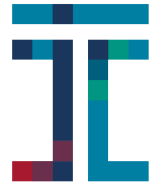

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EEN452 - Control and Operation of Electric Power Systems

Part 7: Current and future trends in power system operation - the path to the smart grid

https://sps.cut.ac.cy/courses/een452/

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Today's learning objectives

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After this lecture and additional reading, you should be able to . . .

- . . . motivate the need for smart grids
- . . . give an overview of technologies and concepts needed to establish smart grids

1st question:
How much energy do you use per year?

2nd question:
Do you spend any time thinking about when to use energy?

1st question:
How much energy do you use per year?
I have no idea.

2nd question:
Do you spend any time thinking about when to use energy?
Of course, not!

1 Outline

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Fossil-fueled energy production

Operation & monitoring system

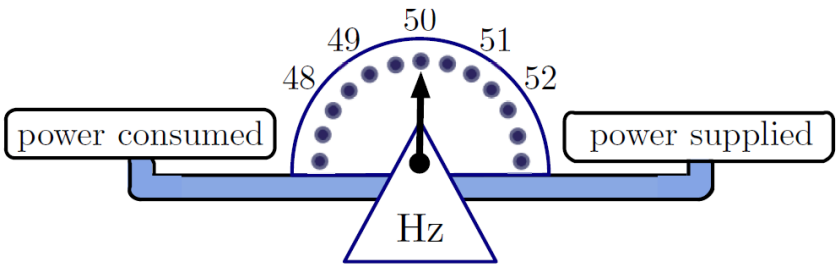
Frequency

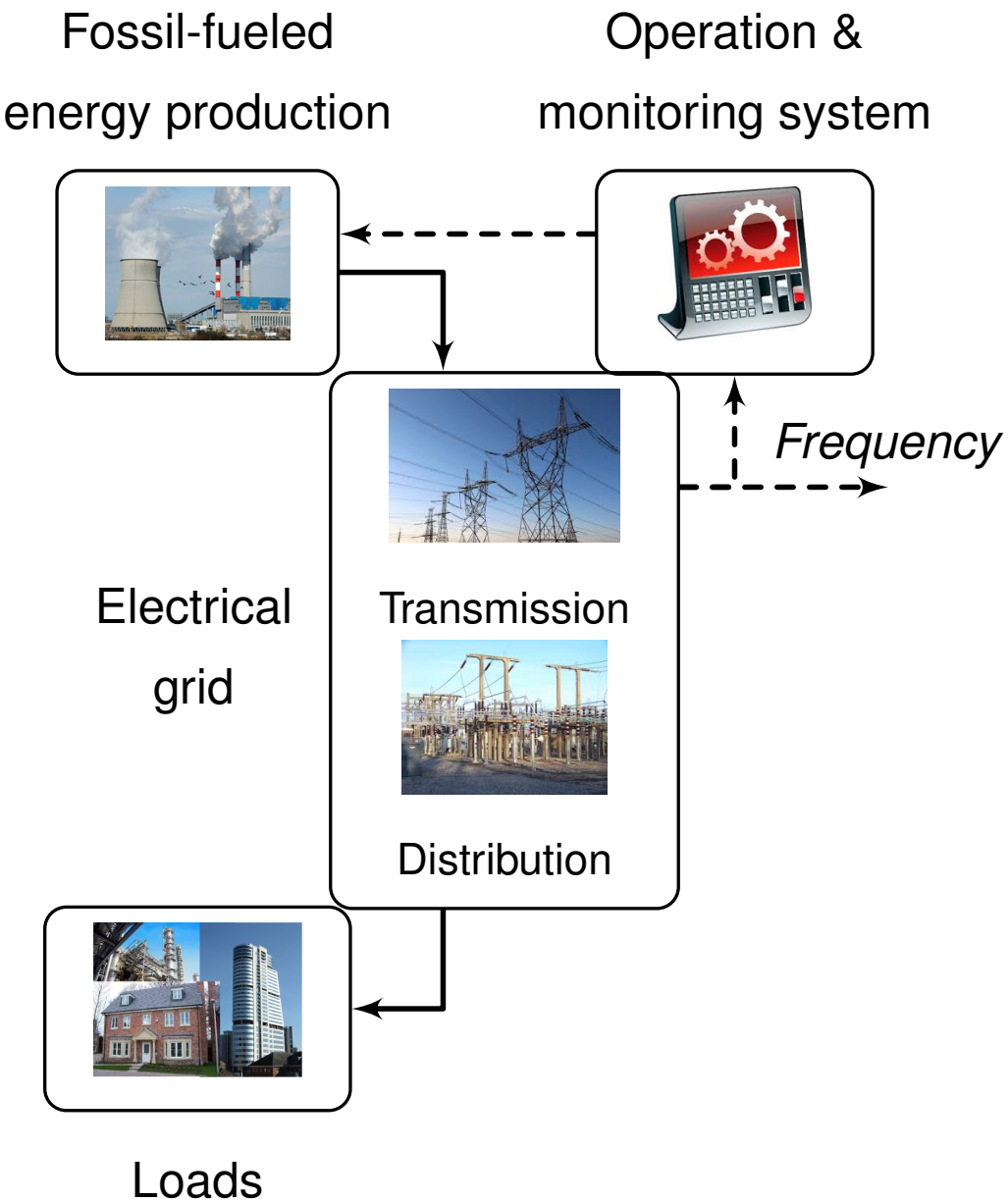
Electrical grid

Transmission

Distribution

Loads



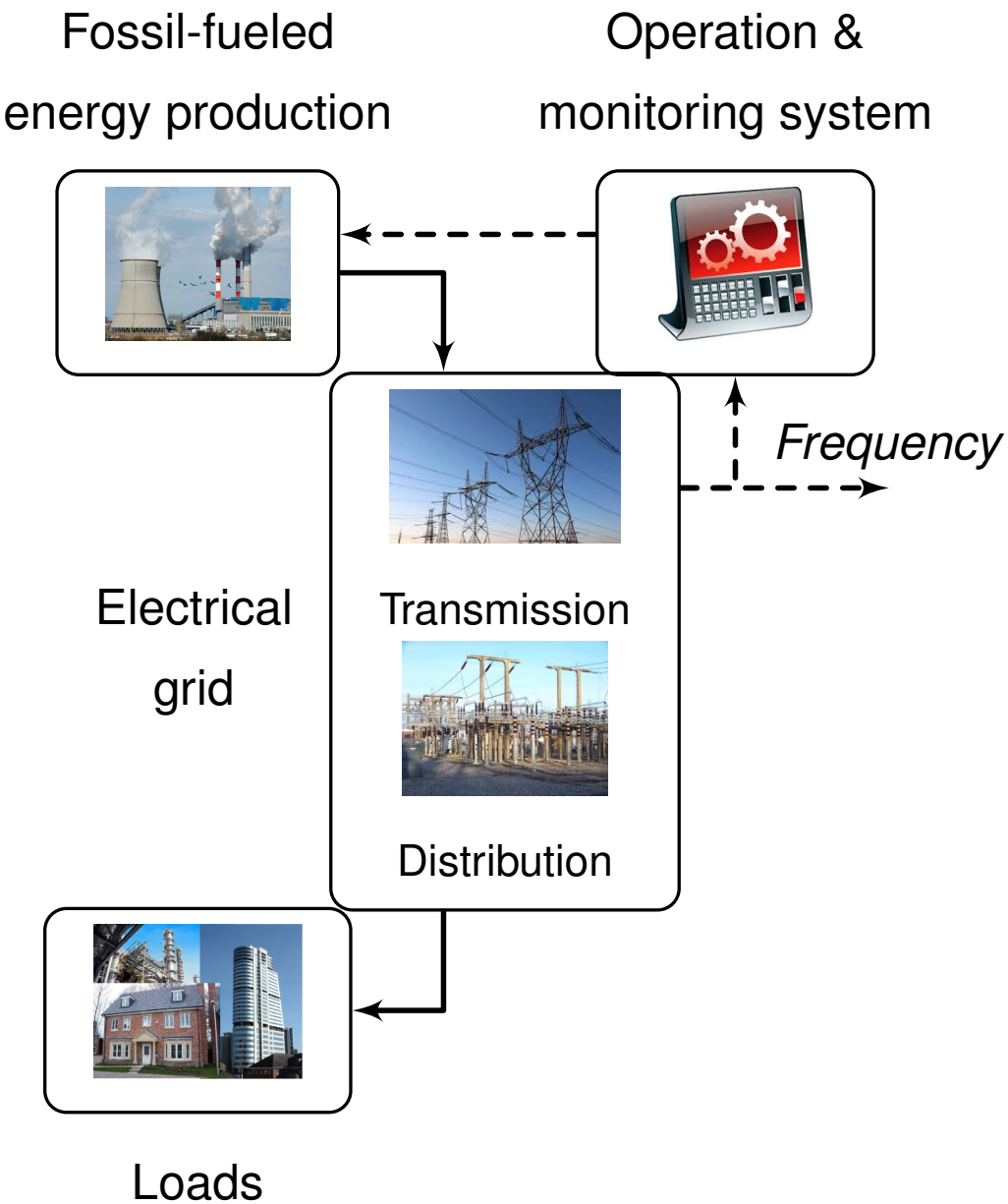


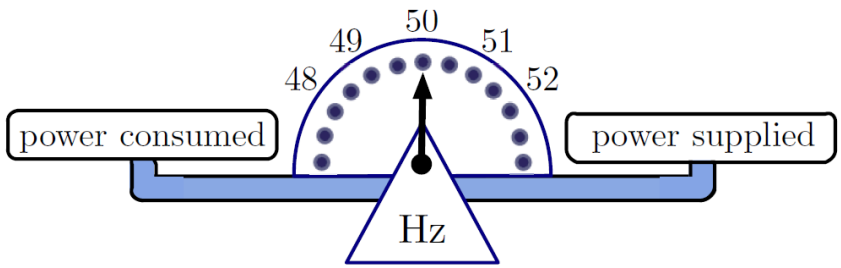
Advantage of fossil fuels:

available on demand
whenever required

Production follows demand

1 The electrical energy system: production follows demand





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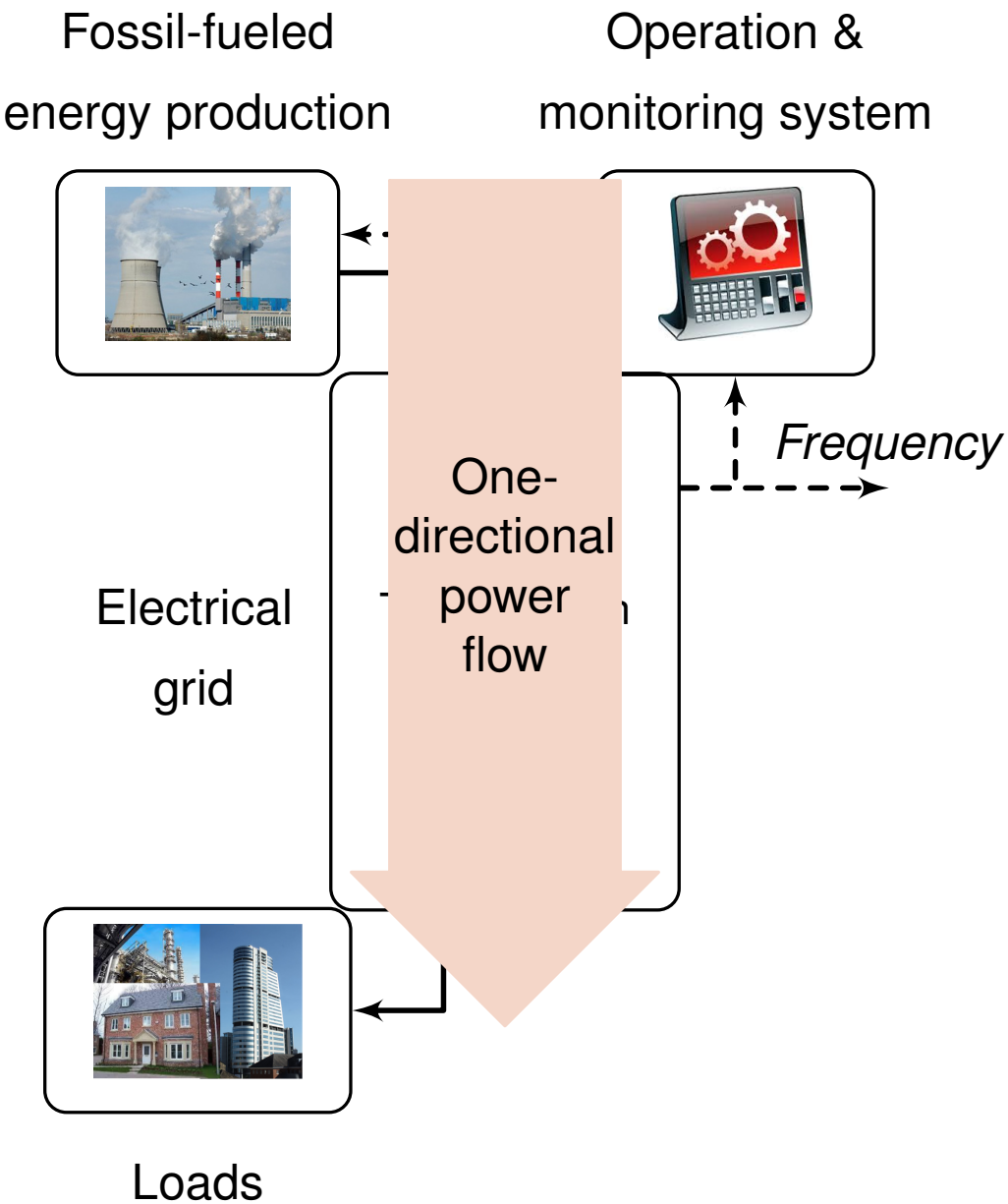

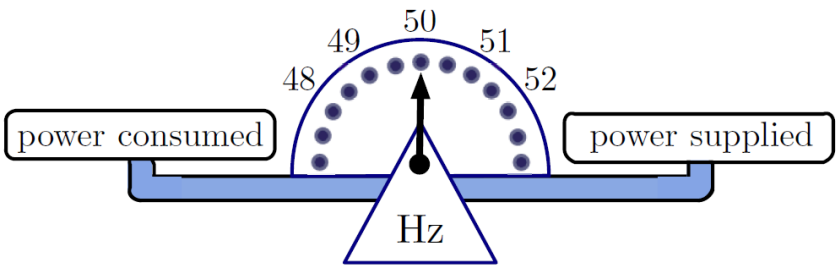

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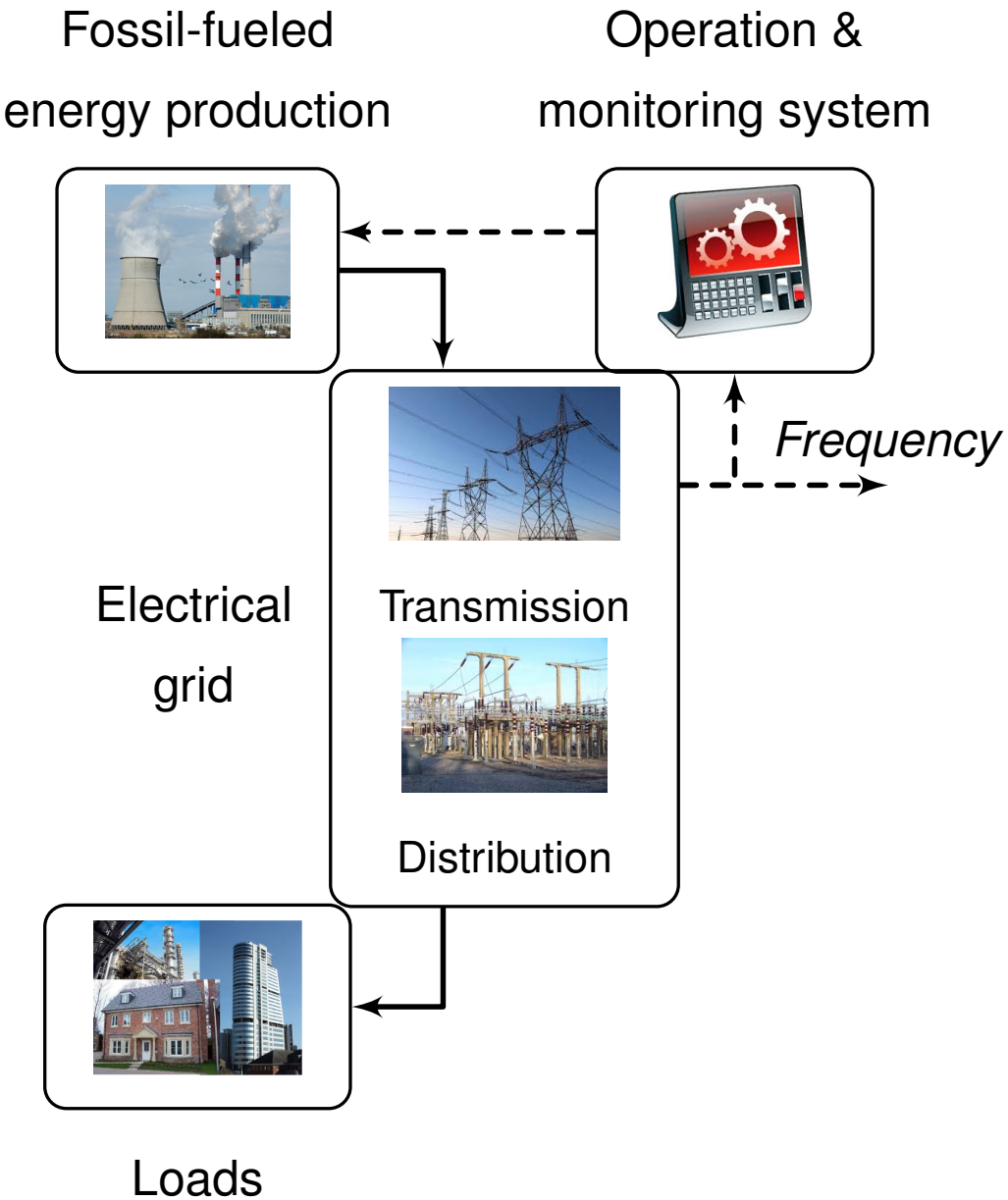
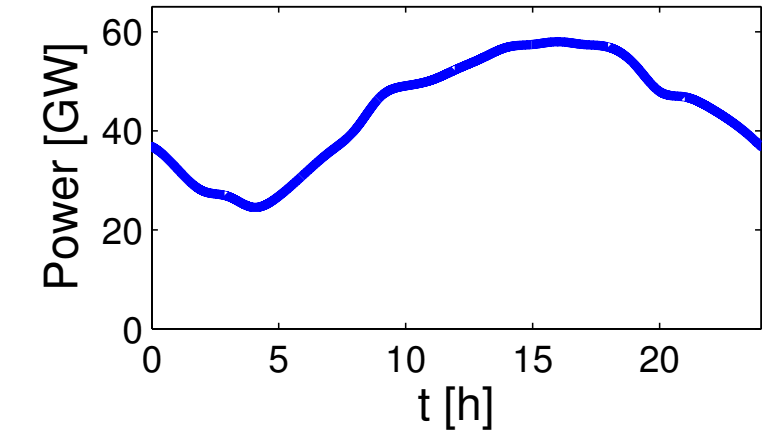
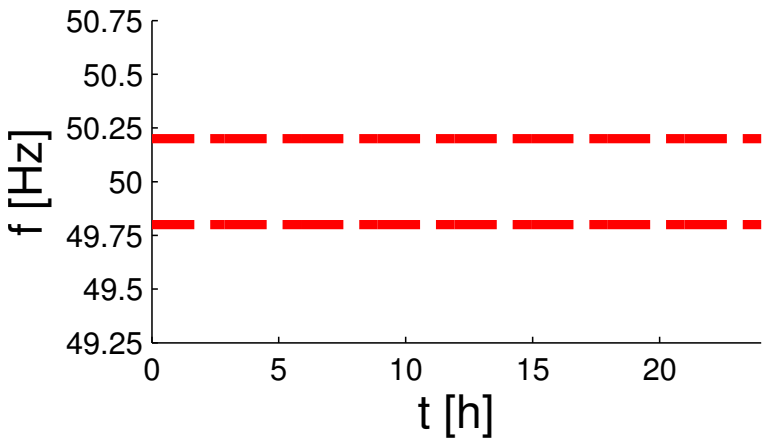






Load

Fossil production

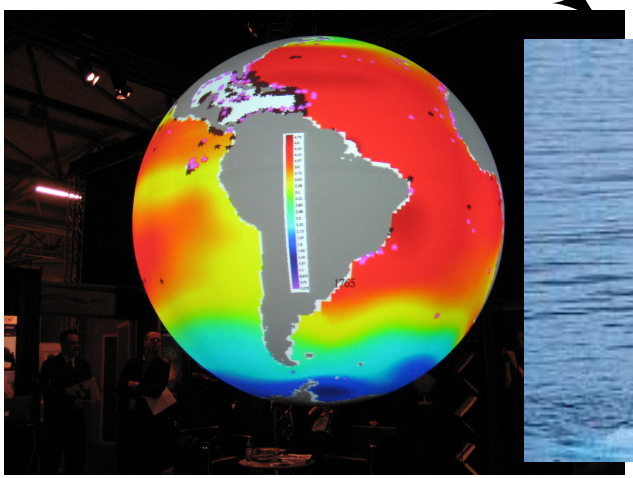
Grid frequency

2 Outline

2 Two major problems with fossil fuels

1) Energy generation from fossil fuels highly contributes to greenhouse gas emissions & climate change!

2) Fossil fuels are finite!



2 A (partial) solution

Onshore wind

Solar power

Offshore wind

Shift energy production from fossil to renewable energy sources!

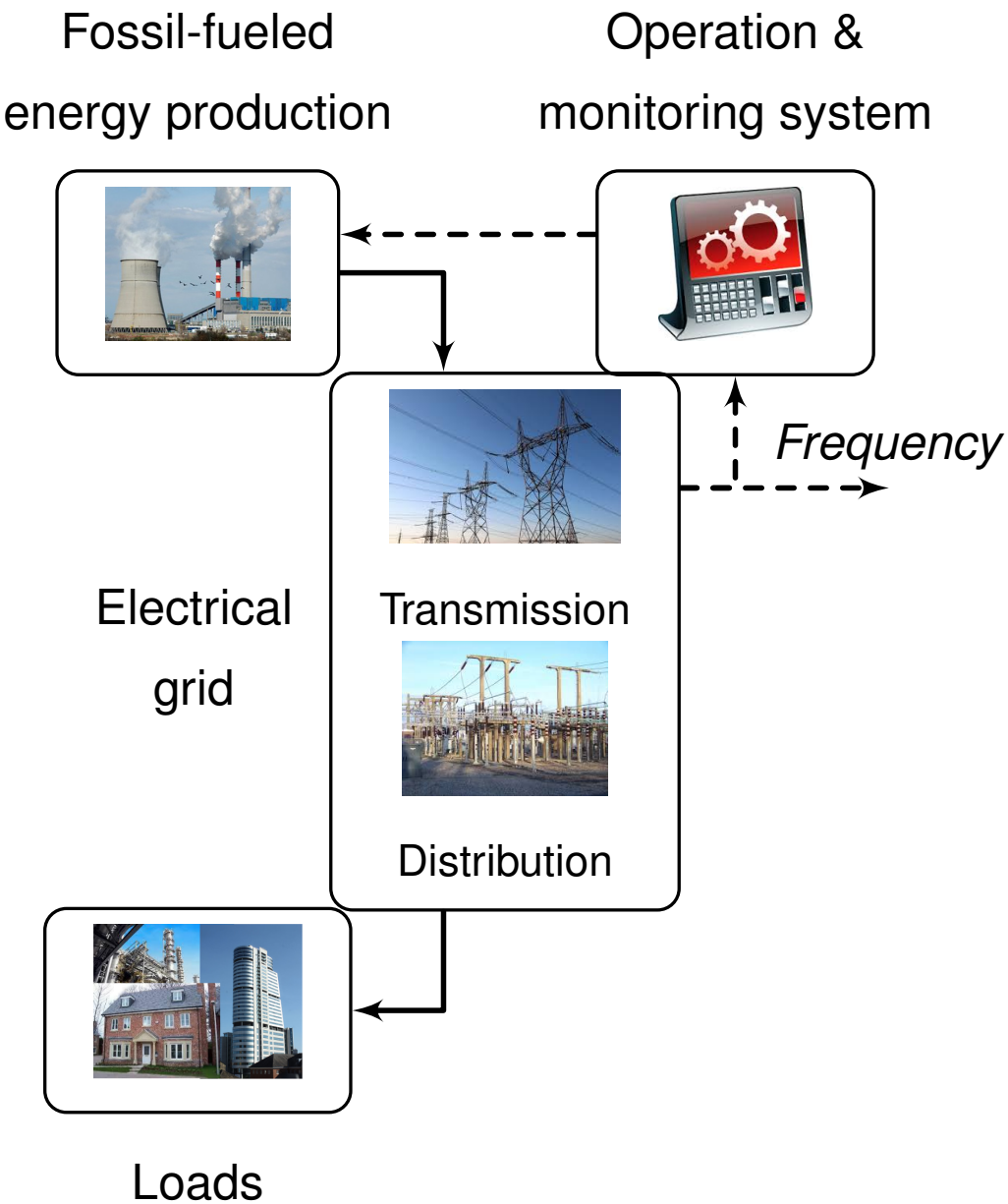
Marine power

Bioenergy

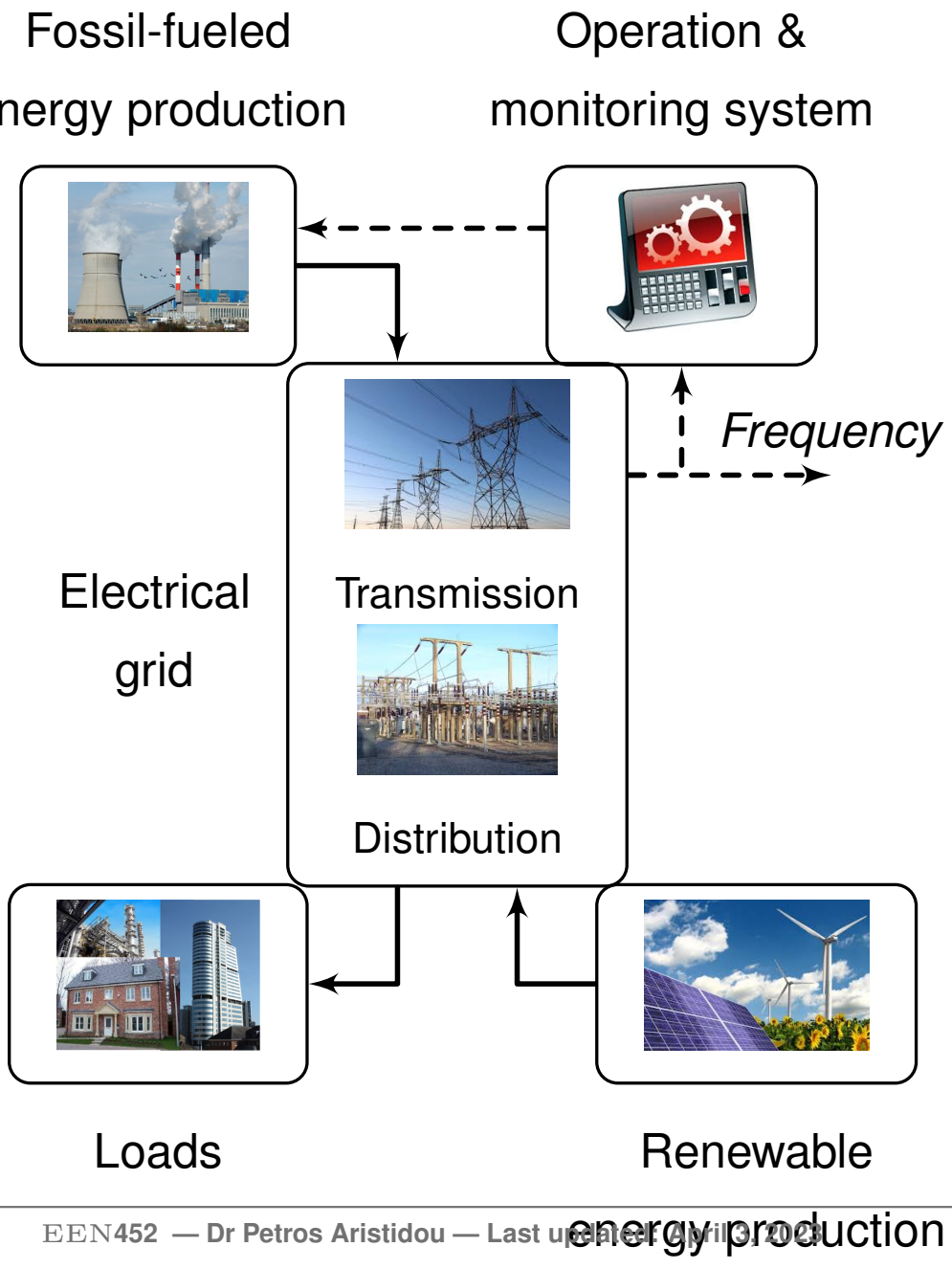
Small hydro power

3 Outline

3 The electrical energy system: present



3 The electrical energy system: present



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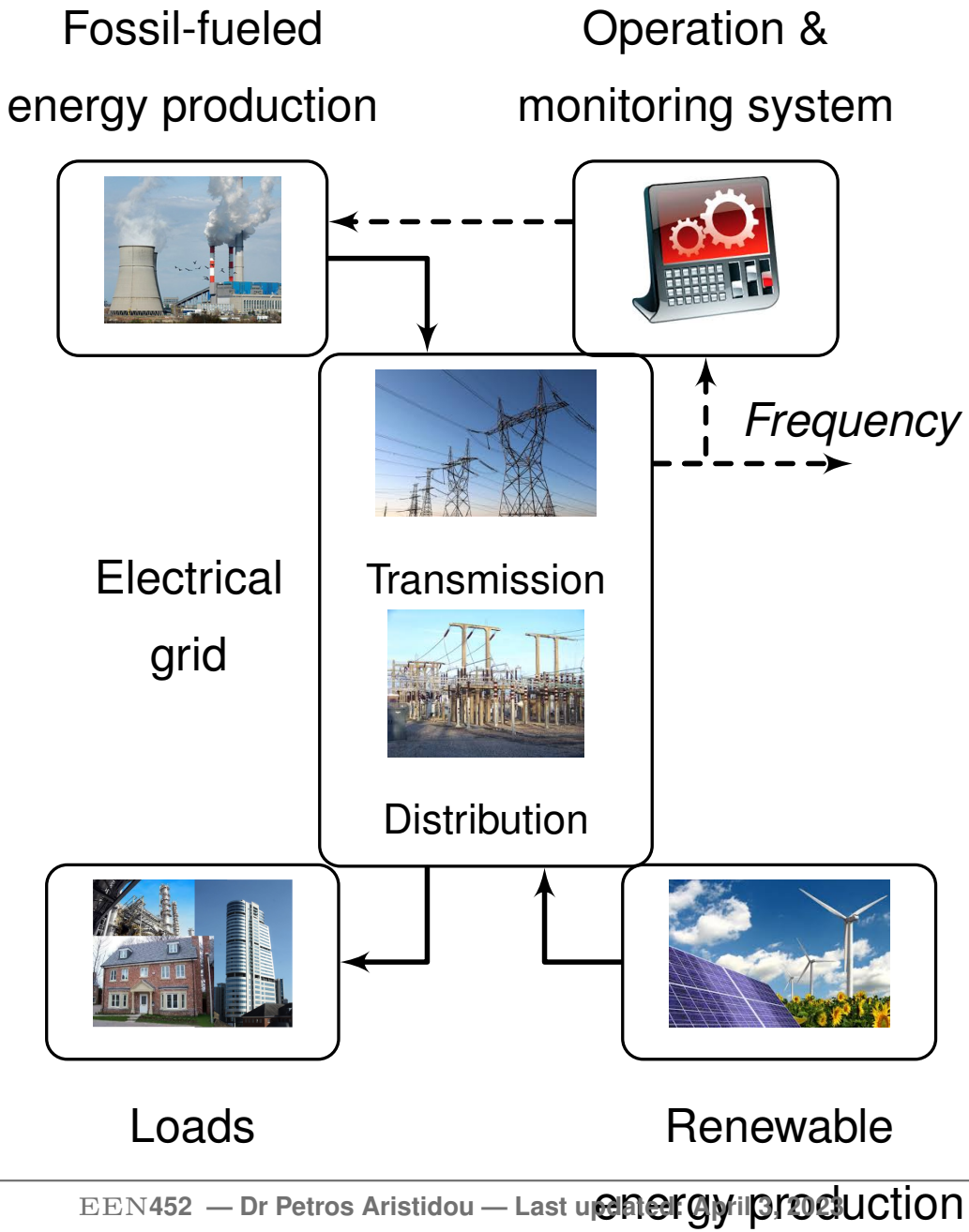
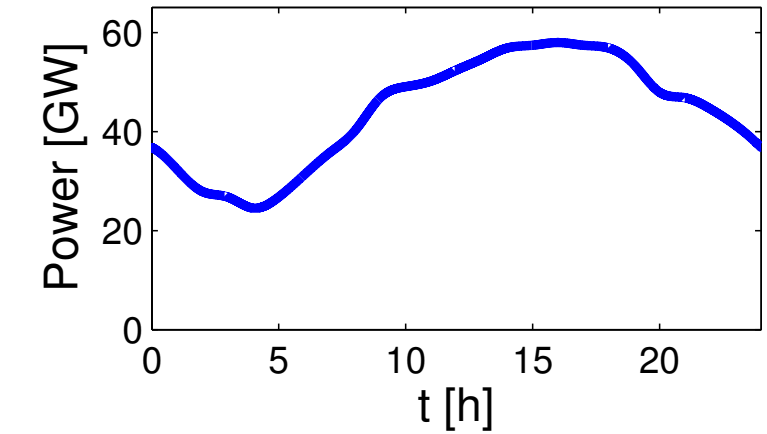
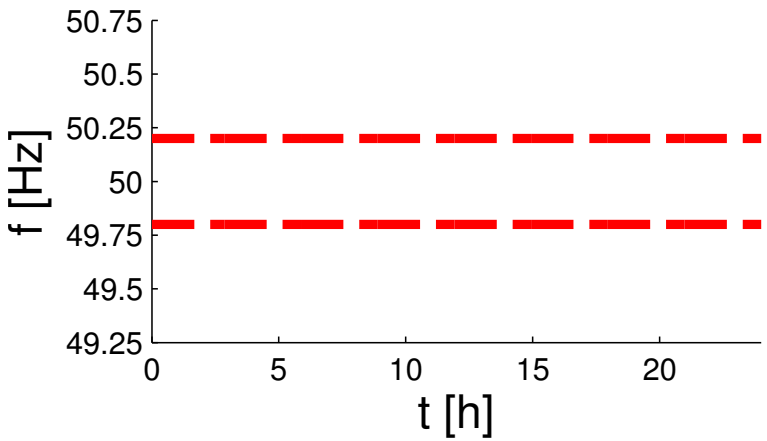






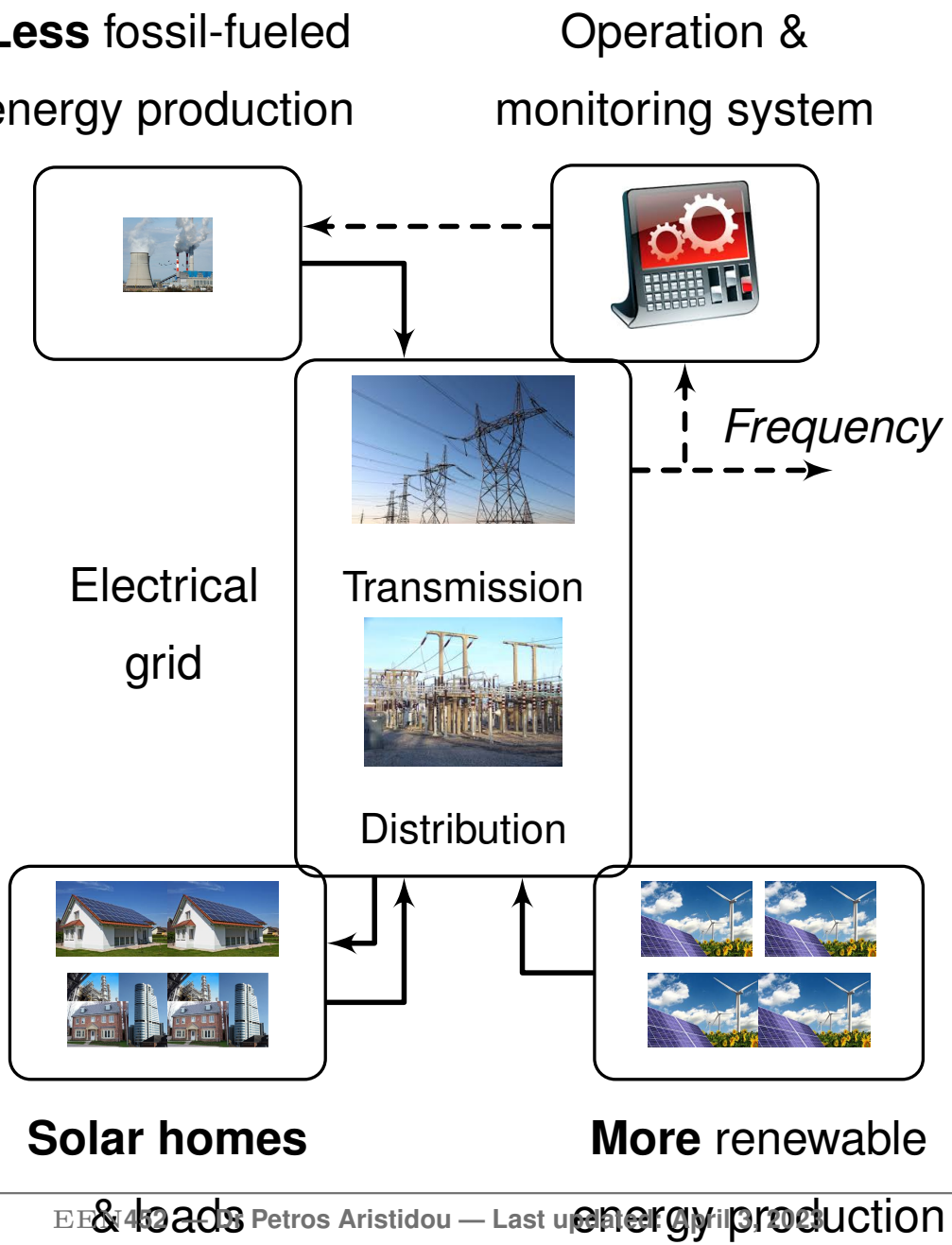
Load

Fossil production

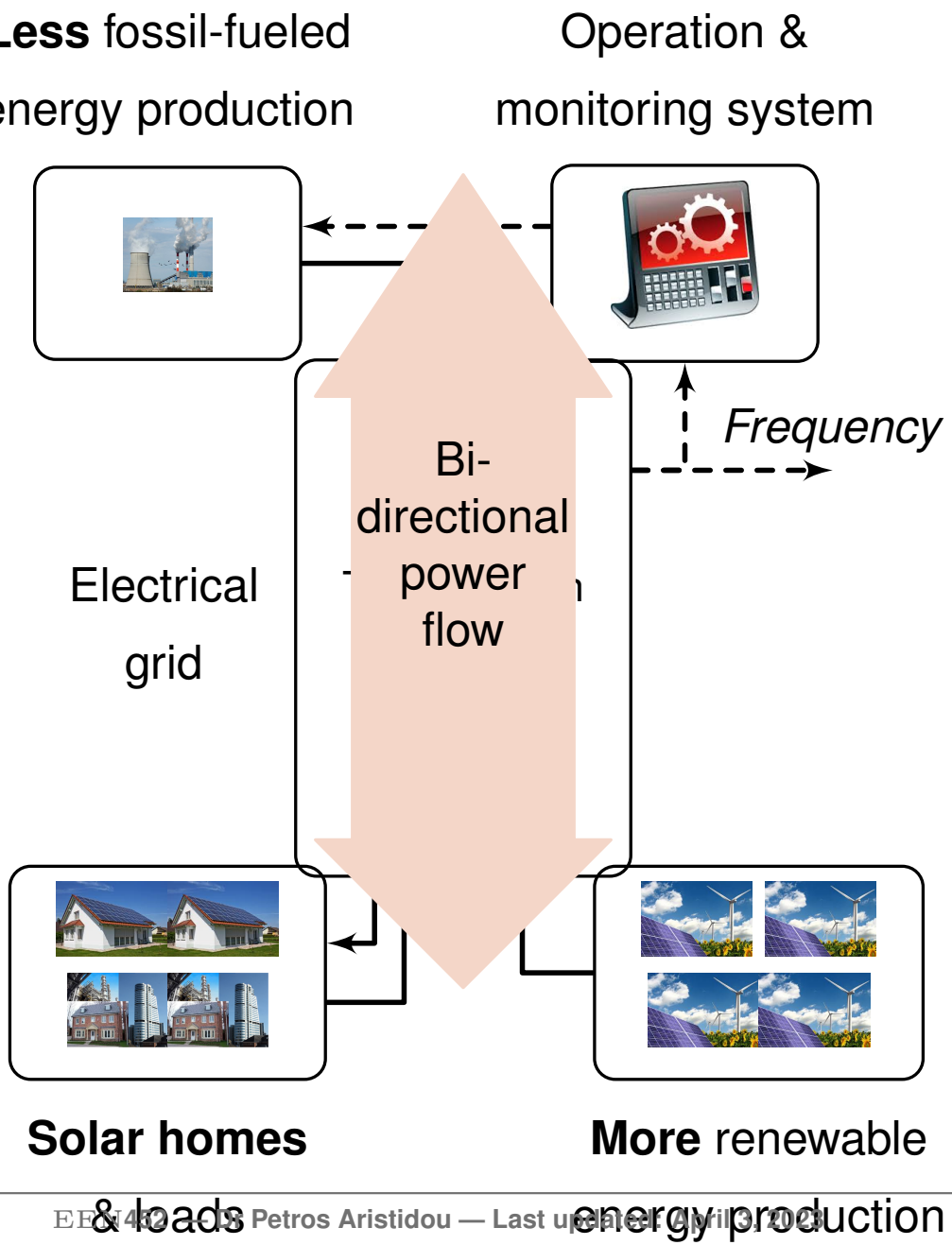
Grid frequency

Renewable production

3 The electrical energy system: future



- Reduction of fossil-fueled power plants
- Increasing amount of renewable energy plants at distribution level
- Increasing amount of solar homes



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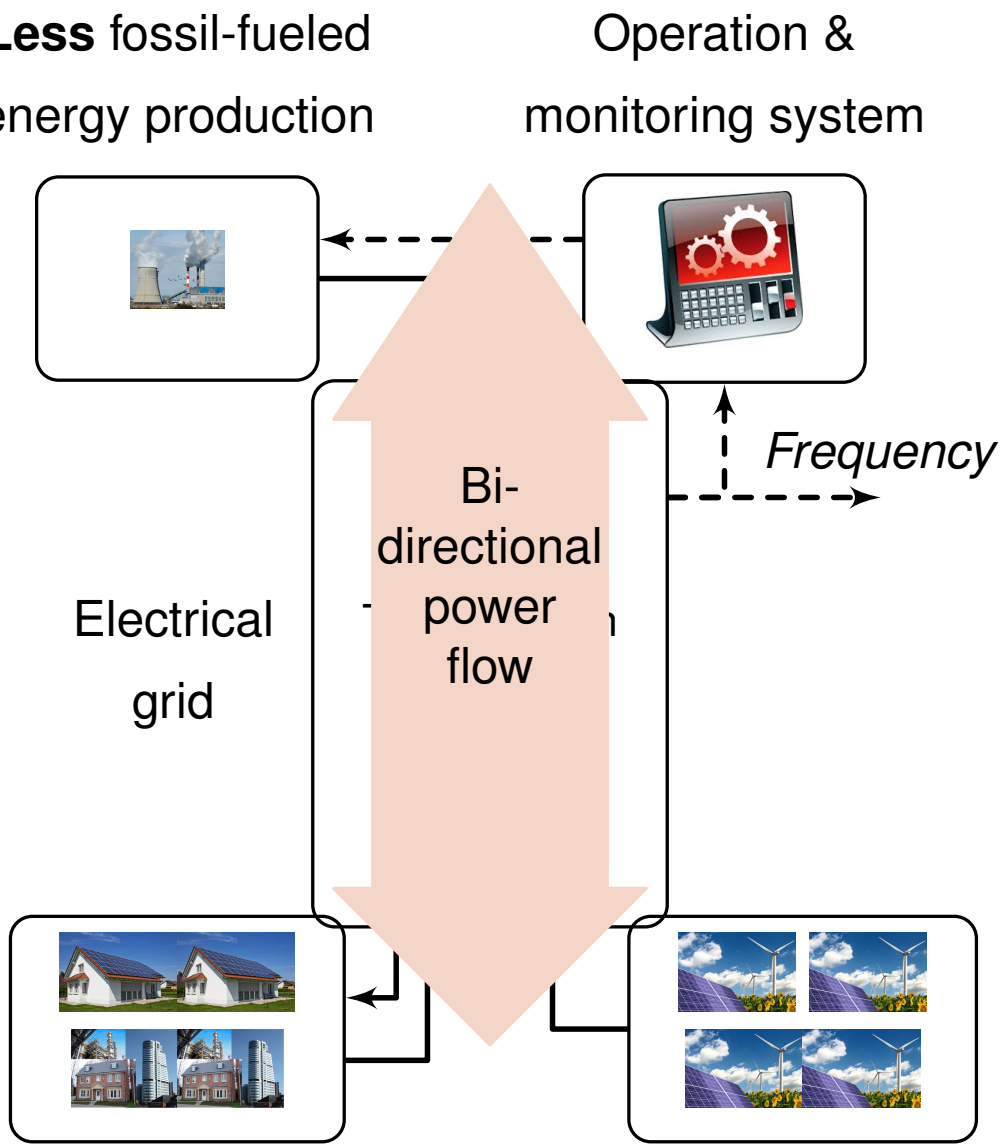
3 The electrical energy system: future

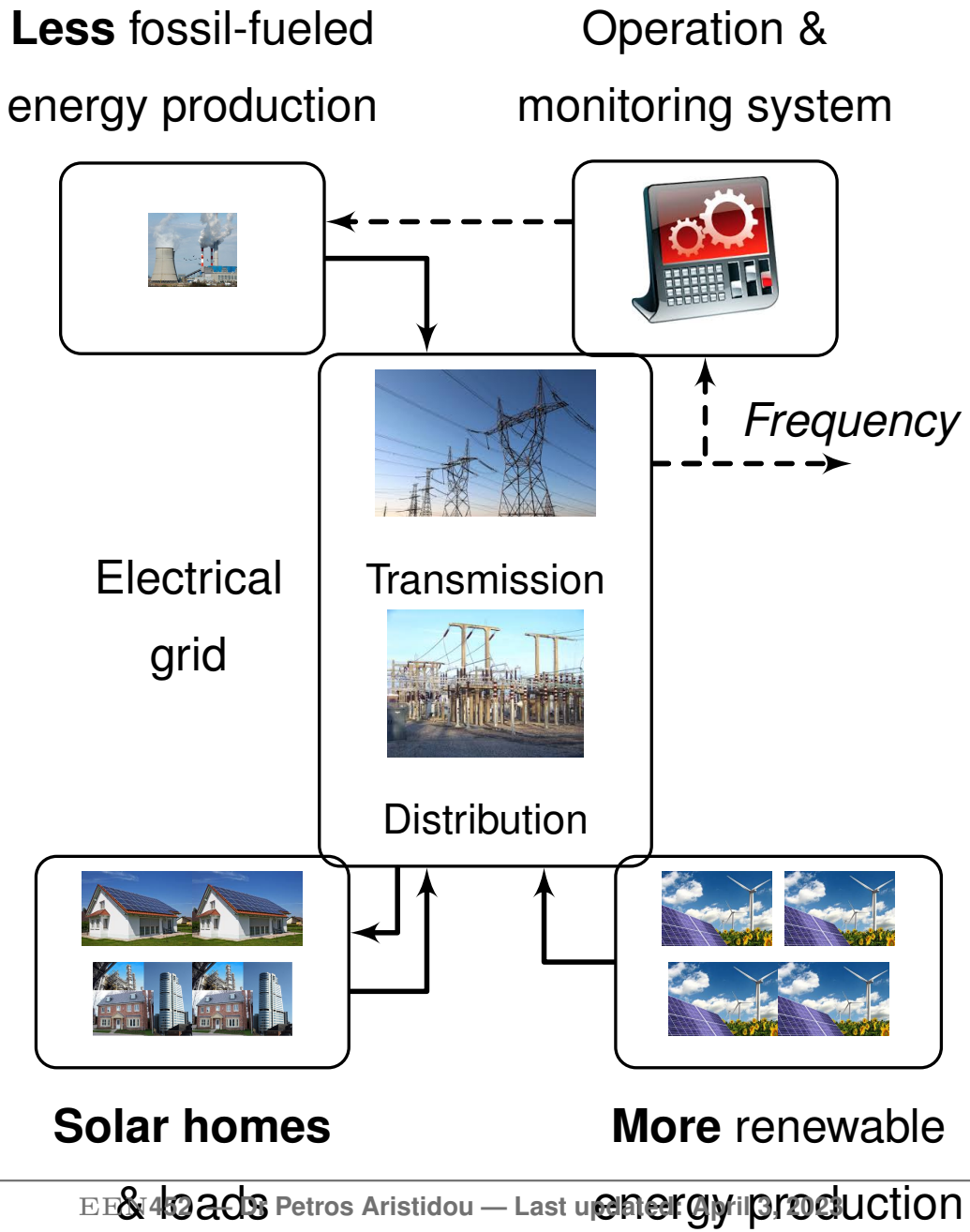


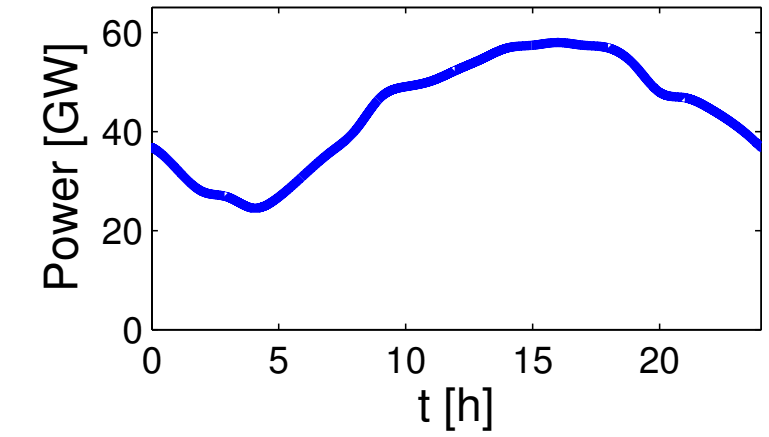
Renewable energies:

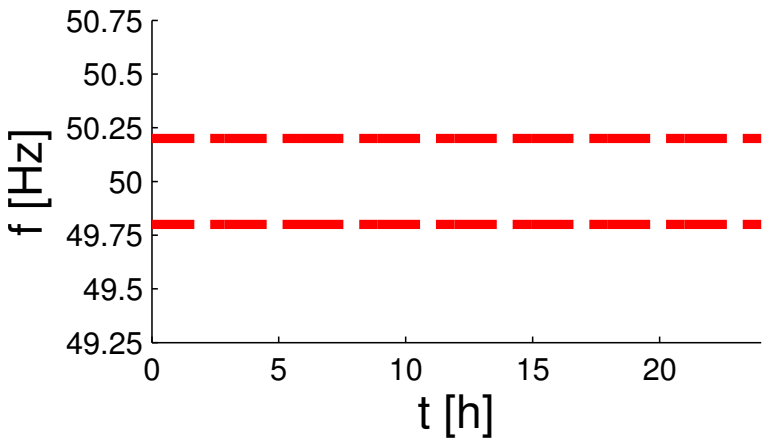
- Depend on natural circumstances, e.g., wind and sun
- Availability is uncertain & not plannable
- Fluctuating energy production

$\Rightarrow$ Renewable energy NOT available on demand

3 The electrical energy system: future







Load
Fossil production
Grid frequency
Renewable production

4 Outline

Demand must follow production
(to certain extent)

⇒ Energy system needs to become more flexible & intelligent

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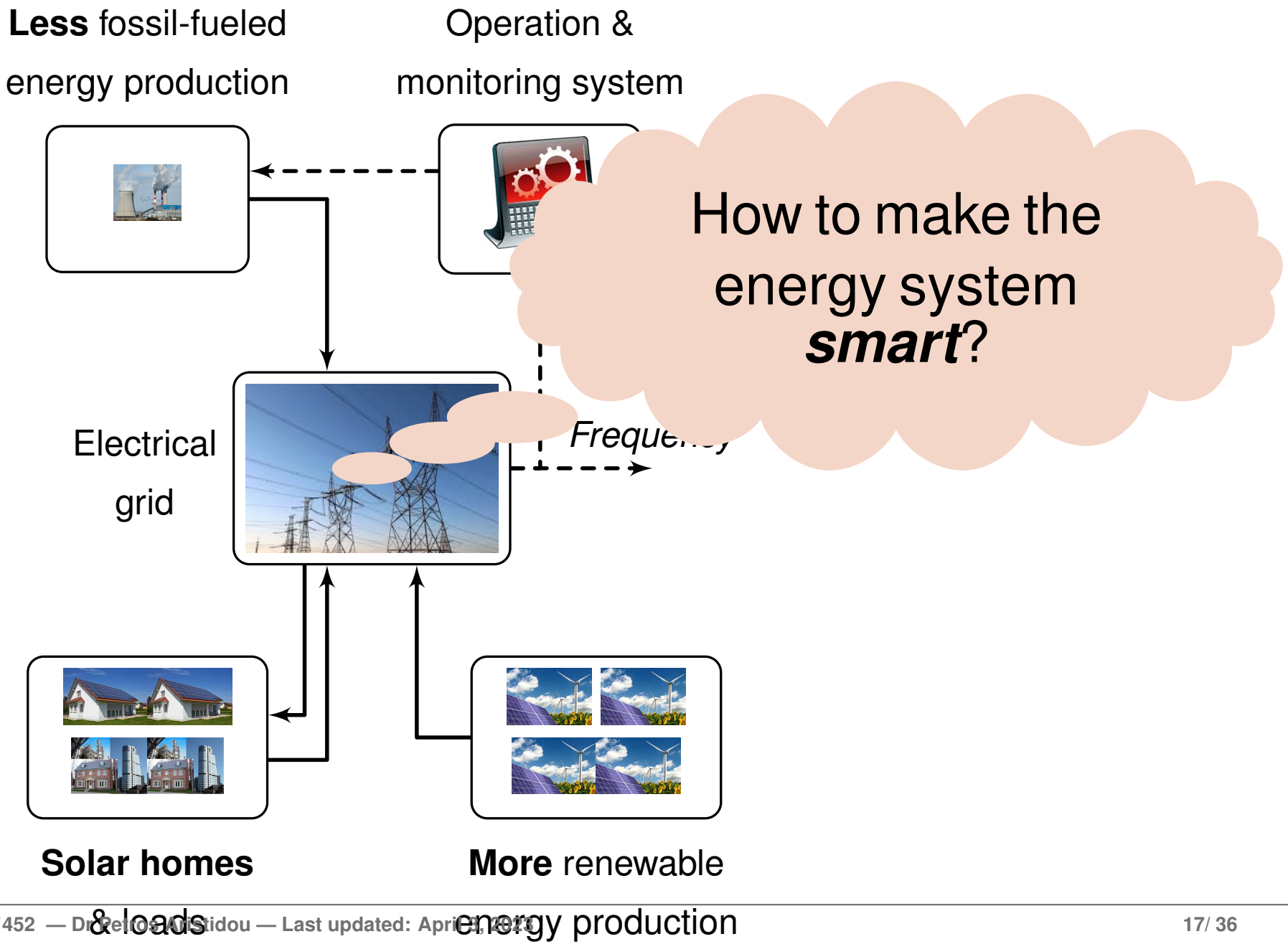
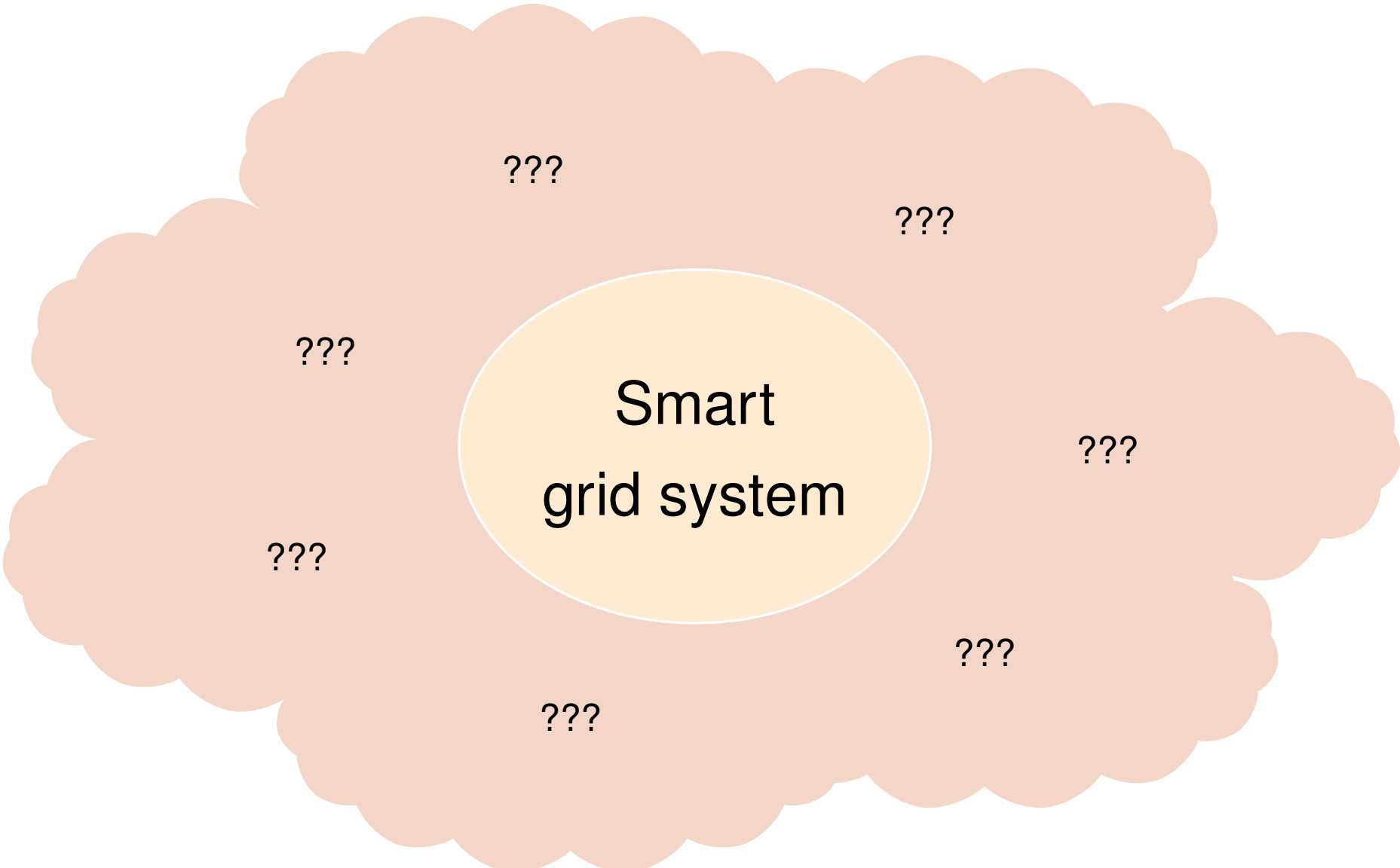
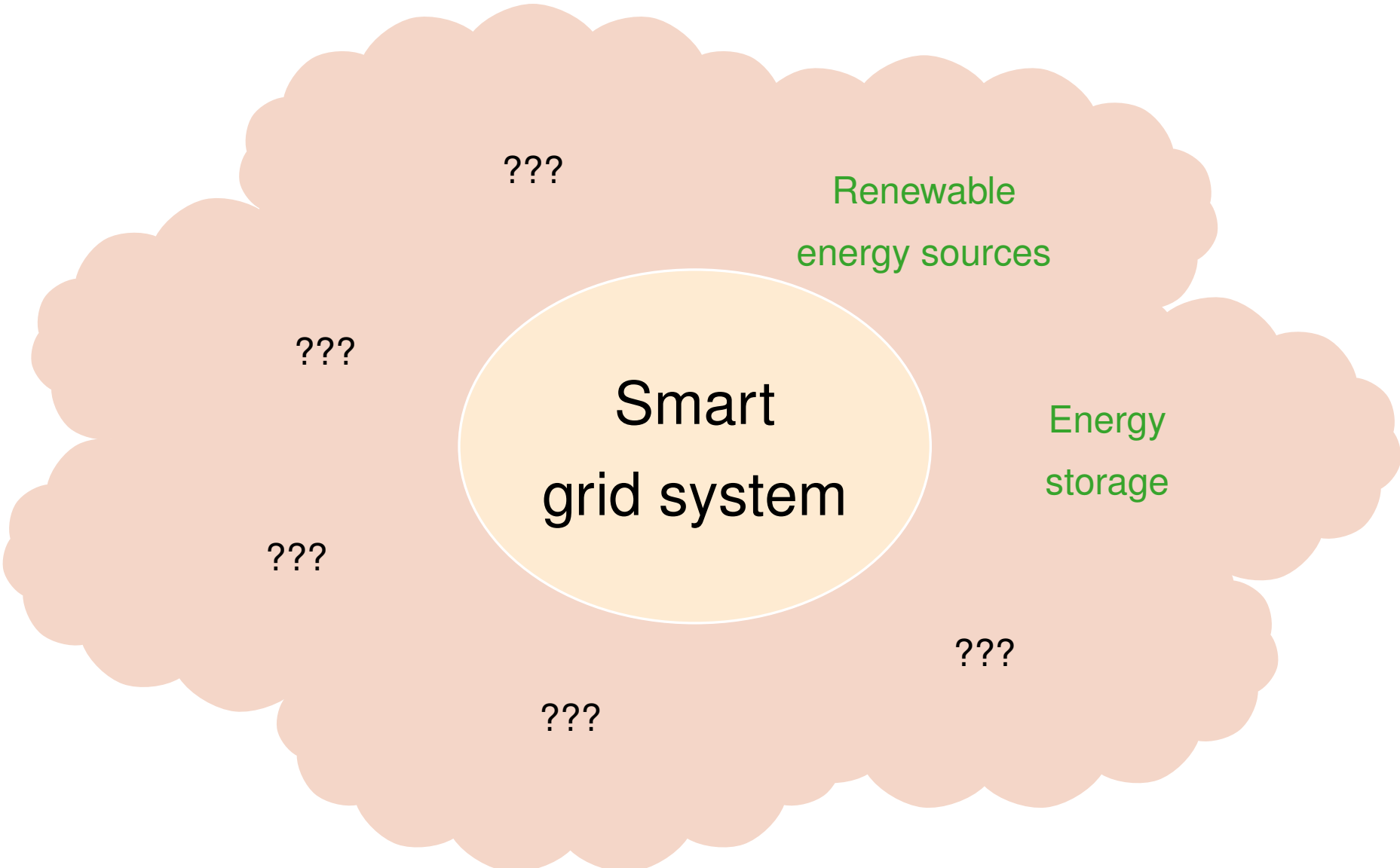


4 What are the key smart grid system (SGS) ingredients?



4 Key SGS ingredients - I. Renewable energies & storage



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Renewable energy sources needed for sustainable energy supply

- Improve technologies (offshore wind, marine,. . .)
- Improve forecasts for weather-dependent stochastic generation
- Actively integrate renewables into grid control & operation

4 Key SGS ingredients - I. Renewable energies & storage

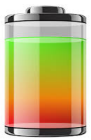
Renewable energy sources needed for sustainable energy supply

- Improve technologies (offshore wind, marine,. . .)
- Improve forecasts for weather-dependent stochastic generation
- Actively integrate renewables into grid control & operation

Energy storage needed to balance fluctuating renewables

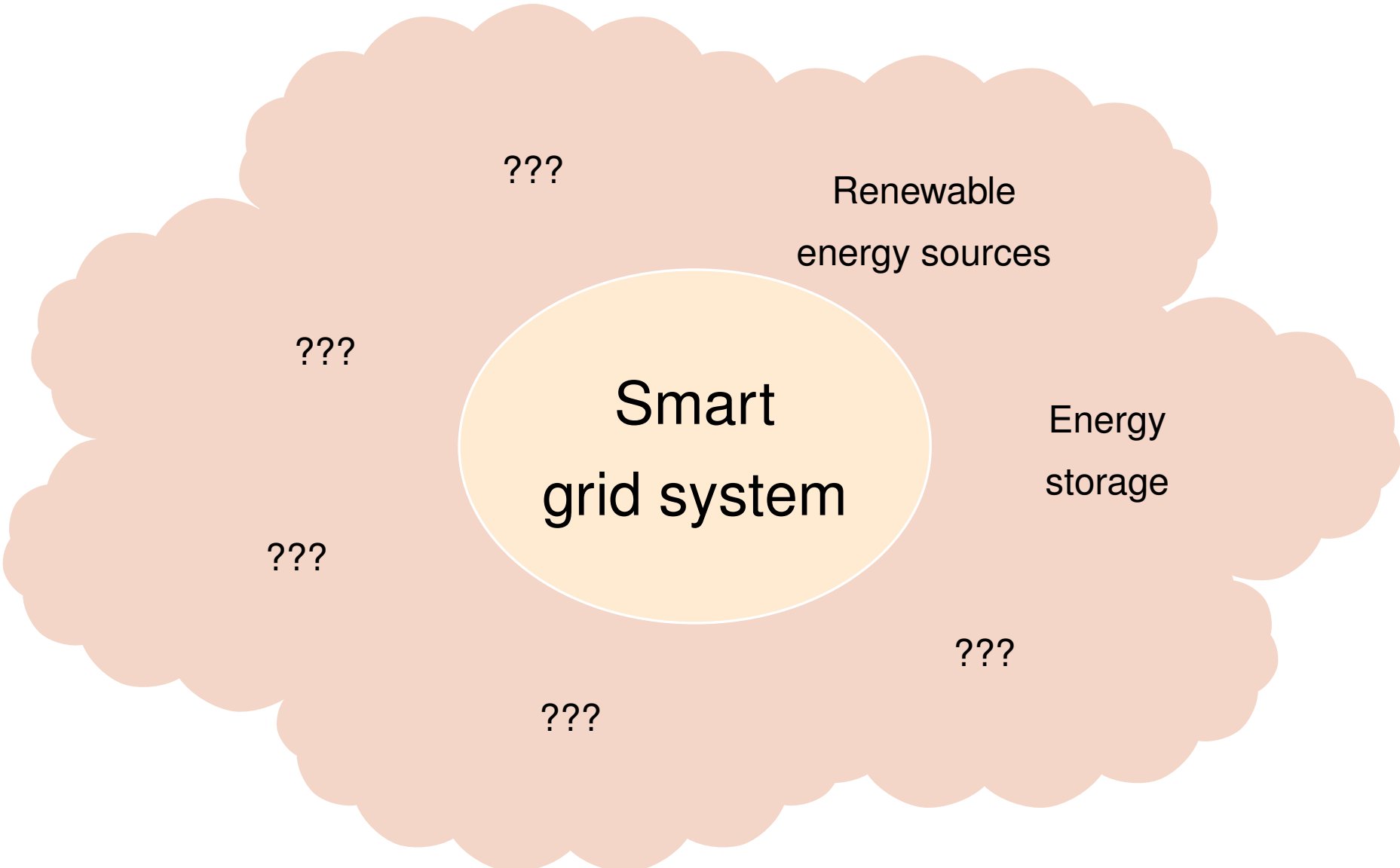
Pumped storage hydroelectricity

Battery technologies

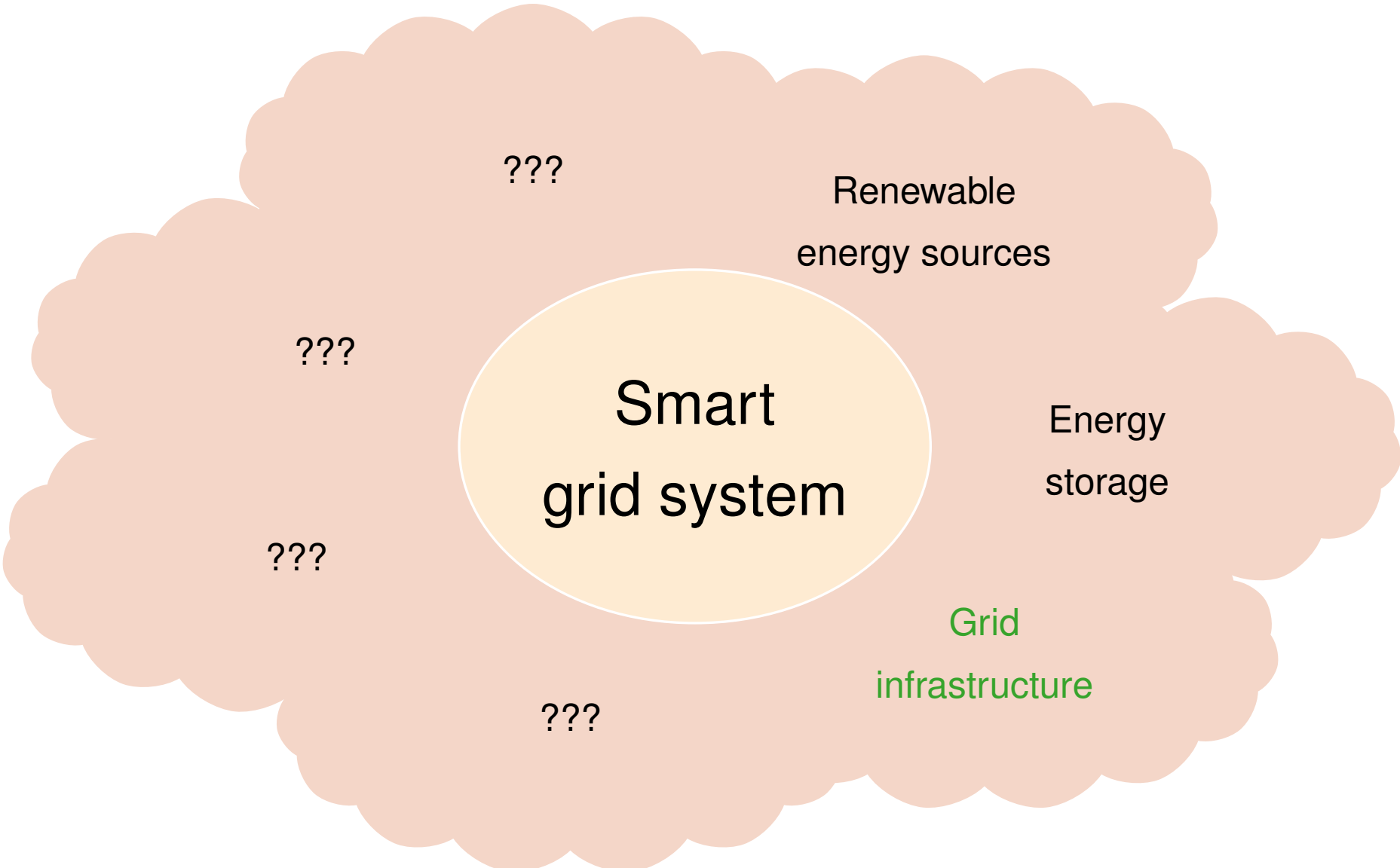


Flywheel

4 Key SGS ingredients



4 Key SGS ingredients - II. Grid infrastructure



4 Key SGS ingredients - II. Grid infrastructure

- Increasing amount of generation in distribution grids

$\Rightarrow$ Bidirectional power flow

Need to **expand and improve electric grid infrastructure**

- Measure status of distribution grids
- Power electronics (e.g., FACTS)
- High voltage direct current (HVDC) links

4 Key SGS ingredients - II. Grid infrastructure

- Increasing amount of generation in distribution grids

⇒ Bidirectional power flow

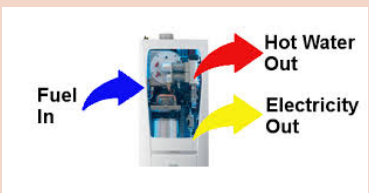
Need to **expand and improve electric grid infrastructure**

- Measure status of distribution grids
- Power electronics (e.g., FACTS)
- High voltage direct current (HVDC) links

Merge electric, heat and transport systems to exploit synergies and increase efficiency

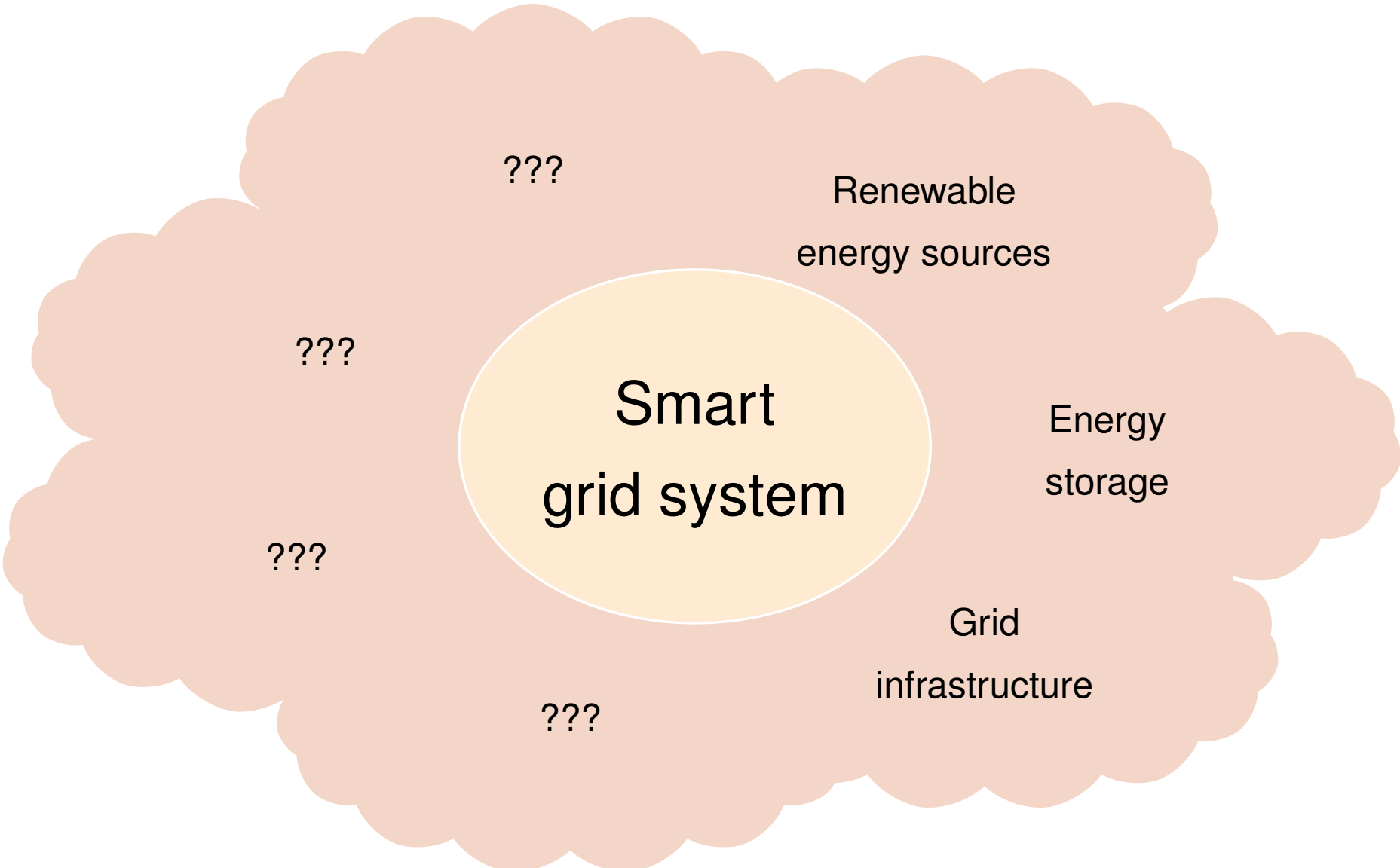
Power-2-gas

Combined heat & power (CHP) plants

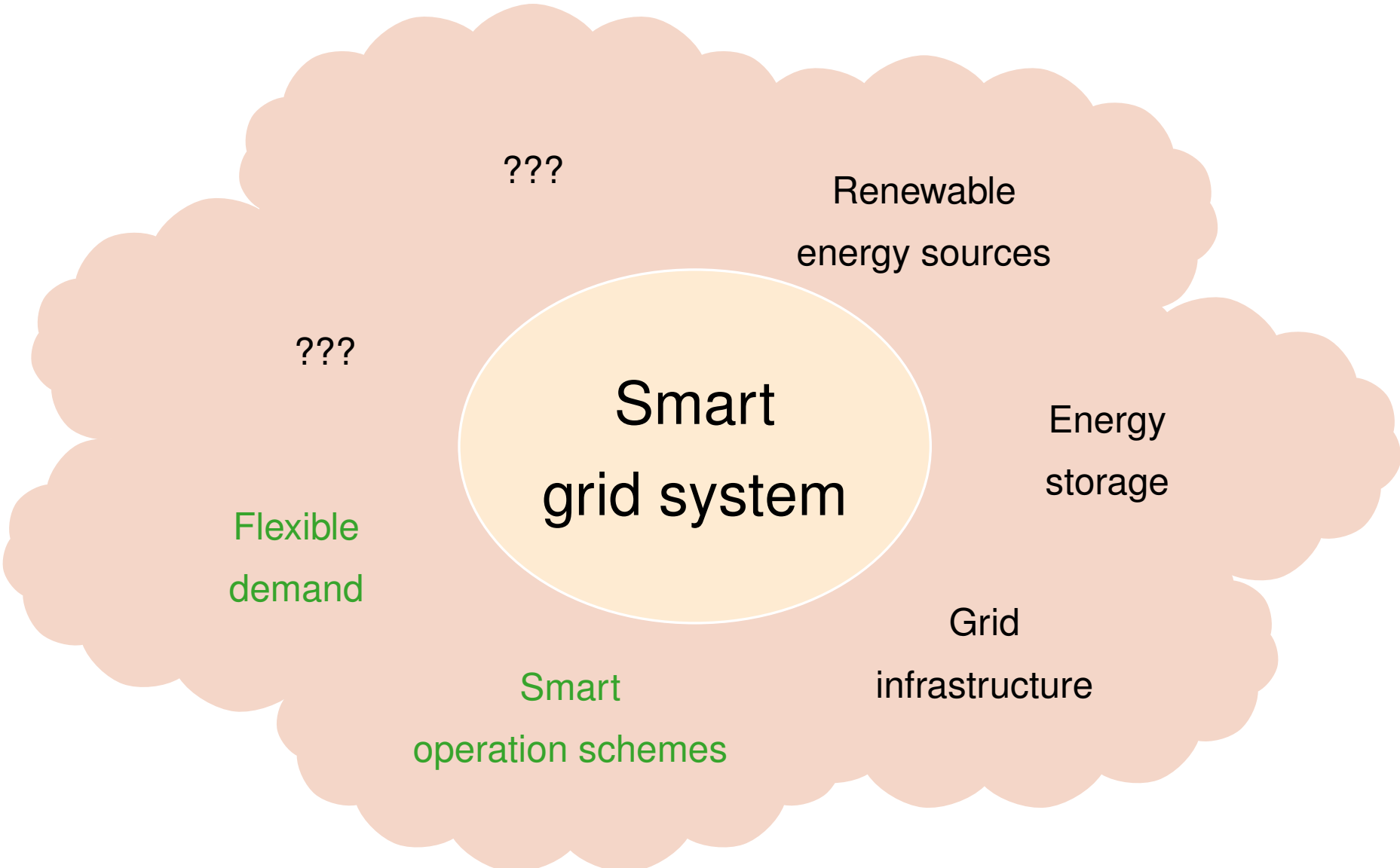


Vehicle-2-grid

4 Key SGS ingredients



4 Key SGS ingredients - III. Smart operation & flexible loads



4 Key SGS ingredients - III. Smart operation & flexible loads

Future operation schemes based on **multi-agent approaches**

Examples for agents in SGS

Energy producers

Energy retailers

End-users

4 Key SGS ingredients - III. Smart operation & flexible loads

Future operation schemes based on **multi-agent approaches**

Examples for agents in SGS

Energy producers

Energy retailers

End-users

Individual agents

Flexible loads

- Demand-side management
- Smart meters & smart homes

4 Key SGS ingredients - III. Smart operation & flexible loads

Future operation schemes based on **multi-agent approaches**

Examples for agents in SGS

Energy producers

Energy retailers

End-users

Groups of agents

Individual agents

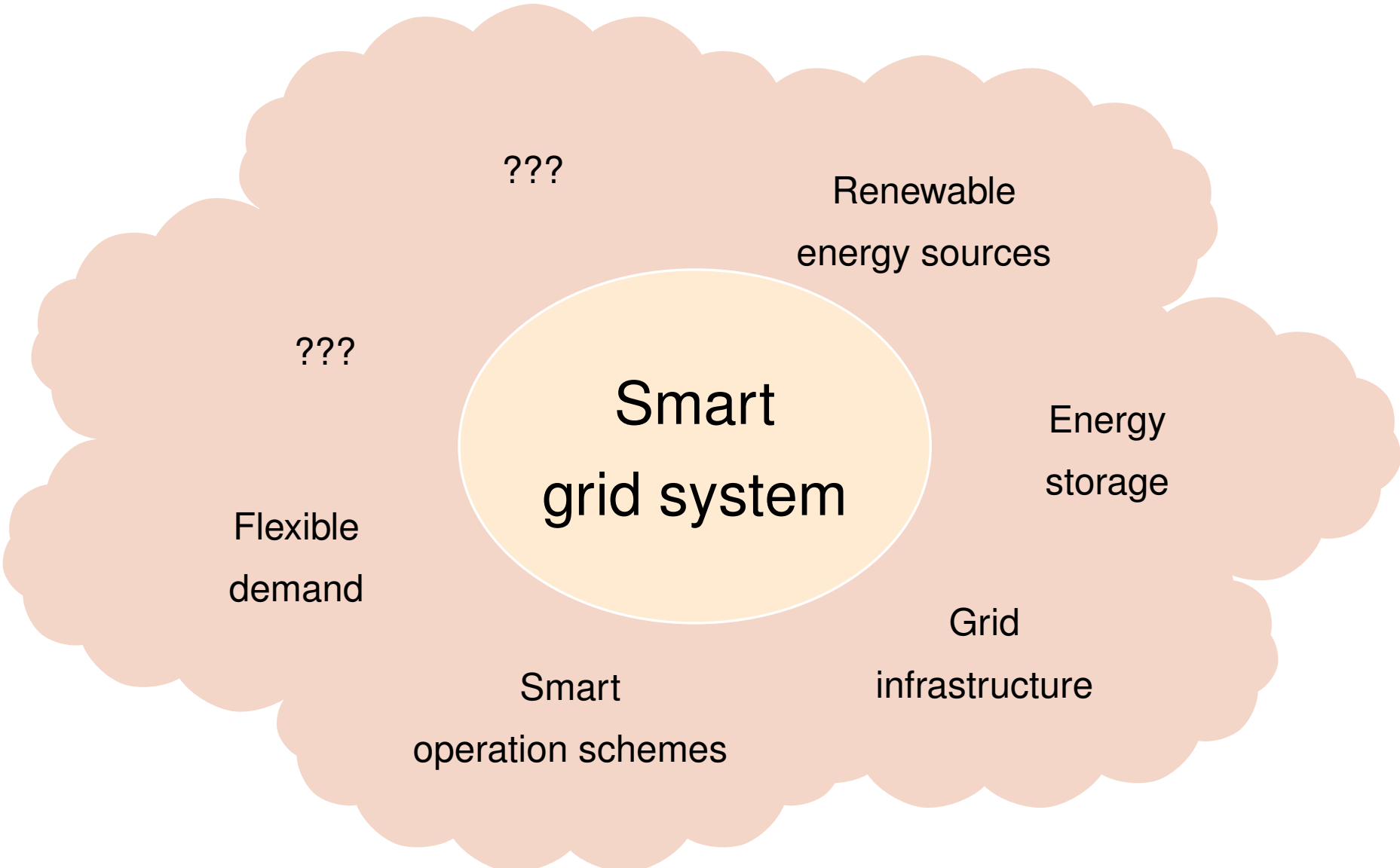
Smart operation schemes

- Virtual power plants
- Microgrids

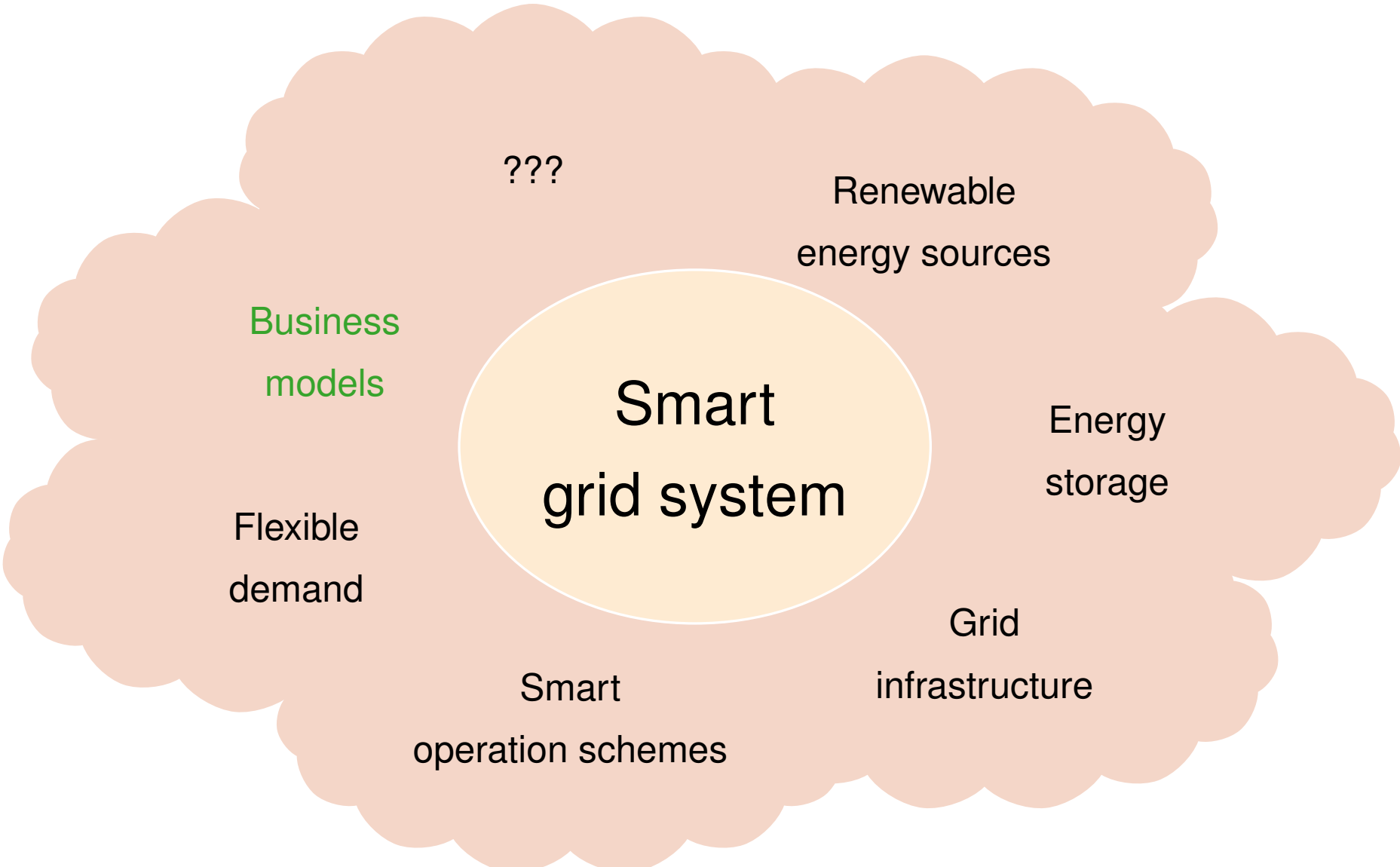
Flexible loads

- Demand-side management
- Smart meters & smart homes

4 Key SGS ingredients



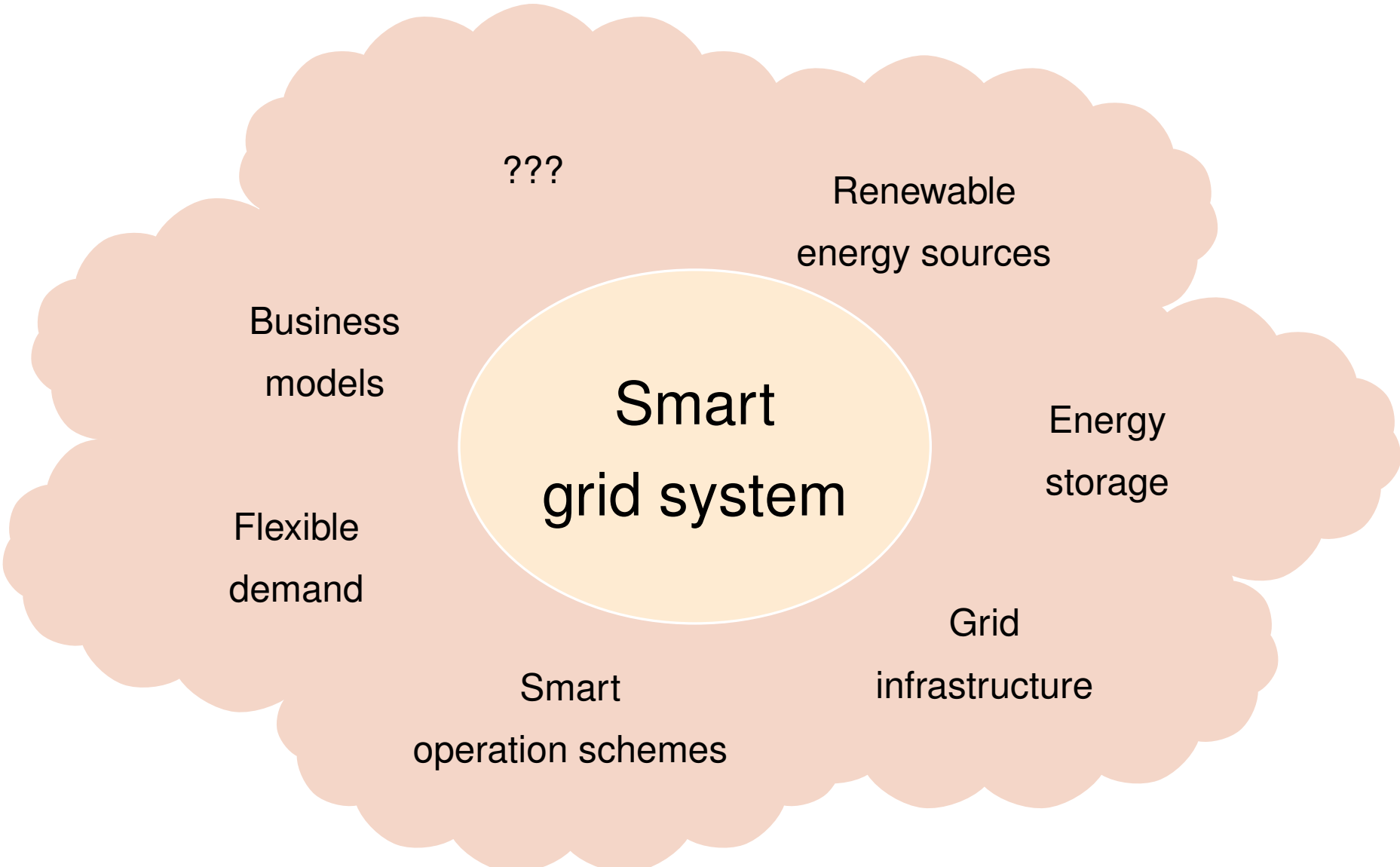
4 Key SGS ingredients - IV. Business models



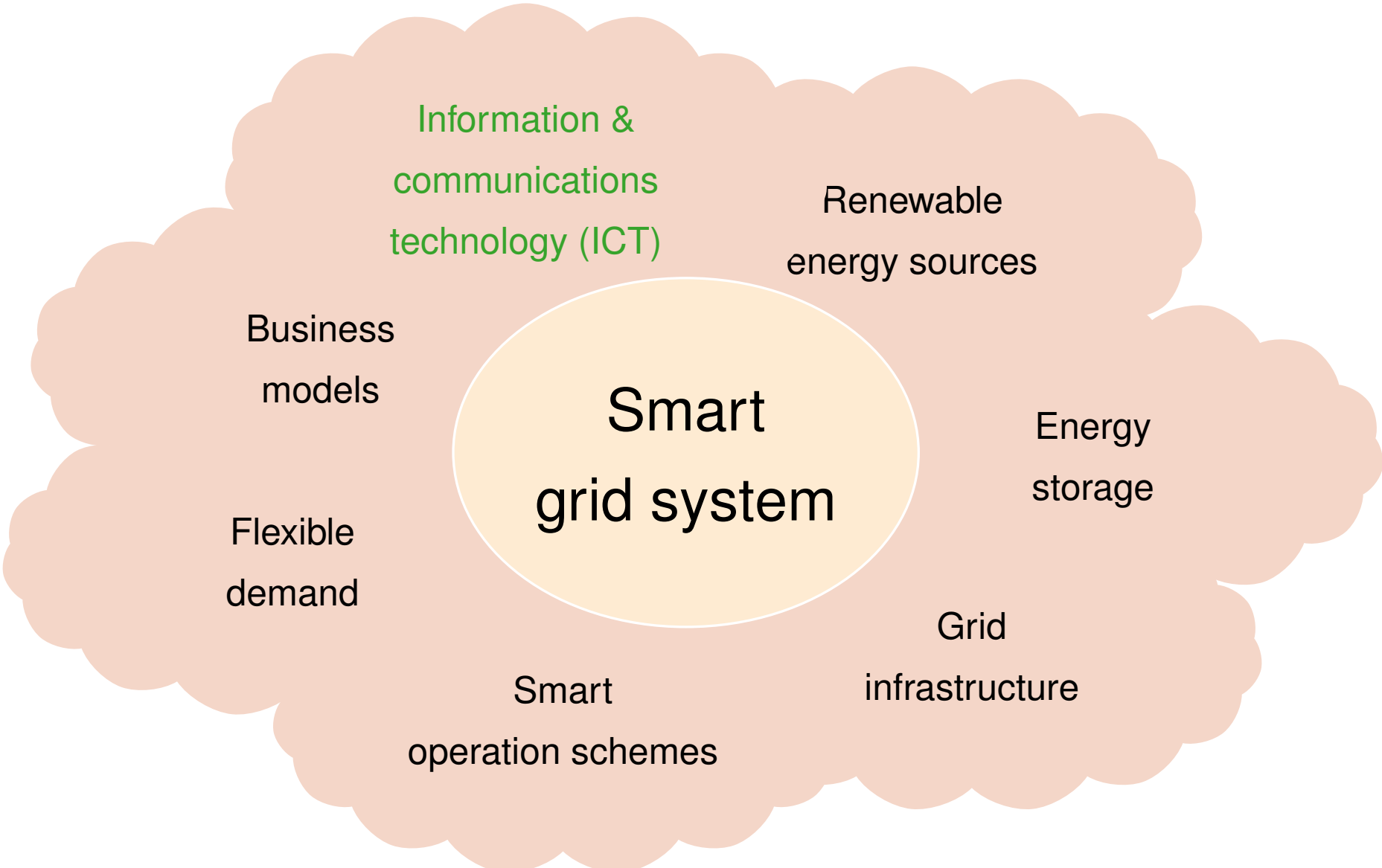
4 Key SGS ingredients - IV. Business models

- Business models are key to support. . .
  - . . . investments in new generation and infrastructure
  - . . . changes to consumer behaviour and social acceptance
- Motivate end-users to become prosumers
  - Receive clear benefits (e.g., savings)
  - Variable tariffs
  - More transparent billing
  - Business cases for electric vehicles and smart appliances
- Feasible business models also depend on political framework and regulations

4 Key SGS ingredients



4 Key SGS ingredients - V. ICT

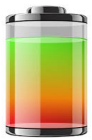


4 Key SGS ingredients - V. ICT

Production

Markets

Storage

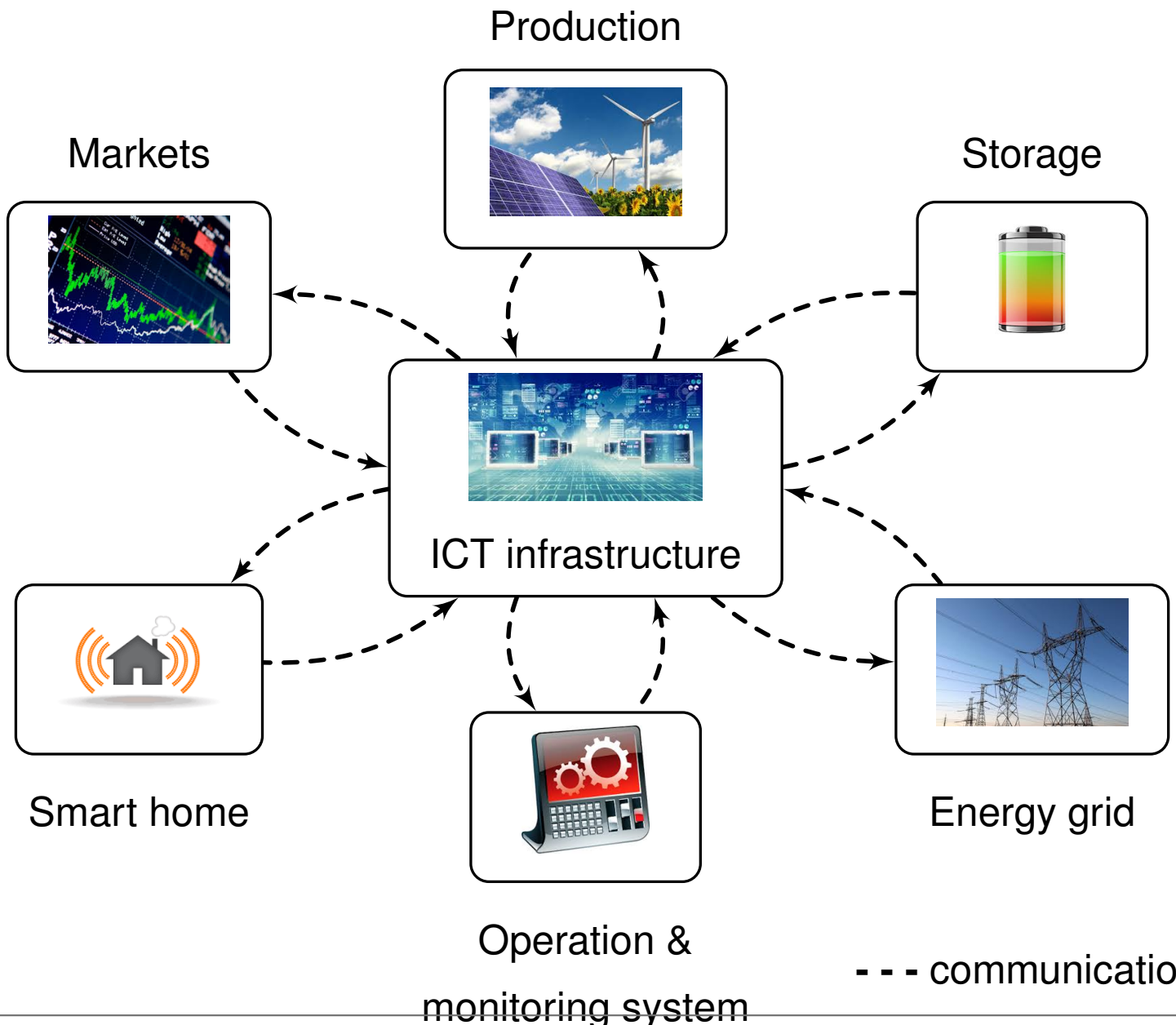


Smart home

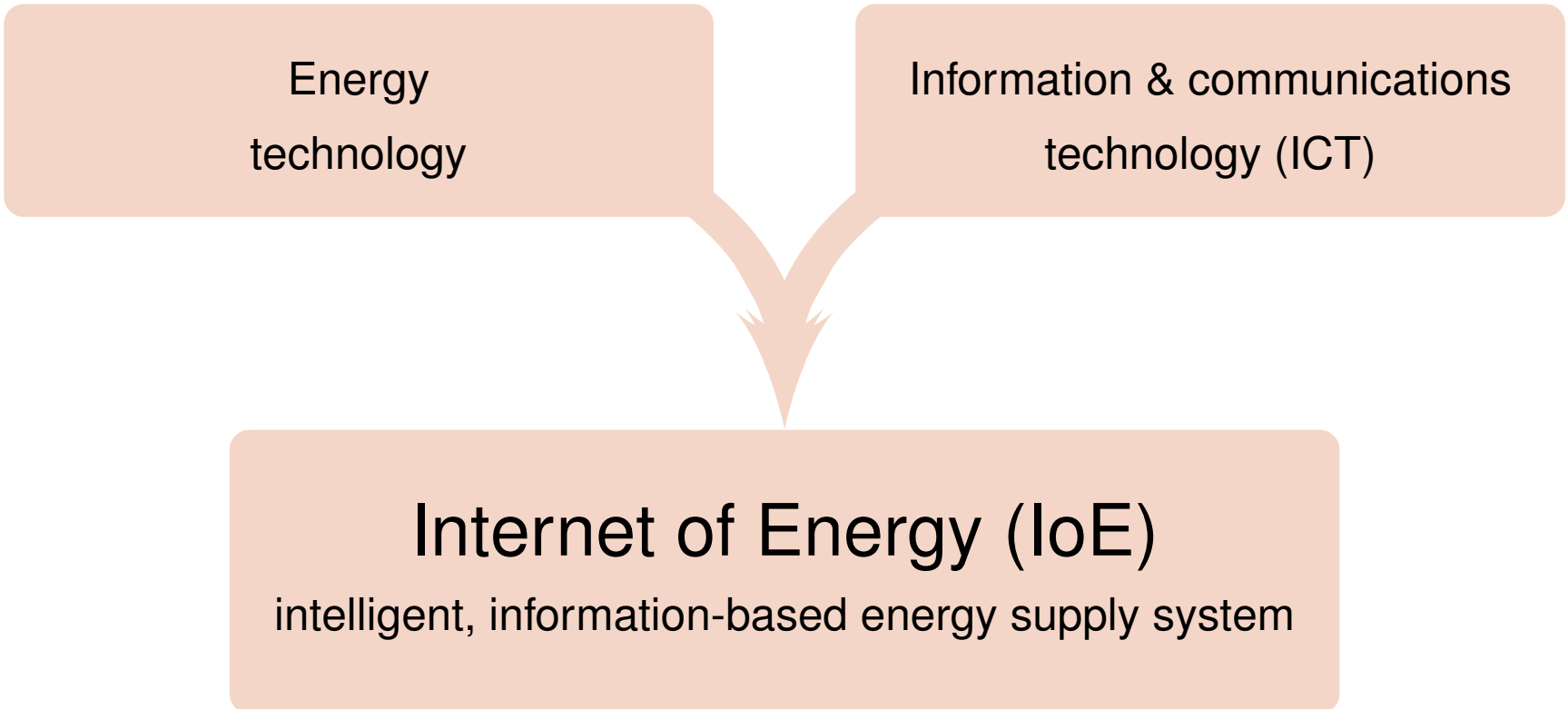
Operation & monitoring system

Energy grid

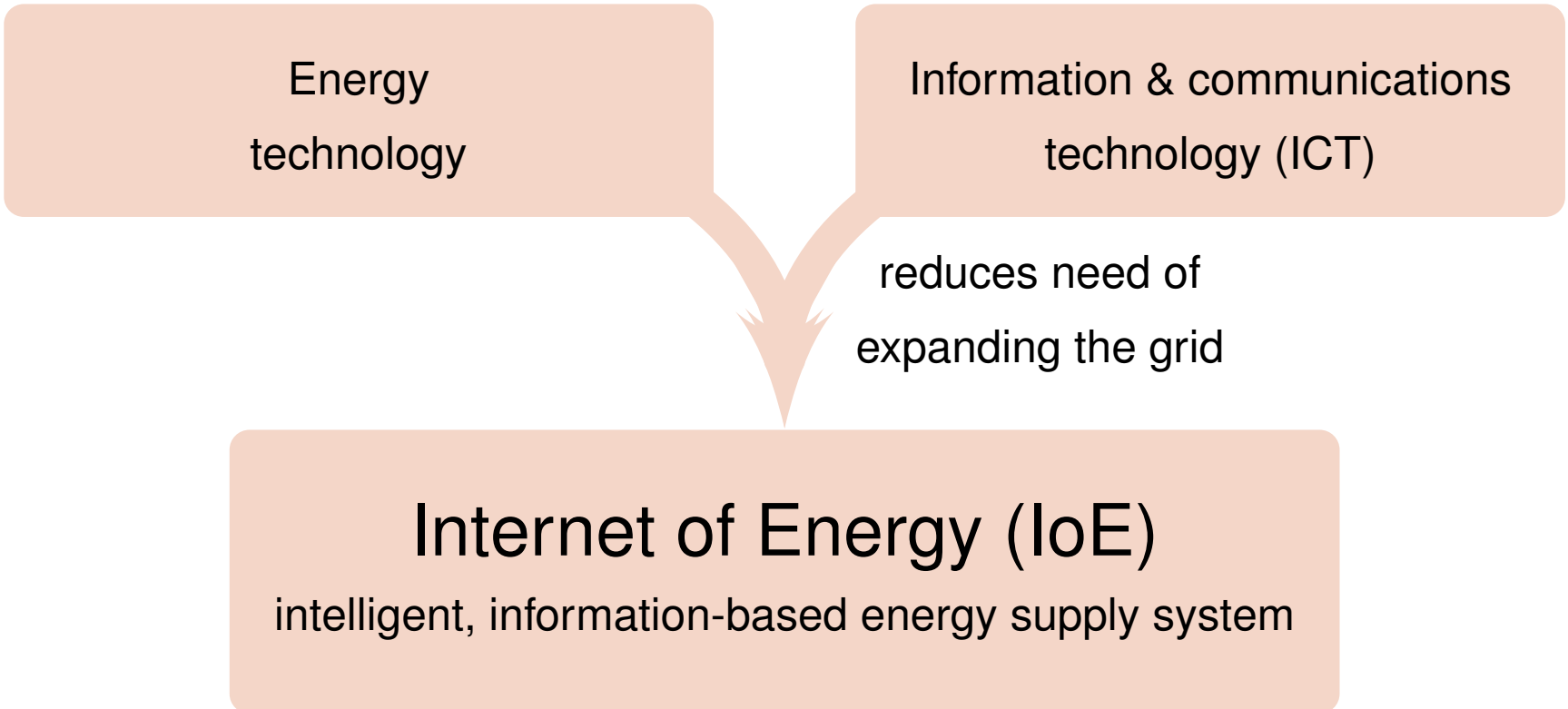
4 Key SGS ingredients - V. ICT



4 Key SGS ingredients - V. ICT (ctd.)



4 Key SGS ingredients - V. ICT (ctd.)



4 Key SGS ingredients - V. ICT (ctd.)

Energy technology

Information & communications technology (ICT)

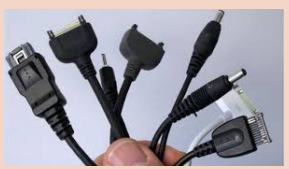
reduces need of expanding the grid

Internet of Energy (IoE)

intelligent, information-based energy supply system

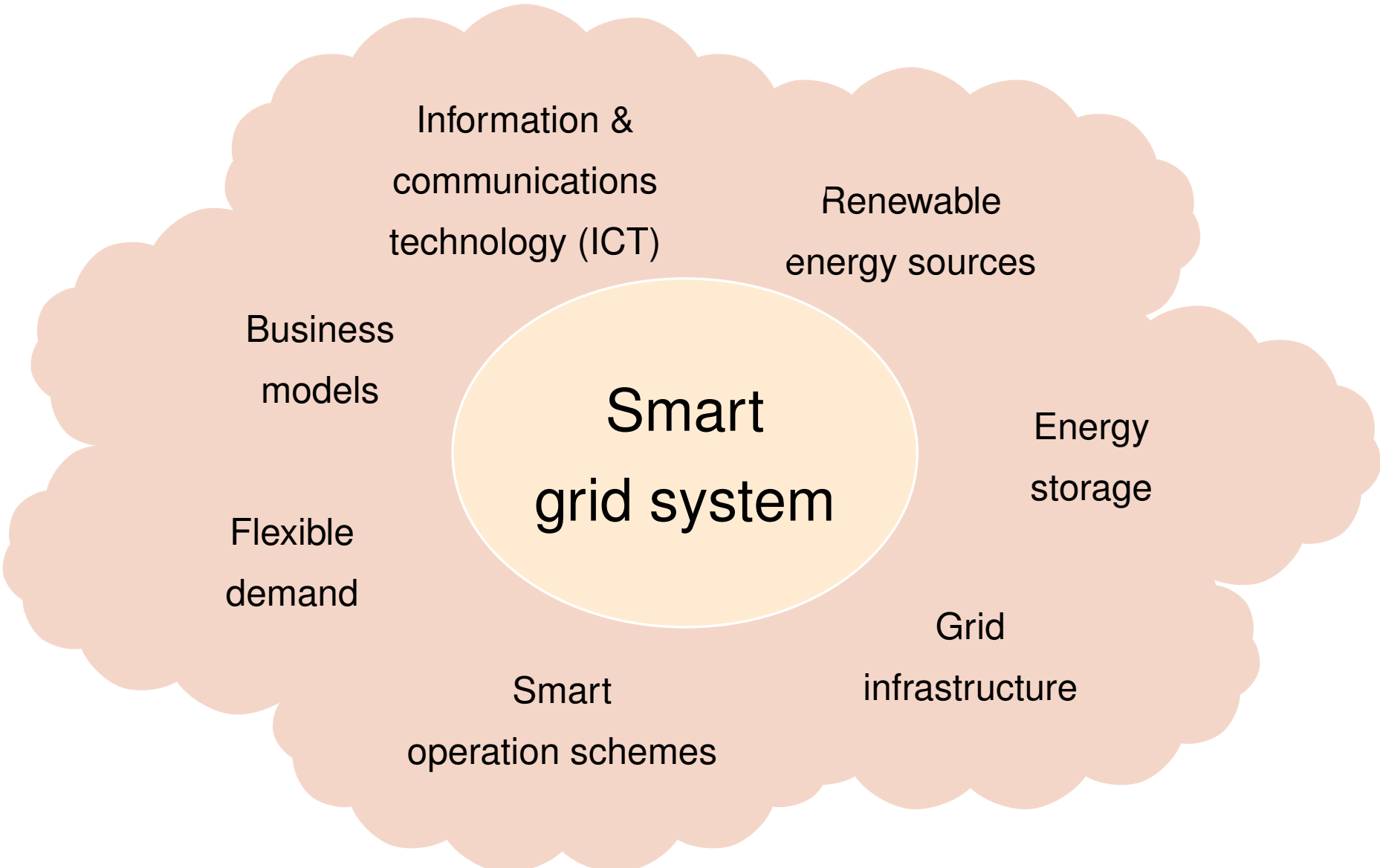
Data management

Standardisation



Data security

4 Key smart energy system (SGS) ingredients



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The smart grid system paradigm

"Demand follows production"

- Key ingredients: ICT, renewables, flexible operation & consumption

⇒ Internet of Energy (IoE)

- Many challenging open questions
- Large investments (EU-wide £500 billion by around 2020)

⇒ Plenty of exciting & interdisciplinary opportunities

4 Further reading

- Hassan Farhangi. ”The path of the smart grid.” IEEE Power and Energy Magazine, 8.1 (2010): 18-28.
- Hans-Jürgen Appelrath, Henning Kagermann, and Christoph Mayer (Eds.) ”Future energy grid. Migration to the Internet of Energy.” acatech STUDY, 2012 www.eitictlabs.eu/fileadmin/studies/Joint_EIT-ICT-Labs_acatech_Study_Future-Energy-Grid.pdf
- http://www.energyplan.eu/smartenergysystems/
- http://www.nist.gov/smartgrid/