear energy? *euronews* (2024). URL <https://www.euronews.com/business/2024/03/18/explainer-what-is-the-current-state-of-europes-nuclear-energy-production>
21. Guitton, M., Tandjaoui, N., Coste, E., Finet, F., Roux-Goeken, V.: La France encore loin d’avoir trouvé le chemin de la neutralité carbone (2023). URL <https://www.contexte.com/article/energie/info-contexte-la-france-encore-loin-davoir-trouve-le-chemin-de-la-neutralite-carbone.178425.html>