AGENT-BASED MODEL TO SIMULATE THE TRANSITION OF THE FRENCH ENERGY SECTOR TOWARDS RENEWABLE ENERGY SOURCES

ODD Protocol for proposed model

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Introduction

The reduction of greenhouse gases is one of the biggest challenges of the 21st century. The IPCC has delivered numerous reports on this topic, with the latest stating we must adapt our energy consumption and production to limit the effects of global warming. France is an interesting case as it produce over 50% of its energy through nuclear plants and renewable energy, resulting in lower greenhouse gases emissions compared to other similarly industrialized countries. This fact may simplify the construction of a model to simulate the reduction of greenhouse gases although this can be discussed. However, France still relies on fossil fuels for more than 40% of its energy consumption, and there are still many challenges to be addressed in optimizing the energy sector, including changes in behaviour, energetic efficiency, and institutional structures.

Overview

Purpose

The purpose of this agent-based model is to learn about the potential for reducing fossil fuel use in France by optimizing the use of existing energy sources and transitioning to renewable energy sources, while considering the influence of laws and personal behaviour. Specifically, we are interested in understanding the effectiveness of different policies and strategies in achieving this transition, and how they might interact with the complex dynamics of the energy system and societal factors.

Entities, state variables and scales

The agents of the model are the following:

- Household: households have their own consumption behaviour mainly electricity and heat system. They can also emit or absorb greenhouse gases.
- Individual: human use transport of the system. This entity is useful as the transport is an important part of the overall consumption of energy, so we need to be able to model it.

(Households and population can be schematised as group of cities with individual using transports to transit from city to city. Cities are therefore a sub model)

- Power Plant: represent nuclear, hydroelectric, and other types of power plants, each with their own production capacity and energy source(s).
- Industries: various industries in France, each with their own energy consumption behaviour.
- Electrical network: network for electricity delivery.
- Policymaker: represents the French government, which sets policies related to the energy sector.
- Transport: entities that allow individuals to move from one location to another. Consume energy and produce gas.
- Investor: entities that provide investment to energy related field
- Environmental factors: Represent various environmental factors that can affect energy production and consumption, such as weather conditions (mainly) and natural disasters.
- Green plant: represents green vegetable entities, act as sinks. Can absorb or emit greenhouse gases (even if overall green plants absorb more than they emit greenhouse, it depends on their maturities).

The states variables are:

- Energy consumption: the amount of renewable and unrenewable energy consumed by households and industries. Unit: kWh.

- Energy production: the amount of renewable and unrenewable energy produced by power plants in France. Unit: kWh.
- Energy prices: The prices of various energy sources in France, which can be affected by supply and demand. Unit: kilo-euro.
- Greenhouse gases production: the amount of gas product by households, transport, and industries. Unit: tons of CO2-equivalent.
- Greenhouse gases absorption: the amount of greenhouse gases absorbed (in case of new technologies and for forest). Unit: tons of CO2-equivalent.
- Policy variables: The energy sector policies set by the French government, such as subsidies for renewable energy or taxes on fossil fuels.
- Environmental variables: Various environmental factors that can affect energy production and consumption, such as temperature, precipitation, and extreme weather events. Theses variables are probabilistic.
- Construction time: time to construct a power plant.

The scales are:

- Temporal scale: The model simulates a 50-year period, broken down into time steps of one month.
- Spatial scale: The model focuses on the energy sector in France but can be broken down into regions or cities if necessary.
- Individual/household scale: The model represents individual households and industries in France, each with their own energy consumption behaviour. It's in a city submodel to reduce computational complexity.

Entities	*State Variables*
Households	Energy consumption, gas emission, income
Individuals	Energy to move
Power Plants	Energy Production, gas emission, material consumption
Industries	Energy consumption, gas emission, production, investments
Policymakers	Policy objectives, regulations, incentives
Transports	Energy consumption, gas emission
Investors	Investment, benefit
Environmental factors	Temperature, weather, destruction power

In reason of the large scale and many fields involved in the model, the entities and variables should be developed and refined as the model is developed and tested e.g. It is maybe not necessary to keep the green plant entity.

Process overview and scheduling

The state variables are initialized with the actual value based on historical data and projected trends provided by the French administration. Then at the beginning of each time step, the model updates the state variables of each entity based on their behaviour, decision-making processes, and the impact of policies and external factors.

The model uses a combination of deterministic and stochastic processes. Deterministic processes represent the predictable aspects of the energy sector, while stochastic processes represent the uncertain aspects of the energy sector, such as the impact of natural disasters and accidental pane of power plant.

It produces outputs at each step, including energy consumption, production, and carbon emissions, which can be used to evaluate the impact of different policies and scenarios on the energy sector's performance.

The processes that change the state variables are:

1. Power generation: Processes that generate electricity from the power plant such as nuclear, hydro, solar, wind, and fossil fuels, and their associated emissions.
2. Energy consumption: Processes that consume energy in the residential, commercial, and transportation sectors. The energy which is produced by the power plants or the energy created by fossil fuel combustion for domestic heat or transportation, such as cars.
3. Greenhouse gas emission: Process that emits greenhouse gases in the atmosphere.
4. Greenhouse sink: Process that absorbs greenhouse gases from the atmosphere.
5. Policy interventions: Processes that change the incentives or disincentives for certain energy sources or consumption behaviours, such as carbon pricing, subsidies for renewables, or regulations on building efficiency standards.
6. Investment decisions: Processes that influence the allocation of capital towards different energy sources and infrastructure, such as investments in renewable energy projects or upgrades to transmission and distribution networks.
7. Technological innovations: Processes that introduce new energy technologies or improve the efficiency of existing ones, such as the development of battery storage, improvements in solar panel efficiency, delivery of new power plant planned such as EPR2 nuclear plant.
8. Behavioural changes: Processes that influence the attitudes and behaviours of individuals and organizations towards energy consumption and generation, such as education campaigns or incentives for energy-efficient behaviour.

All these processes can interact with each other and with the state variables of the model entities to shape the overall trajectory of the energy transition.

Design concepts

Basic principles

The model uses the fact that industrial country must transition to renewable energy to limit climate change and consider the conclusion of the IPCC and IEA. As the subject is also economical and sociological, the model lies on the production/ consumption concept and demand and offer principle modulated by political incentive to diminish the use of fossil fuel both at households and industrial levels. It also includes the behaviour of individuals to estimate their consumption of energy and their greenhouse gases emissions based on different trend and actual data.

Overall, the model is designed to explore how different policies and market conditions can influence the transition from fossil fuels to renewable energy sources in France, while considering the behaviour of different actors in the energy sector.

As the subject is interdisciplinary (political, sociological, environmental, and technological) the use of many theories and sub model is necessary.

Emergence

The model's important results and outputs include:

1. The level of reduction in fossil fuel use and the transition to renewable energy sources achieved over a 50-year period.
2. The effect of policy interventions and changes in personal behaviour on the achievement of the energy transition goals.
3. The cost-benefit analysis of the transition to renewable energy sources.
4. The overall level of greenhouse gases emits by the system (here France).

The outputs that emerge from the mechanistic representation of the adaptive behaviour of individuals include changes in energy consumption patterns, adoption of renewable energy sources, and changes in transportation patterns.

The outputs that are imposed by rules and force the model to produce certain results include the incentive law and its application, the level of investment in renewable energy sources, the timeline for the phasing out of fossil fuel-based energy, the rate of adoption of new technologies.

Adaptation

Agents (i.e., individuals and organizations) are assumed to have adaptive behaviours such as:

- The policymakers and industries can choose to install, decommission, or transform power plants that can be green or fossil. In our context "green" mean free greenhouse gases energy source such as nuclear, solar, hydro-electric, or geothermal.

- Interaction with the energy market: agents may participate in the energy market (e.g., selling excess renewable energy, purchasing energy from the grid) based on their cost and profit calculations.
- Adjusting their energy consumption based on changes in energy prices and social behaviour.
- Changing their transportation mode based on changes in fuel prices, availability of public transportation, or personal preferences.
- Modifying their housing or building designs to incorporate energy-efficient technologies or renewable energy sources.
- Adopting new technologies or practices that reduce energy consumption or promote renewable energy use.

These adaptive behaviours can be influenced by various factors such as individual preferences, social norms, economic incentives, and government policies. The model can simulate the interactions between these factors and the adaptive behaviours of agents to explore the potential for reducing fossil fuel use and transitioning to renewable energy sources in France.

Objectives

Individual and households want to have energy to fulfil their needs such as electricity and transportation. They base their decisions to buy certain type of energy on the cost and social and environmental considerations e.g., if the use of green energy has better appreciation, then the individual has a greater probability to use it if the cost is considered acceptable.

The industry and investors based their decisions on the most benefiting cost and return on investment. They adapt their price to have more gain and attract more customers.

Power plant adapt their production to meet the demands of household, industries, and part of transports. They want to make profits and set their price based on the European electric market.

Policymakers want to incentivize other agents to decrease their consumption and keep the greenhouse gases emission under a level coherent with the IPCC, Paris Agreement, and the aspirations of their fellow citizens. Their incentive isn't too rash as they don't want to hurt the economy.

Learning

Energy consumers may learn to reduce their energy consumption based on feedback from their energy bills, while policymakers may learn from the successes and failures of past policies.

Prediction

As the model use the IPCC predictions, agents will also do, particularly policymakers, households, and individuals. All agents plan their use of energy to have access to energy all the time, making their decisions data-driven. Predictive models will also be used to forecast future energy prices based on supply and demand principle, historical data and planned available resources.

Sensing

Agents are assumed to sense various variables including:

- Energy prices
- Availability of energy sources
- Government policies and regulations
- Public opinion and attitudes towards energy sources and sustainability
- Temperature

Policymakers also sense the level of greenhouse gases as they based their decision on prediction using it.

All those data are sensed accurately with a reasonable margin of error. We suppose that we have access to reliable data sources and accurate measurement techniques.

Interaction

All agents are interconnected so their interactions are both direct and indirect through the energy market mechanism.

Individuals and households (and cities, by extension) are directly impacted by policymakers, industries, and power plants.

Industries and power plants are directly impacted by all the other agents. They also directly impact each other.

As policymakers impact industries and power plants, their impacts on individuals, households and cities are also indirect.

Individuals, households, transports, industries, and power plants impact their environment which impact them back when policymakers adapt their policy based on the environmental change or when environmental event occurs which can increase the consumption of energy by households or decrease/shutdown the production of energy by power plant.

There isn't competition for resources, only competition for price based on supply and demand, although the price can be impacted by the scarcity of the resources.

Stochasticity

Randomness will be used to simulate events such as power outages, fluctuations in energy prices. More specifically, the probability occurrence of extreme event is increased when level of greenhouse gases increases to reflect the observation that the occurrence of disaster such as intense heat, tempest and flood are more common.

Stochastic processes are also used to simulate changes in weather patterns and therefore reproduce the variability of renewable energy sources such as wind and solar power.

Collectives

Cities are represented as collectives of households and individuals linked to the electric market and by transports.

The behaviour of agents give rise to emergent phenomena at the collective level as the behaviour of individual, households and industries will influence the overall energy demand and policy of policymakers.

Observation

The model shows the amount of electricity produced by power plants. This data is observed in a plot showing two curves: energy produced by non-emitting and emitting greenhouse gases power plant.

A second plot show the domestics production of energy by individuals and households.

A third shows the energy consumed by the country.

A fourth shows the estimated quantity of greenhouse gases produced by France. The amount of greenhouse gases in the atmosphere isn’t measured as it doesn’t give information on the country production.

These measures provide an overall picture of how well the system is transitioning to renewable energy. This provides insights into the most effective policies and strategies for achieving this transition.

To observe the internal dynamics of the model, the outputs include the values of the state variables for each agent over time, as well as any changes in the adaptive traits of agents over time although it isn’t display directly. This gives information on how individual agents are responding to changes in their environment.

Detail

Initialization

The model will be initialized with data on the current state of the French energy sector and current climate, including the distribution of energy sources, the existing infrastructure, and the consumption patterns. The initial state of the agents will also be defined based on their current behaviour and preferences towards energy consumption.

Input Data

The model uses the following input data:

- Historical and estimated energy consumption patterns to determine how to update variable.
- Historical and estimated energy prices to determine how to update price.
- Weather patterns (for hydroelectricity, solar and wind production, and temperature)
- Policy scenarios provided by French government and IPCC (e.g., carbon taxes, subsidies for renewable energy sources, parameters to be used to study the relevant scenarii)

Submodels

As the subject is on a large scale and interdisciplinary, many submodels are used:

- Energy production: This submodel simulates the production of energy based on the energy sources available and the weather patterns.
- Energy consumption and consumer decision: This submodel simulates the consumption of energy by households and industries based on their needs and the energy prices.
- Energy pricing: This submodel simulates the pricing of energy based on the supply and demand in the energy market, as well as any policies that influence the prices.
- Policy implementation: This submodel simulates the implementation of policies, such as carbon taxes or subsidies for renewable energy sources, and their impact on the energy sector.
- Infrastructure: The infrastructure required for energy production and distribution will be simulated, such as the building of new power plant, the expansion/update of the electricity grid and construction of ecological house or building.
- City development: This submodel simulates the evolution of cities and summarizes data of households and individuals agglomerate in the same area as group of cities. It allows better visualisation with individuals leaving cities by transportation. It’s a submodel like the model but in a restraint scale.
- Transport system: This submodel simulates the evolution of the transport sector. It can be the development of electrical car, train etc.

The submodels will interact with each other to simulate the complex dynamics of the energy sector, and the results of the simulation will be evaluated using various indicators and metrics describe earlier and those specific to the submodels. The simulation will be run for multiple scenarios to evaluate the impact of different factors on the energy sector's transition towards renewable energy sources.

Sources

Data about energy in France:

https://ourworldindata.org/energy/country/france

Literature review of Agent-based modelling and socio-technical energy transitions:

https://www.sciencedirect.com/science/article/abs/pii/S2214629618306418

Site of the IPCC:

https://www.ipcc.ch/