

Energy Communities

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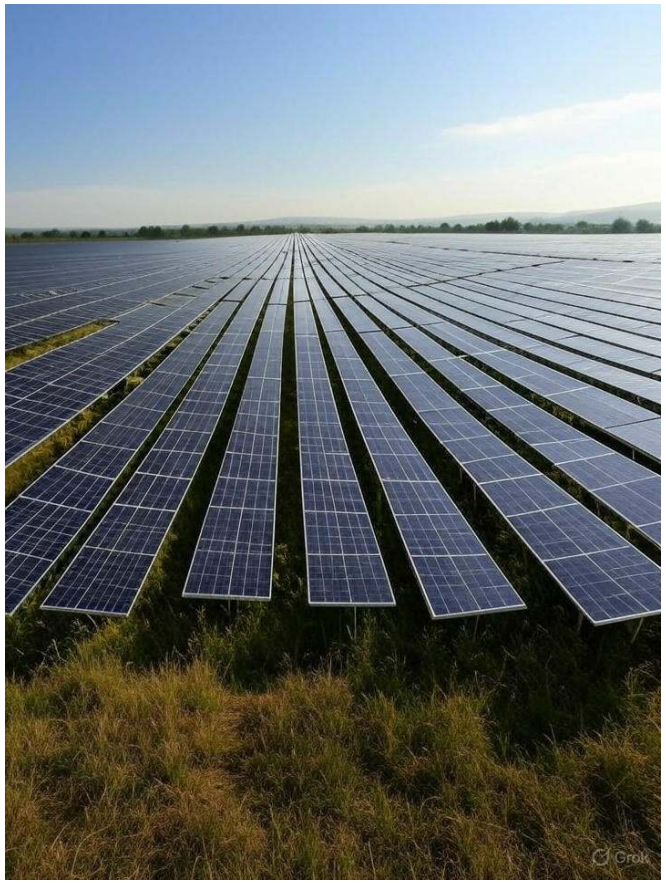
1. Energy Communities

1.1 Context

- According to the Paris Agreement, the world must limit the global average temperature increase to 2°C above pre-industrial levels
- The residential sector is responsible for around 20% of the global CO_2 emissions
- Three main ways:
    - increasing the renewable energy production
    - increasing the energy efficiency
    - more sobriety of energy users

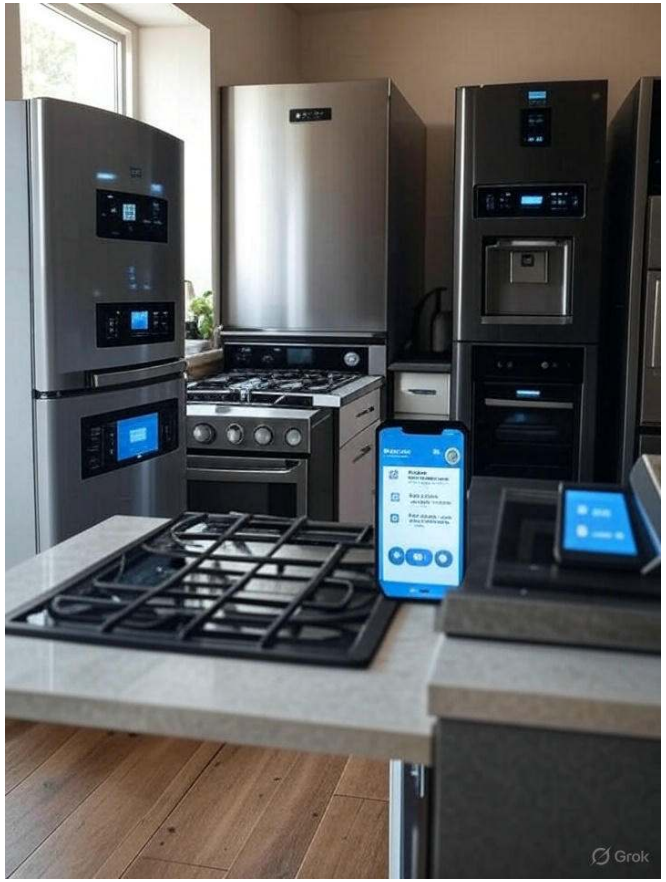
1.1.1 Increasing the renewable energy production

- Can renewable energy production be used as a robust energy source?
- Is renewable energy production stable enough?
- What would be the impact of renewable energy production on the energy system?
- What is the cost of renewable energy production?
    - in terms of investment
    - in terms of operation and maintenance
    - in terms of space usage



1.1.2 Increasing the energy efficiency

- Increasing energy efficiency - using less energy to do the same job
- Demand side management (DSM) - strategies to control the appliances and, inheritely, the energy consumption
- Is demand side management a good idea?
- What about human behaviour and comfort?



1.1.3 Focusing on energy sobriety

Energy sobriety - being aware of the energy consumption and the impact on the environment

- gaining a deep understanding of the energy consumption and production
- being aware of the usage patterns of his appliances
- being able to understand the impact of modifying his behaviour on the energy consumption



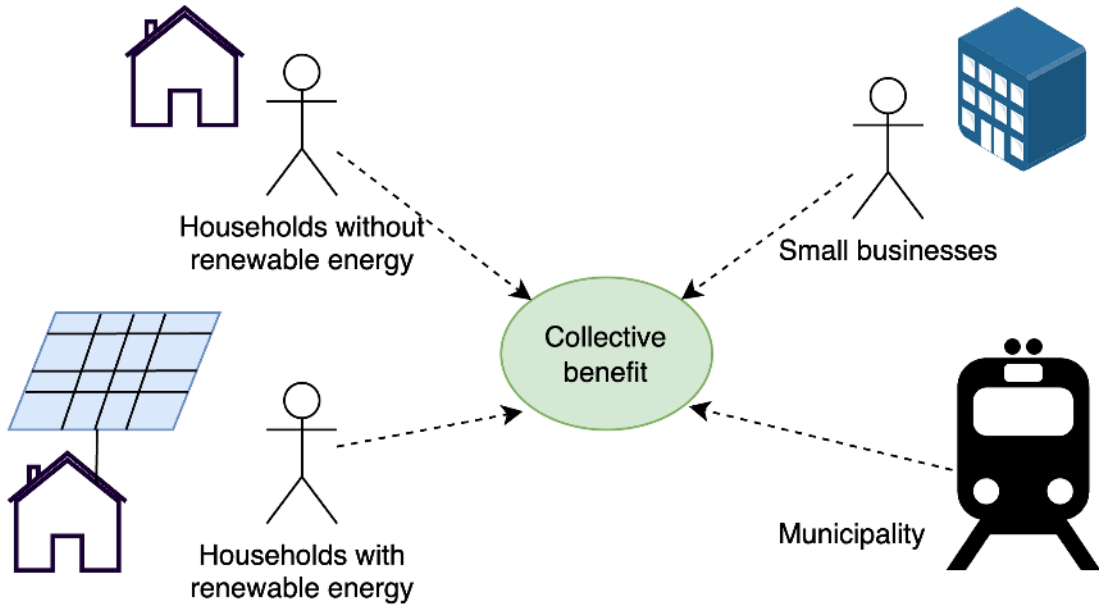
How to increase energy sobriety?

1.2 What is an energy community?

Energy community - a group of people/small to medium enterprises/local authorities who voluntarily participate in democratic energy sharing mechanisms to obtain a certain environmenal/social/economic benefit.

1.3 Who can participate in an energy community?

Energy community - a group of people/small to medium enterprises/local authorities who voluntarily participate in democratic energy sharing mechanisms to obtain a certain environmenal/social/economic benefit.



- people - individuals who want to contribute towards a common goal (with or without production capabilities)
- small to medium enterprises - shops, restaurants, small offices, etc.
- local authorities - public institutions/transportation companies/etc.

Why not large enterprises?

1.4 How is the decision making done?

Energy community - a group of people/small to medium enterprises/local authorities who voluntarily participate in democratic energy sharing mechanisms to obtain a certain environmenal/social/economic benefit.

- all participants have the same rights and responsibilities
- all participants have the same decision making power
- hierarchical structures may be implemented upon democratic principles

1.5 What are the benefits of an energy community?

Energy community - a group of people/small to medium enterprises/local authorities who voluntarily participate in democratic energy sharing mechanisms to obtain a certain environmenal/social/economic benefit.

- environmenal - reducing the CO_2 emissions
- social - collectively working towards a common goal, inspiring each other
- economic - reducing the energy costs

2. Modeling energy communities

2.1 The challenge

- The concept of energy community is very flexible
- We can imagine many different scenarios
  - residential urban communities
  - rural communities
  - urban communities with a mix of residential and commercial buildings

2.1 The challenge

As engineers and scientists, we are interested in:

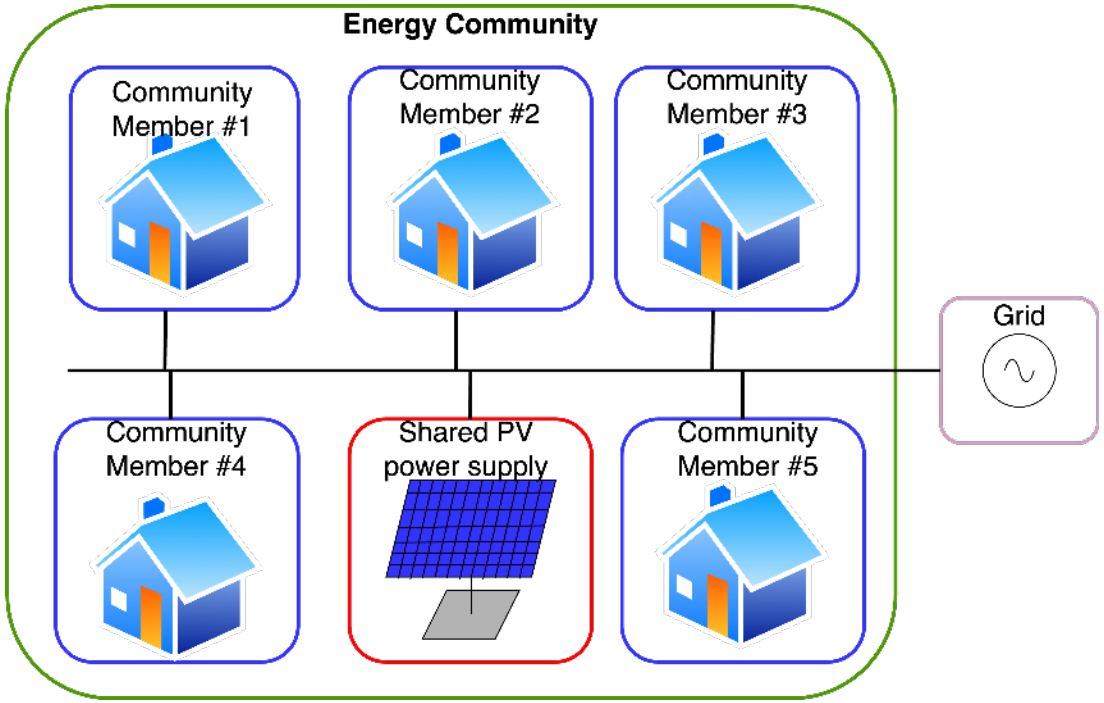
- understanding and modeling the behaviour of such communities
- finding ways to increase energy sobriety
    - using information
    - leveraging informational systems
- quantifying the benefits (social, economic, environmenal)
- investigating possible implementations

2.1.1 Questions needing answers

- How would the energy sharing mechansim work in a community?
- How would the benefits be distributed among the participants?
- How do we quantify the benefits? Reduction in the bill?
- How do we make the members more aware of the energy consumption?
- How to make the members more engaged towards obtaining the benefits?

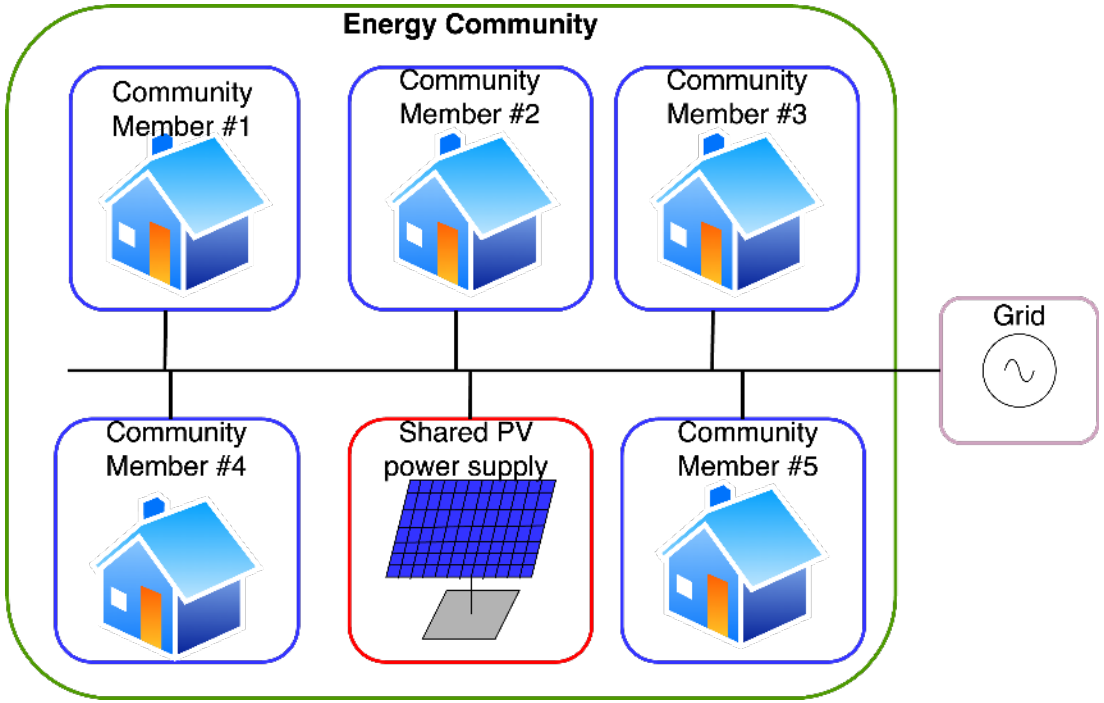
2.2 The physical system

- Let's consider a residential community formed of households $\mathcal{H} = \{h_1, h_2, \ldots, h_H\}$ where H is the total number of households
- It can be:
  - a neighborhood
  - a set of households in different parts of the city
  - apartments in a building



2.3 Measurment devices

- Each household is equiped with smart meters, measuring the power consumption $P_i(t)$ of the house at the time t
- We consider they share the power of a physical PV plant, generating power $P_{\text{PV}}(t)$
- The houses decide to share the power of the PV plant and togather to act as a single entity

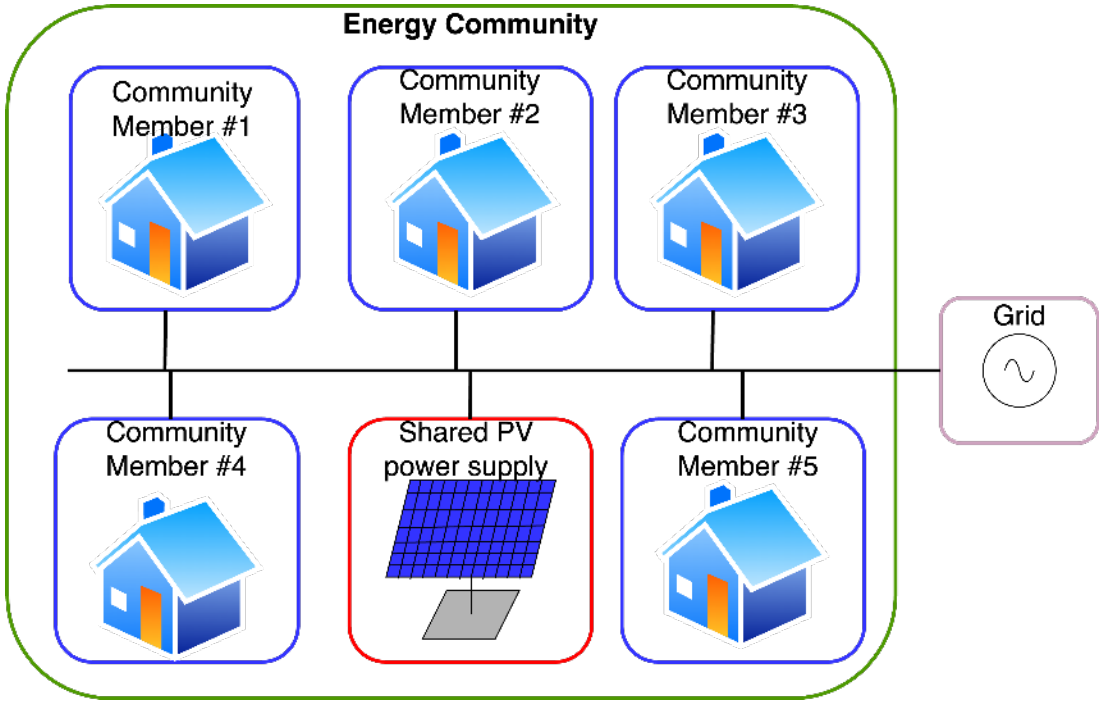


Therefore, the total power consumption $P_{\text{comm}}(t)$ of the community is given by:

$$P_{\text{comm}}(t) = \sum_{i=1}^{H} P_i(t)$$

2.4 Energy balance

- The power produced by the PV plant is characterised by uncertainty.
- At some points, it can be higher than the power consumption of the community (summer, for example).
- At other points, it can be lower than the power consumption of the community (winter or at night).



The energy balance in function of the power extracted from the grid $P_{\text{extract, grid}}(t)$ and the power injected into the grid $P_{\text{inject, grid}}(t)$ is given by:

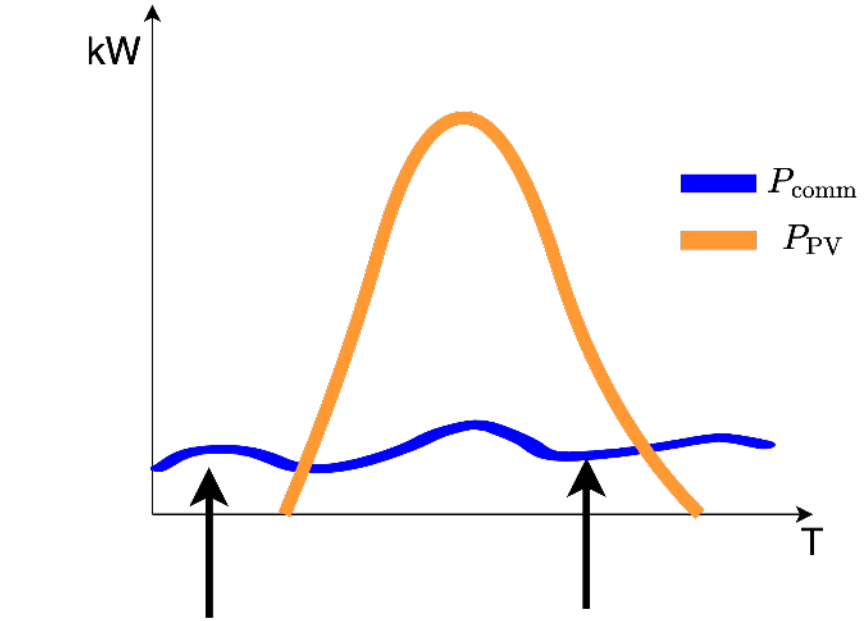
$$P_{\text{comm}}(t) = P_{\text{PV}}(t) + P_{\text{extract, grid}}(t) - P_{\text{inject, grid}}(t)$$

2.4 Energy balance

Let's investigate the energy balance.

$$P_{\text{comm}}(t) = P_{\text{PV}}(t) + P_{\text{extract, grid}}(t) - P_{\text{inject, grid}}(t)$$

- The consumption of the community $P_{\text{comm}}(t)$ at a time t is known.
- The production of the PV plant $P_{\text{PV}}(t)$ at a time t is known.
- The power extracted from the grid $P_{\text{extract, grid}}(t)$ and the power injected into the grid $P_{\text{inject, grid}}(t)$ are determined by the energy balance.

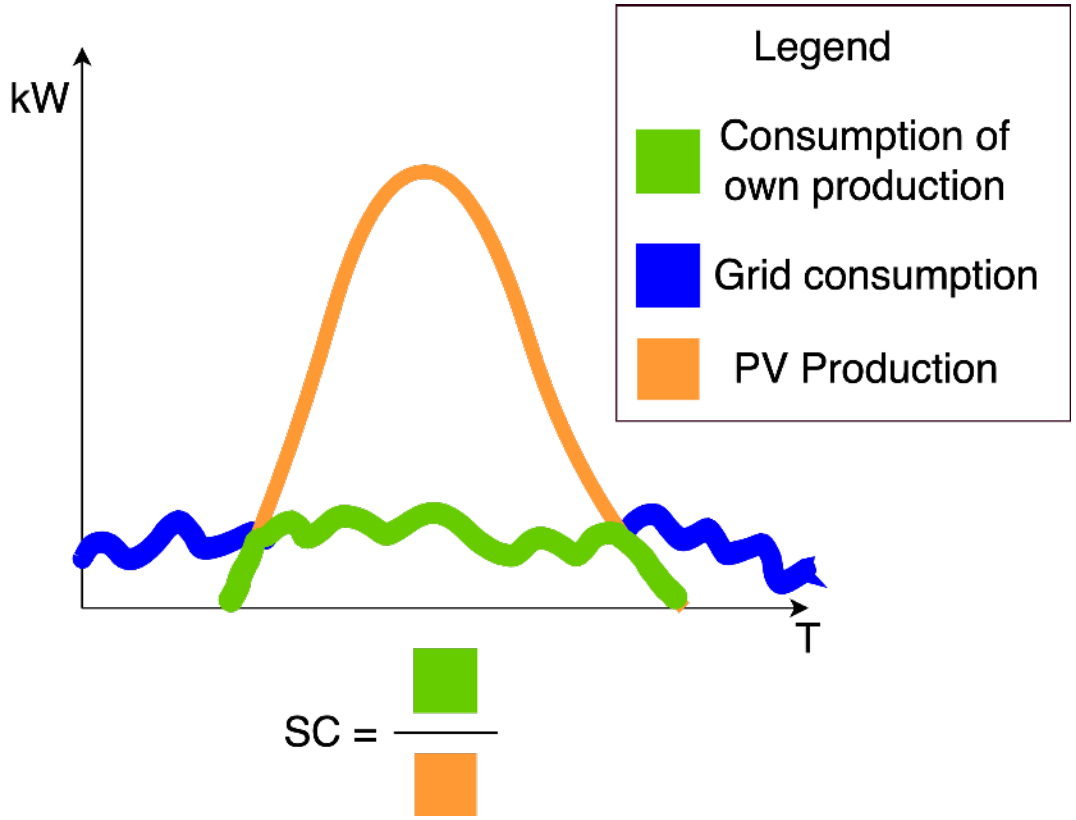


Example: a summer day with high PV production

2.5 Evaluating the benefits - self-consumption

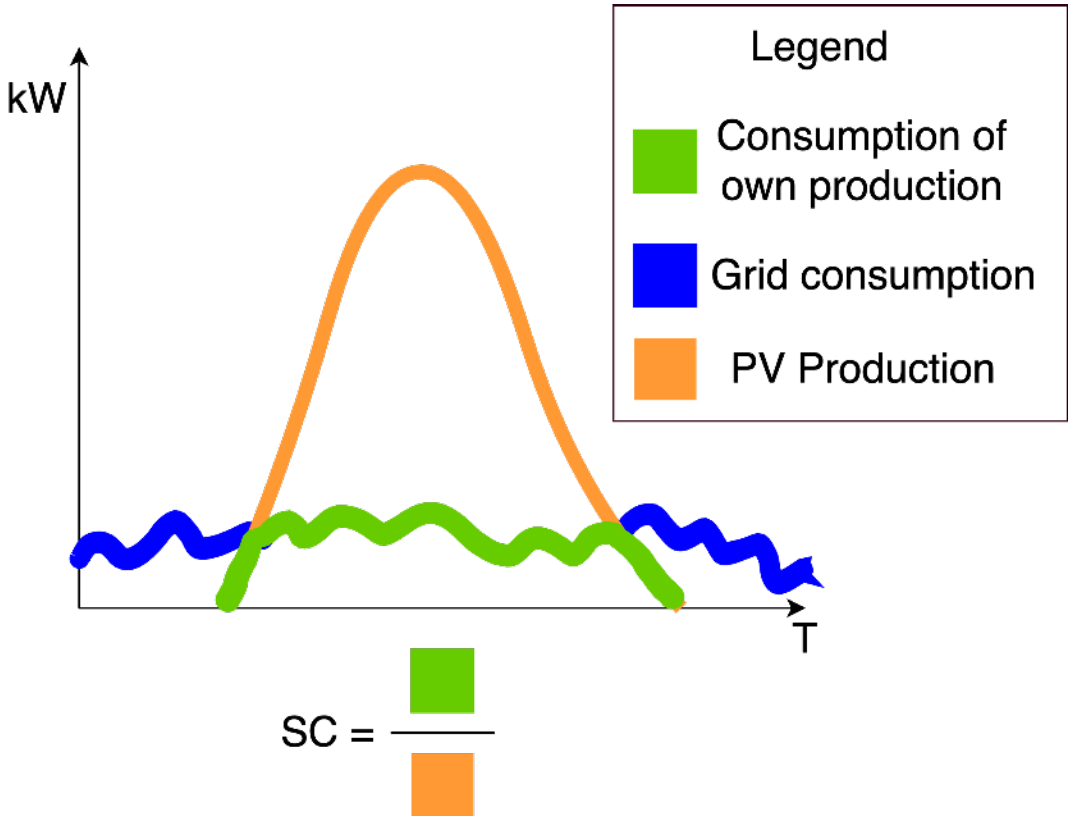
- We can evaluate the environmental benefits using the self-consumption ratio.
- The self-consumption ratio (SC) refines how much of the PV production is consumed by the community over a period of time T:

$$\mathrm{SC} = \frac{\sum_{t=1}^{T} min(P_{\mathrm{comm}}(t), P_{\mathrm{PV}}(t))}{\sum_{t=1}^{T} P_{\mathrm{PV}}(t)}$$



2.5.1 Self consumption interpretation

- Self-consumption reflects the enviornmental benefits because we want to consume as much energy as possible from the PV plant
- Self consumption can range from 0 to 1
  - 0 means that the community is either:
    - not consuming any energy from the PV plant
    - not consuming any energy at all
    - consuming outside of the PV plant production hours
  - 1 means that the community is consuming all the energy produced by the PV plant

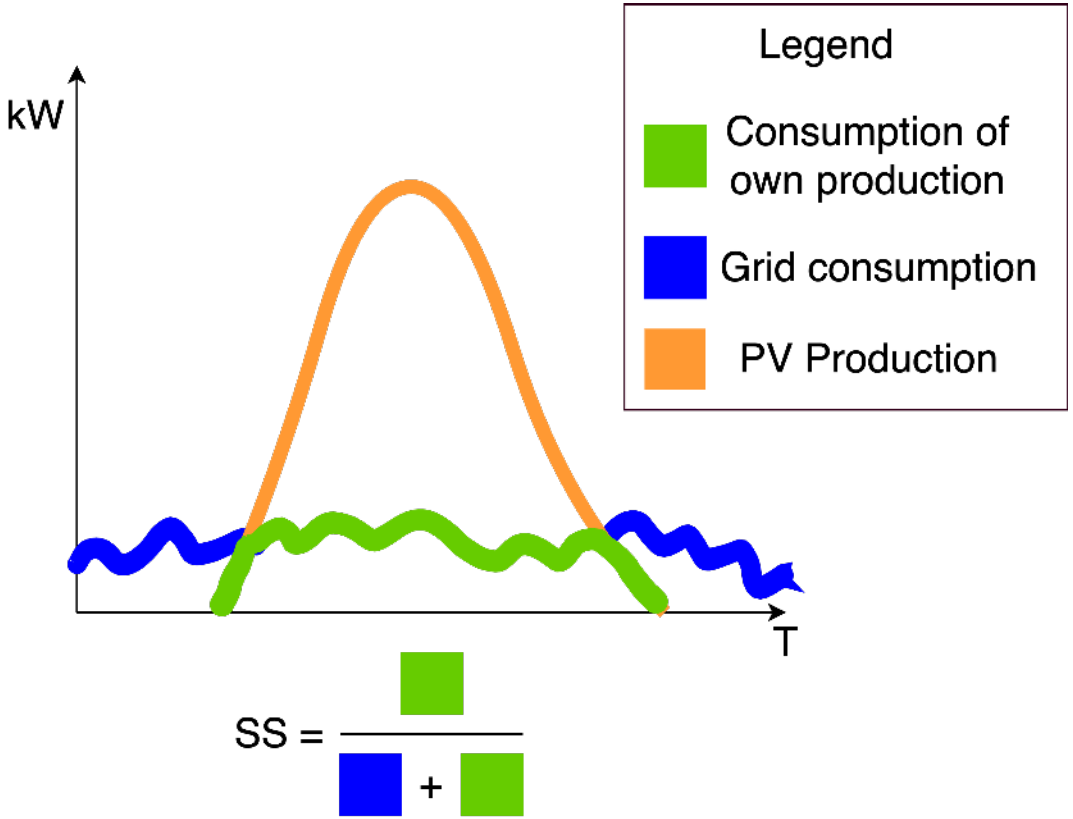


Note: self consumption is defined as long as the community is producing energy

2.6 Evaluating the benefits - self-sufficiency

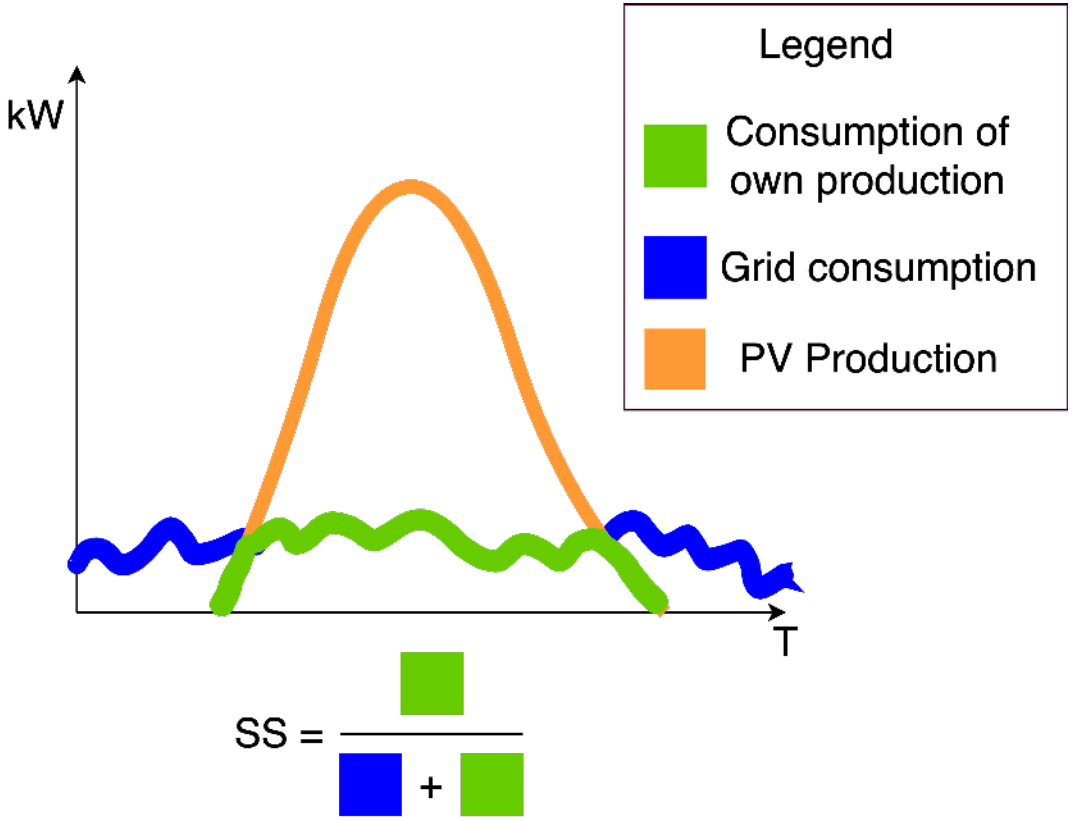
- We can evaluate the economic benefits using the self-sufficiency ratio (SS).
- The self-sufficiency ratio (SS) refines how much of the energy consumption is covered by the PV production over a period of time T:

$$\mathrm{SS} = \frac{\sum_{t=1}^{T} min(P_{\mathrm{comm}}(t), P_{\mathrm{PV}}(t))}{\sum_{t=1}^{T} P_{\mathrm{comm}}(t)}$$



2.6.1 Self-sufficiency interpretation

- Self-sufficiency reflects the economic benefits because it shows how much of the energy bill is covered by the PV production
- Self-sufficiency can range from 0 to 1
  - 0 means that the community is either:
    - not producing any energy
  - 1 means that the community is not consuming any energy from the grid

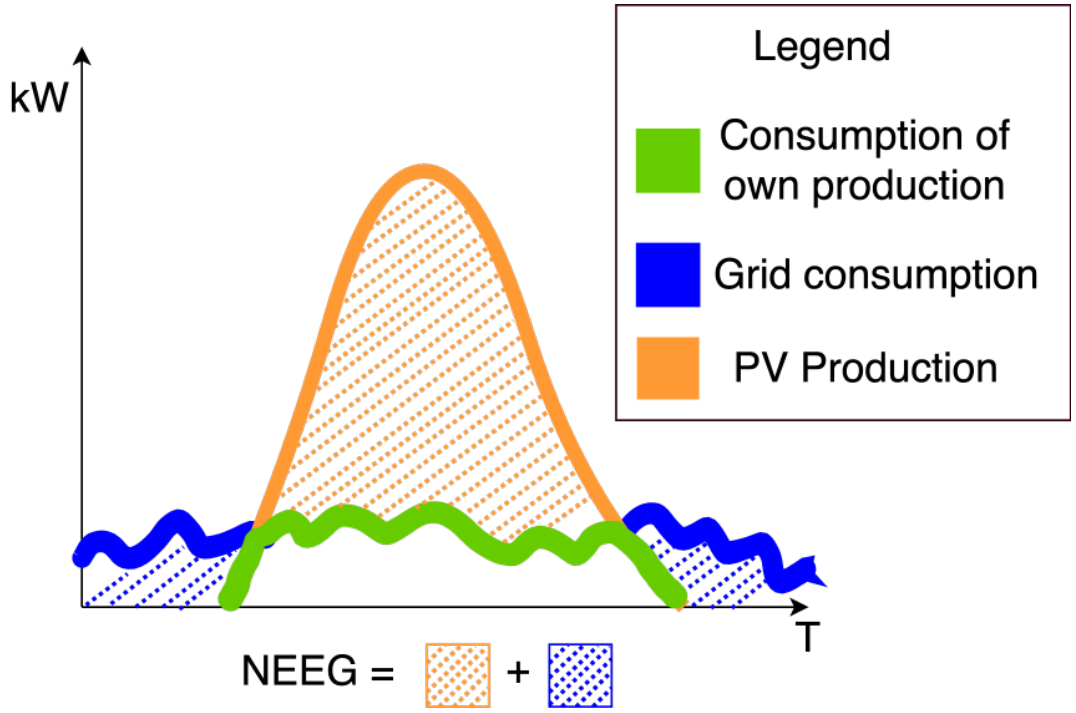


Note: self sufficiency is defined as long as the community is consuming energy

2.7 Evaluating the benefits - the net energy exchanged with the grid

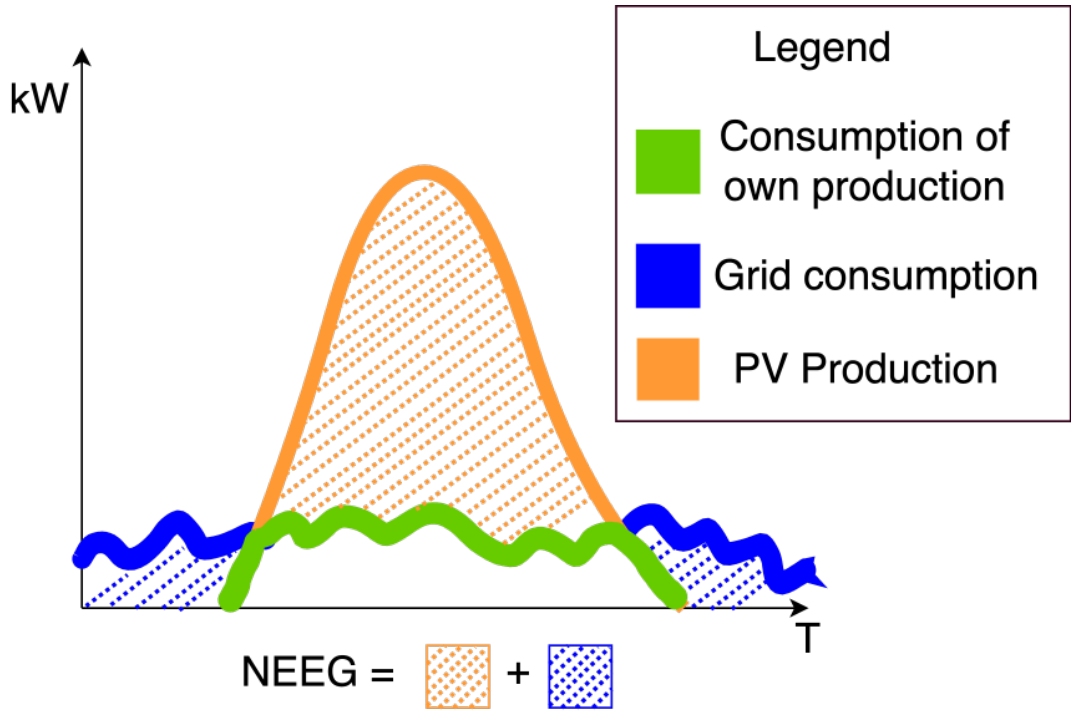
- The net energy exchanged with the grid (NEEG) reflects the total energy consumed from the grid and the total energy injected into the grid over a period of time T:

$$\mathrm{NEEG} = \sum_{t=1}^{T} |P_{\mathrm{comm}}(t) - P_{\mathrm{PV}}(t)| \Delta t$$



2.7.1 NEEG interpretation

- NEEG is usefull especially in minimisation problems
- NEEG reflects a physical quantity of energy
- Minimising NEEG is equivalent to maximising the self-consumption and self-sufficiency



2.8 Community behaviour

- The community is a single entity, but the members are still individuals
- Each member can have different behaviours

How can we model the individual behaviours?

3. Multi-agent systems

3.1 Definition

> Multi-agent systems represent simulation models where the agents are software entitites interacting with each other and making decisions based on their own knowledge and the knowledge of the other agents.

Typicall applications:

- factory automation
- traffic control
- energy management
- disaster simulation

3.2 Characteristics

- at least one agent
- there is interaction between the agents
- there is a simulation time frame
- the environment is clearly defined
- there is a coordination mechanism
- each agent has its own knowledge, behaviour and goals



Note: to understand multi-agent systems, one can imagine a play, where the stage is the simulation and the actors involved are the agents.

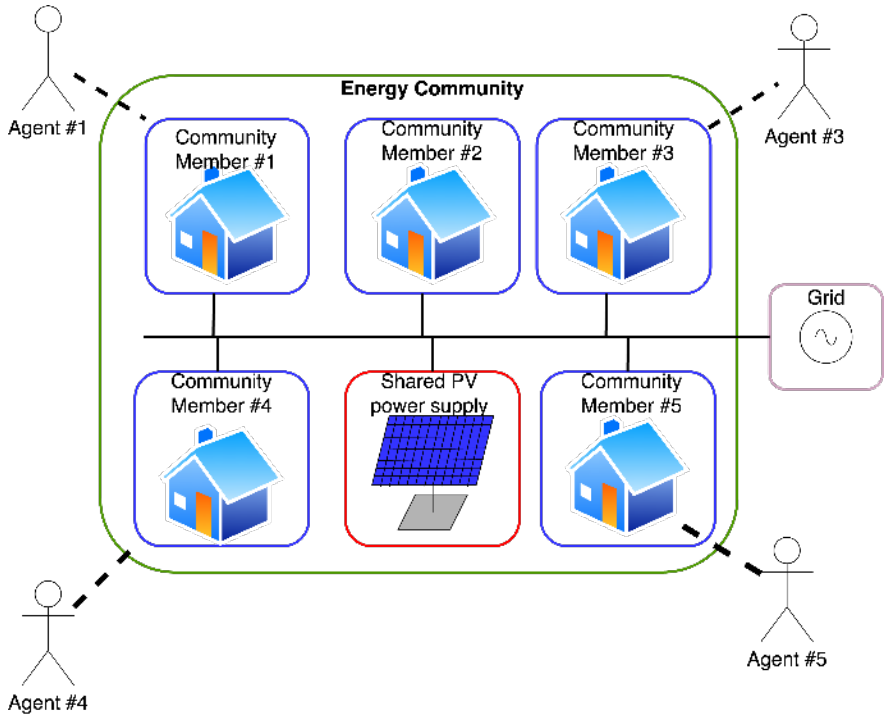
3.3 A residential energy community as a multi-agent system

Let's imagine how to model a residential energy community as a multi-agent system.

- We should start from the characteristics of the multi-agent system.
- We should also consider the defintion of the energy community.
- Agents should act together to achieve the goals of the energy community.

3.3 A residential energy community as a multi-agent system

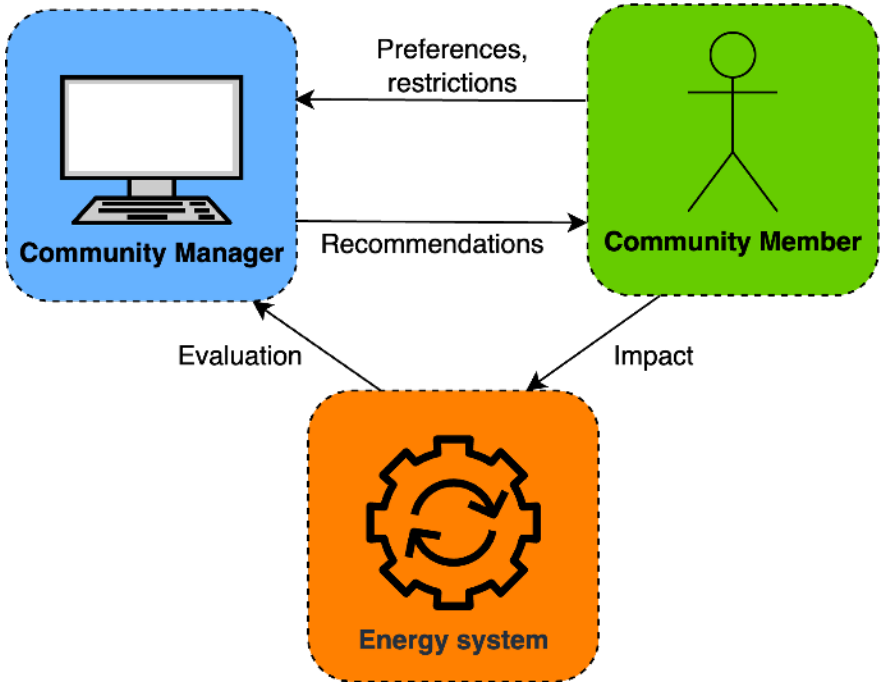
- at least one agent
- there is interaction between the agents
- there is a simulation time frame
- the environment is clearly defined
- there is a coordination mechanism
- each agent has its own knowledge, behaviour and goals



We imagine that each house acts as an agent, regardless of the number of people living in it.

3.3 A residential energy community as a multi-agent system

- at least one agent
- there is interaction between the agents
- there is a simulation time frame
- the environment is clearly defined
- there is a coordination mechanism
- each agent has its own knowledge, behaviour and goals



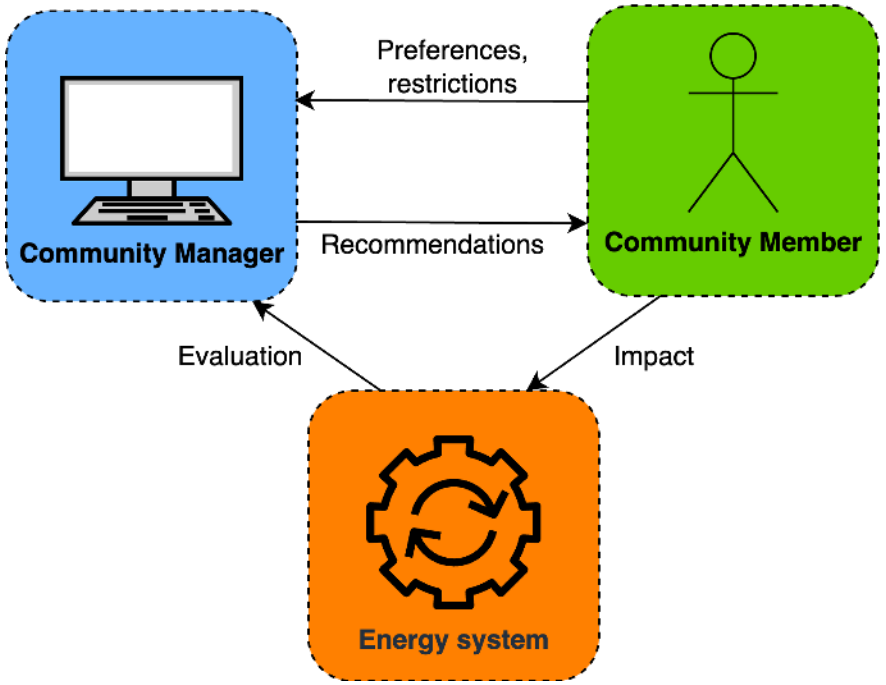
We imagine there is a special agent, the manager, who interacts with the community members.

3.3.1 The community manager

- The community manager reflects the behaviour of an automated recommendation system.

> - The role of the manager is to send recommendations to the community members on how to adapt their consumption in order to achieve the goals of the energy community.

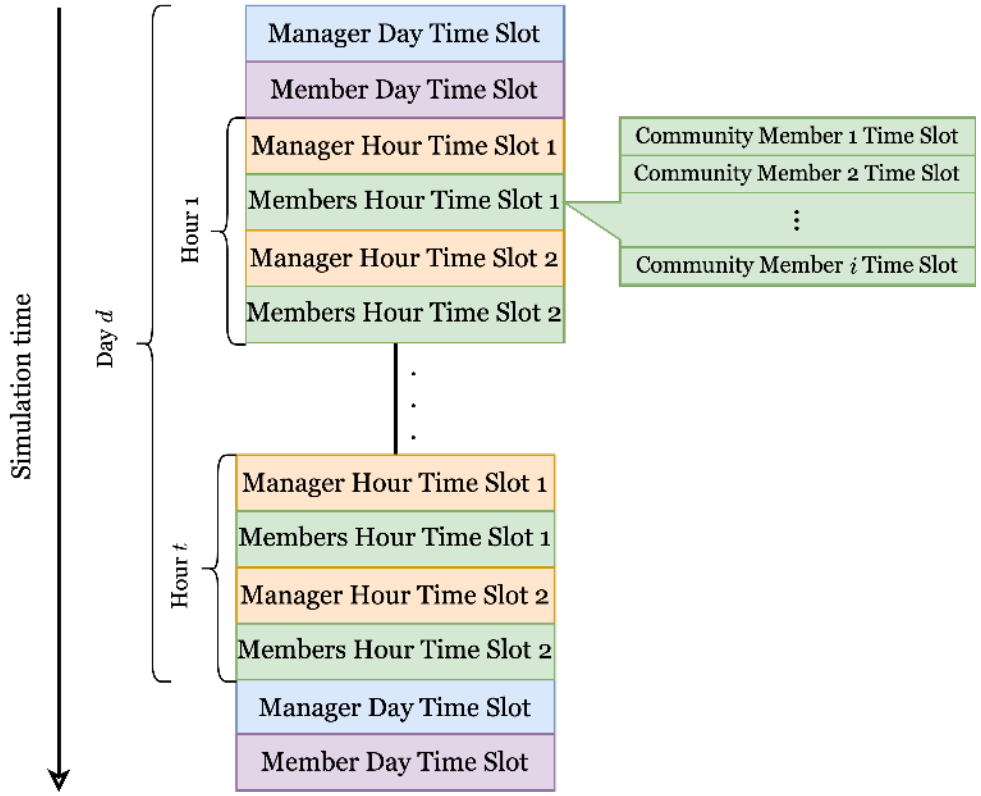
- The manager can gather information from the physical system and preferences/constraints or signals from the community members.
- In this way, we try to improve the sobriety of the community members, who will still act independently.



Note: the manager can be seen as a "helper" service

3.3 A residential energy community as a multi-agent system

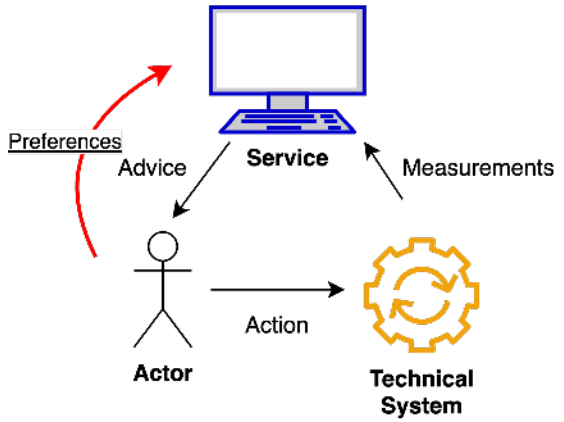
- at least one agent
- there is interaction between the agents
- there is a simulation time frame
- the environment is clearly defined
- there is a coordination mechanism
- each agent has its own knowledge, behaviour and goals



The members and the manager act in turns, in a loop.

3.3 A residential energy community as a multi-agent system

- at least one agent
- there is interaction between the agents
- there is a simulation time frame
- the environment is clearly defined
- there is a coordination mechanism
- each agent has its own knowledge, behaviour and goals



- we can imagine that community members receive recommendations thorugh portable devices (tablets, phones, etc.)
- the manager uses an estimation of the energy consumption and the production of the community to send recommendations
  - he is able to measure the consumption in real time at community level

3.3 A residential energy community as a multi-agent system

- at least one agent
- there is interaction between the agents
- there is a simulation time frame
- the environment is clearly defined
- there is a coordination mechanism
- each agent has its own knowledge, behaviour and goals

- Coordination is provided by the manager.
- The hour time slot allows the members to react to the recommendations.
- The day segmentation allows the members to develop behaviours over a longer period of time.

3.3 A residential energy community as a multi-agent system

- at least one agent
- there is interaction between the agents
- there is a simulation time frame
- the environment is clearly defined
- there is a coordination mechanism
- each agent has its own knowledge, behaviour and goals

- the goals are shared by the community (can be reflected by self-sufficiency and self-consumption)
- each agent can see his impact on the community
    - he may also see the impact of the others, thus motivating him to act in a certain way
- the agents can learn from the manager's recommendations or from his own experience

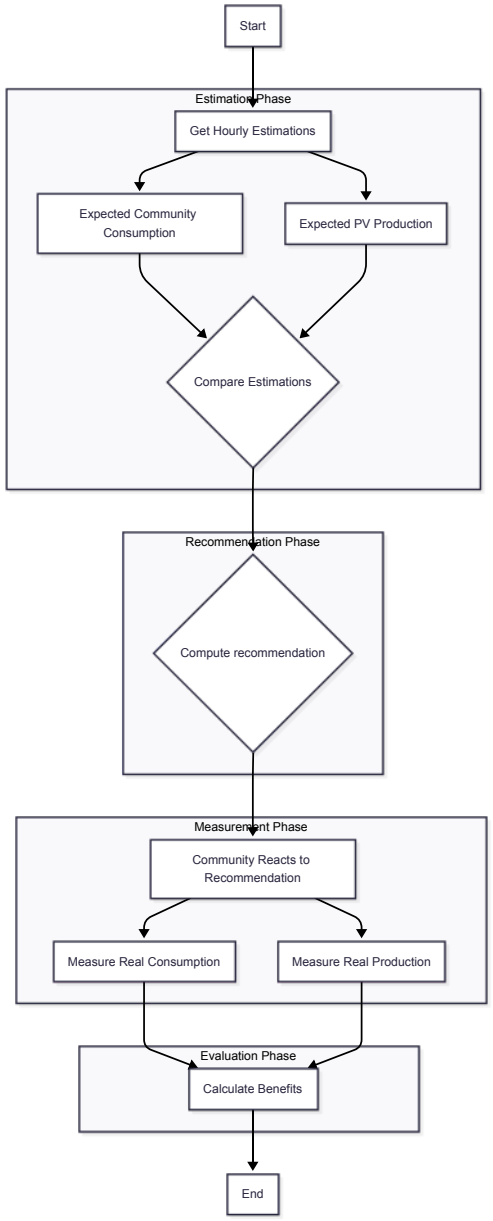
4. Case study

4.1 Context

- Let's consider a residential community.
- The community shares the production of a PV plant.
- We want to model a manager acting as a service and providing recommendations to the community members whether to increase or decrease their energy consumption, depending on the current situation and the available PV production.
- Each member reacts individually to the recommendations.

4.2 How does the manager provide a recommendation?

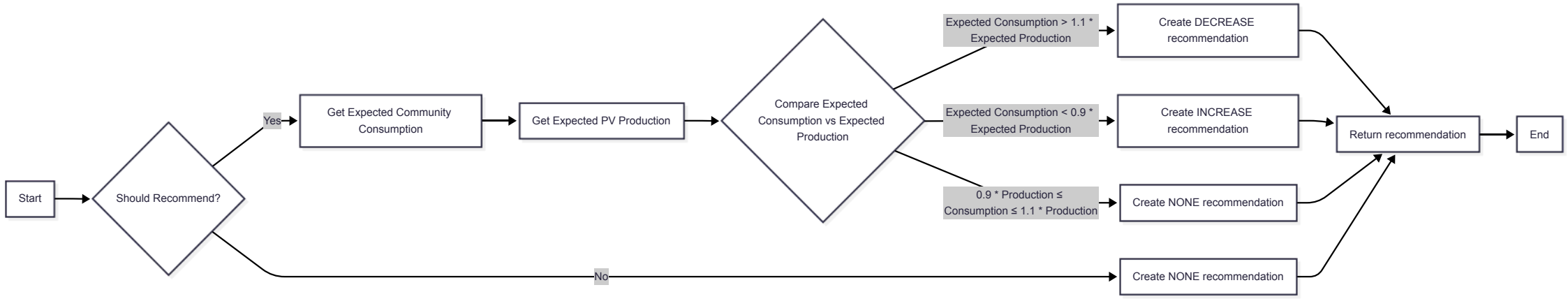
- We assume that the manager has an hourly estimation of the energy consumption and the production of the community (it can come from real data).
- The manager provides a recommendation based on these estimation.
- To quantify the benefits, the manager measures the real consumption (after recommendations) and the real production.



4.3 The basic manager

The basic manager can provide three types of recommendations:

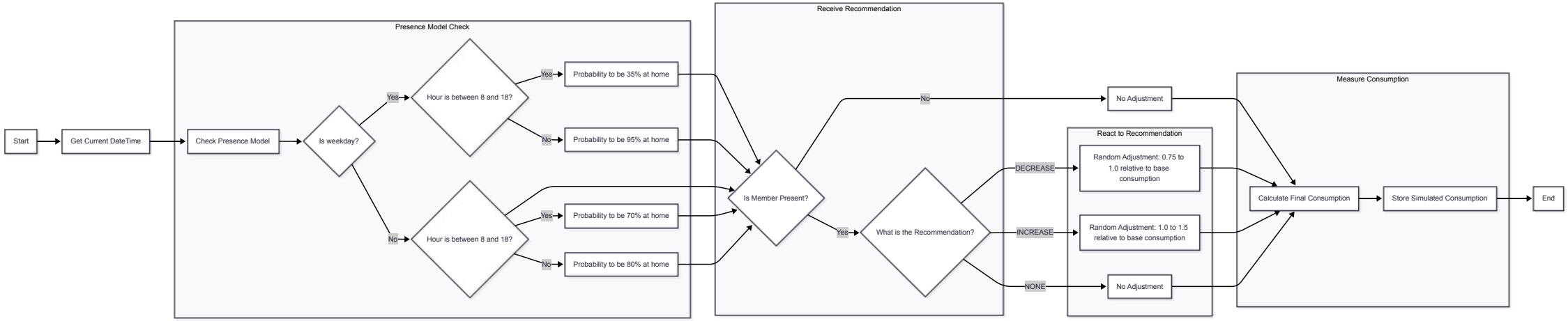
- DECREASE - when the expected consumption is higher than the expected production
- INCREASE - when the expected consumption is lower than the expected production
- NONE - when the expected consumption is within the bounds of the expected production



4.4 The reaction to recommendations

The member reacts in 4 steps:

- Check if the member is present
- Receive the recommendation
- React to the recommendation
- Measure the consumption

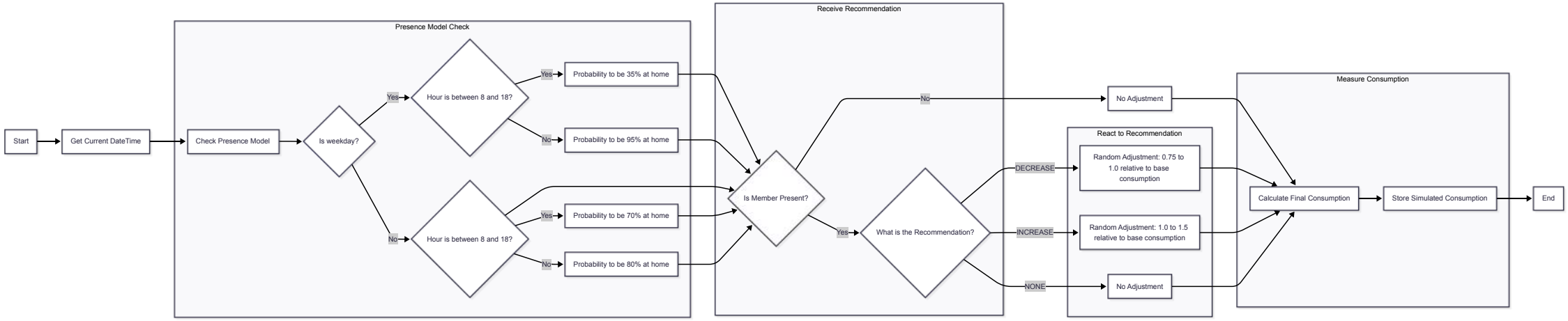


4.4 The reaction to recommendations

The presence step

We can model the presence with probabilities depending on:

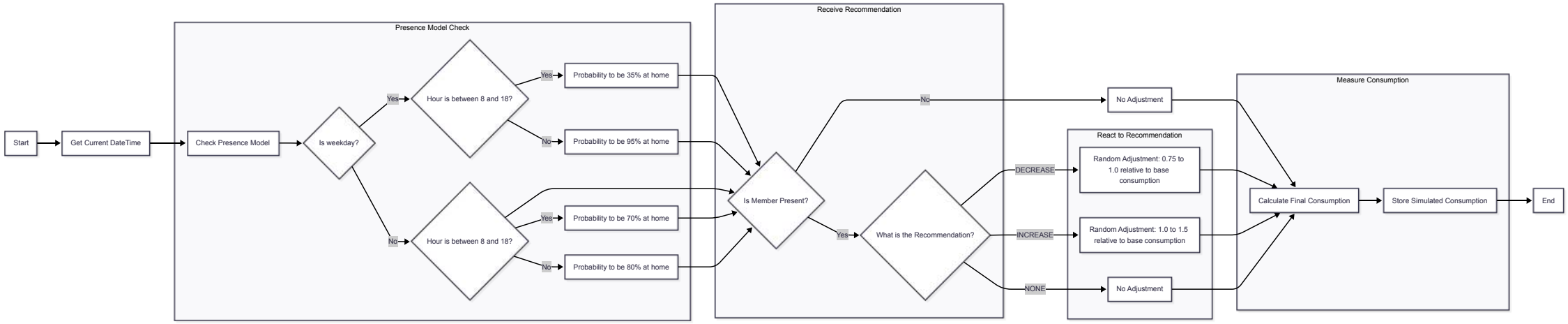
- the time of day
- the day of the week



4.4 The reaction to recommendations

The reaction step

The reaction is reflected by a percentage of change in the base consumption.

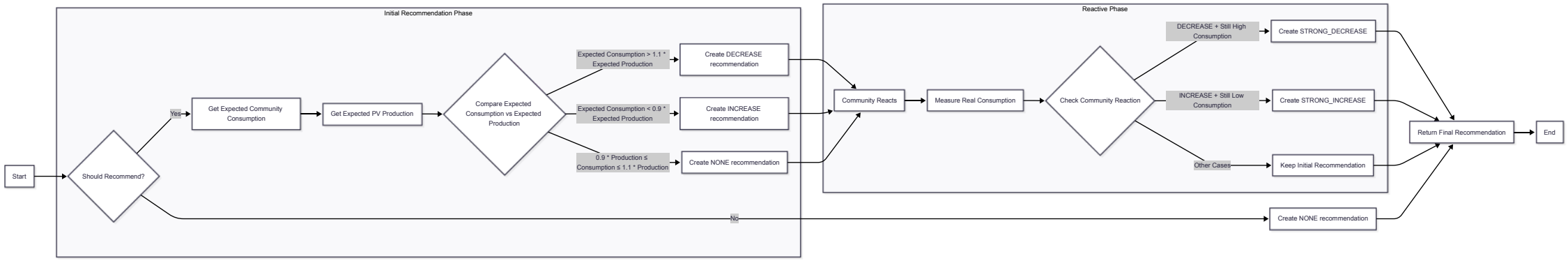


Note: we assume that the members always react to the recommendations.

4.5 The reactive manager

The reactive manager is a basic manager that provides an additional step:

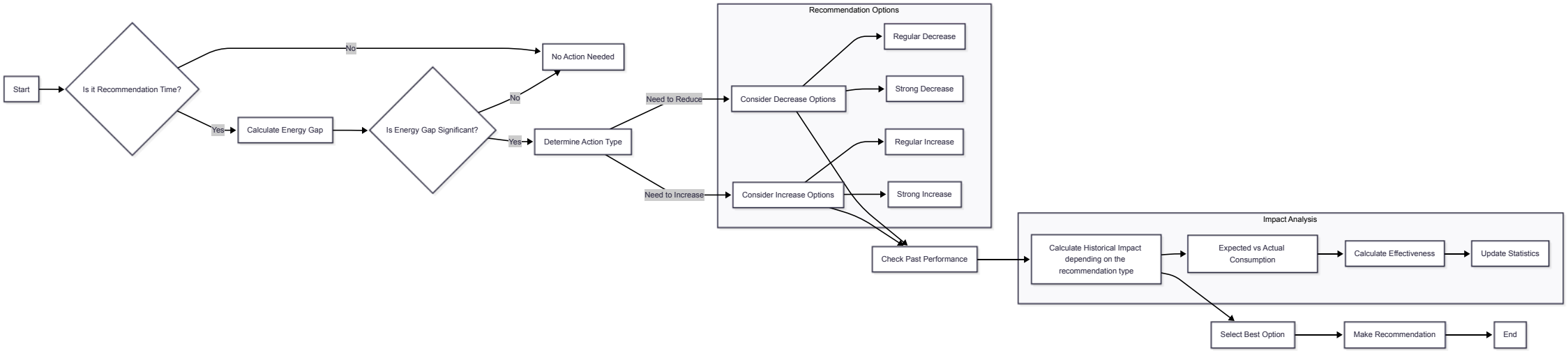
- it measures the consumption after the reaction
- it compares the consumption with the expected consumption
- it provides a new recommendation if the consumption is not as expected



4.6 The adaptive manager

The adaptive manager is a manager that learns from the past recommendations.

- it makes an average previous energy impact of each recommendation type
- it compares the impact with the current energy gap
- it provides a new recommendation based on the impact



Self-check questionnaire

12 questions — energy communities

Choose the best answer each time.

(In class: discuss in pairs; answers on the following slides.)

Q1 — Context (three levers)

To limit warming, the slides highlight three main levers for the residential sector (~20% of global CO_2):

- A. More renewable production, higher efficiency, and sobriety (awareness/behaviour)
- B. Only nuclear fusion in each home
- C. Eliminating all electricity use
- D. MPPT voltage tracking only

Q2 — Efficiency vs sufficiency vs sobriety

Which pairing matches the lecture?

- A. Efficiency = less energy for the same service; DSM controls loads; sobriety = awareness of consumption and behaviour change
- B. Efficiency and sobriety are identical legal terms in ThBAT
- C. Sobriety means only installing PV
- D. DSM replaces democratic governance

Q3 — Definition of energy community

An energy community is best described as:

- A. People/SMEs/local authorities who voluntarily join democratic energy-sharing to pursue environmental, social, or economic benefits
- B. A mandatory utility monopoly for large industry only
- C. A heat-pump refrigerant cycle
- D. A single smart meter with no participants

Q4 — Community power aggregation

For households h_i with metered power $P_i(t)$ and shared PV $P_{\mathrm{PV}}(t)$, community consumption is:

- A. $P_{\mathrm{comm}}(t) = \sum_{i=1}^{H} P_i(t)$
- B. $P_{\mathrm{comm}}(t) = P_{\mathrm{PV}}(t)$ only
- C. $P_{\mathrm{comm}}(t) = \max_i P_i(t)$
- D. $P_{\mathrm{comm}}(t) = U_{\mathrm{bat}} \times \mathrm{HDD}$

Q5 — Energy balance with the grid

The slides write the balance as:

- A. $P_{\text{comm}}(t) = P_{\text{PV}}(t) + P_{\text{extract,grid}}(t) - P_{\text{inject,grid}}(t)$
- B. $P_{\text{comm}} = P_{\text{PV}}$ with no grid term ever
- C. $P_{\text{inject}} = P_{\text{extract}}$ always at each instant
- D. $\text{SC} = \text{SS}$ by definition

Q6 — Self-consumption (SC)

Self-consumption over period T is defined as:

- A. $\mathrm{SC} = \dfrac{\sum_t \min(P_{\mathrm{comm}}(t), P_{\mathrm{PV}}(t))}{\sum_t P_{\mathrm{PV}}(t)}$ (PV share used on site)
- B. $\mathrm{SC} = \sum_t P_{\mathrm{comm}} / \sum_t P_{\mathrm{PV}}$ without $\min$
- C. $\mathrm{SC} = \mathrm{COP}_{\mathrm{heating}}$
- D. $\mathrm{SC} = 2.58\times$ primary energy

Q7 — Self-sufficiency (SS)

Self-sufficiency over period T is defined as:

- A. $\mathrm{SS} = \dfrac{\sum_t \min(P_{\mathrm{comm}}(t), P_{\mathrm{PV}}(t))}{\sum_t P_{\mathrm{comm}}(t)}$ (load share covered by PV)
- B. $\mathrm{SS} = \sum_t P_{\mathrm{PV}} / \sum_t P_{\mathrm{comm}}$ without $\min$
- C. $\mathrm{SS} = \mathrm{NEEG}$ with no Δt
- D. SS is always 0 at night by definition

Q8 — NEEG

Net energy exchanged with the grid (NEEG) on the slides is:

- A. $\mathrm{NEEG} = \sum_t |P_{\mathrm{comm}}(t) - P_{\mathrm{PV}}(t)|\Delta t$; useful to minimize in optimization
- B. The same formula as SC with no absolute value
- C. Only injection, never extraction
- D. HDD + CDD

Q9 — Multi-agent systems

A multi-agent system in this course is:

- A. Software agents interacting over a defined environment/time frame, with coordination and individual knowledge/goals
- B. Only hardware PV panels with no simulation
- C. A single ARX model with no agents
- D. The French electricity TSO only

Q10 — Residential community mapping

In the proposed MAS model, each household is typically:

- A. One agent; a special manager agent sends recommendations to members
- B. One agent per person worldwide
- C. The manager replaces all households physically
- D. The grid operator is the only agent

Q11 — Basic manager recommendations

The basic manager issues:

- A. DECREASE if expected load > expected PV; INCREASE if load < PV; NONE if within bounds
- B. Only INCREASE at night always
- C. Random recommendations with no measurements
- D. COP targets for the expansion valve

Q12 — Manager variants

Reactive vs adaptive managers differ because:

- A. Reactive compares actual vs expected consumption and may re-recommend; adaptive learns average impact of past recommendation types
- B. Reactive learns long-term tariffs; adaptive ignores measurements
- C. Both are identical to the basic manager with no feedback
- D. Adaptive manager replaces democratic participation

Answer key (1/2)

Q	Answer	Short rationale
1	A	Renewables, efficiency, sobriety.
2	A	Efficiency / DSM / sobriety distinctions.
3	A	Voluntary, democratic, triple benefits.
4	A	Sum of household powers.
5	A	Load = PV + extract – inject.
6	A	SC: min(load,PV) over sum(PV).

Answer key (2/2)

Q	Answer	Short rationale
7	A	SS: min(load,PV) over sum(load).
8	A	NEEG: sum of |load−PV| Δt.
9	A	Software agents + coordination + environment.
10	A	One agent per house + manager.
11	A	DECREASE / INCREASE / NONE logic.
12	A	Reactive: feedback loop; adaptive: learned impacts.

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