

## EEN320 - Power Systems I (Συστήματα Ισχύος I)

Part 8: Current and future trends in power system operation - the path to the smart grid

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Last updated: April 6, 2020

## Today's learning objectives

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:

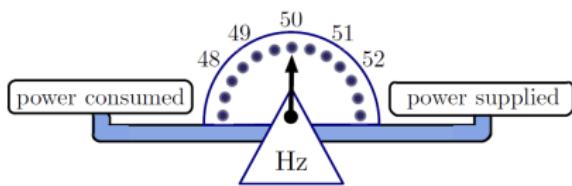
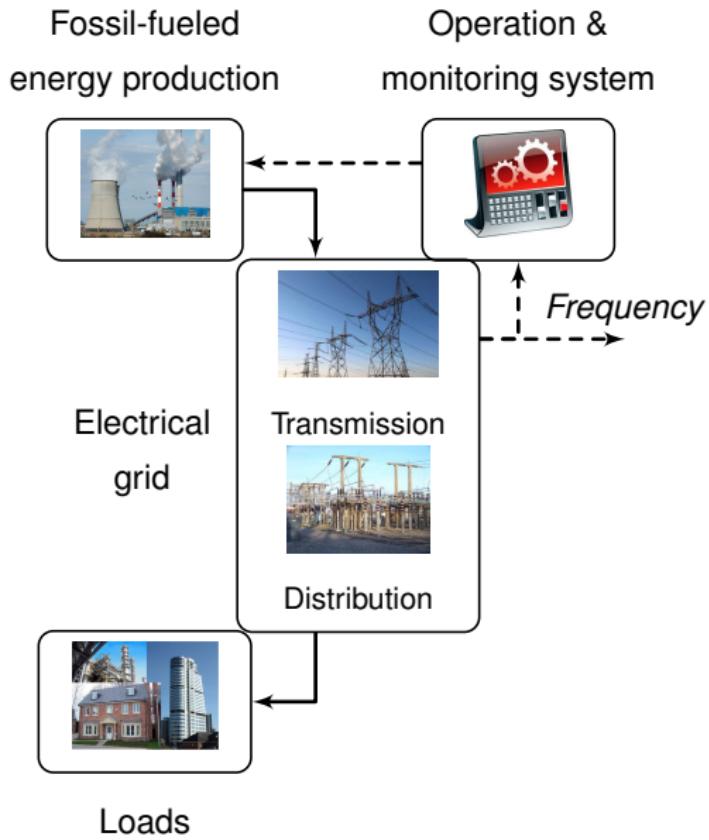
Do you spend any time thinking about  
when to use energy?

Of course, not!

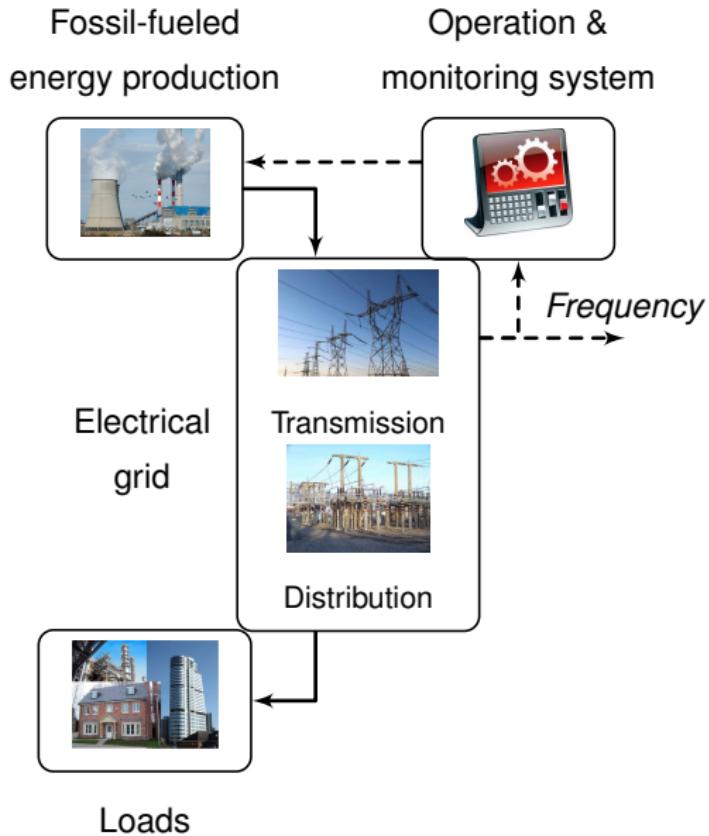
# 1 Outline

- 1 The electrical energy system: past & present (review)
- 2 The uprise of renewable energy
- 3 The path of the electrical energy system
- 4 The smart grid system paradigm

## 1 The electrical energy system: review of traditional setup



# 1 The electrical energy system: review of traditional setup

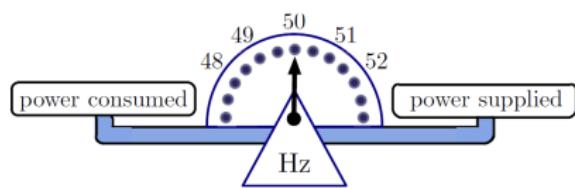
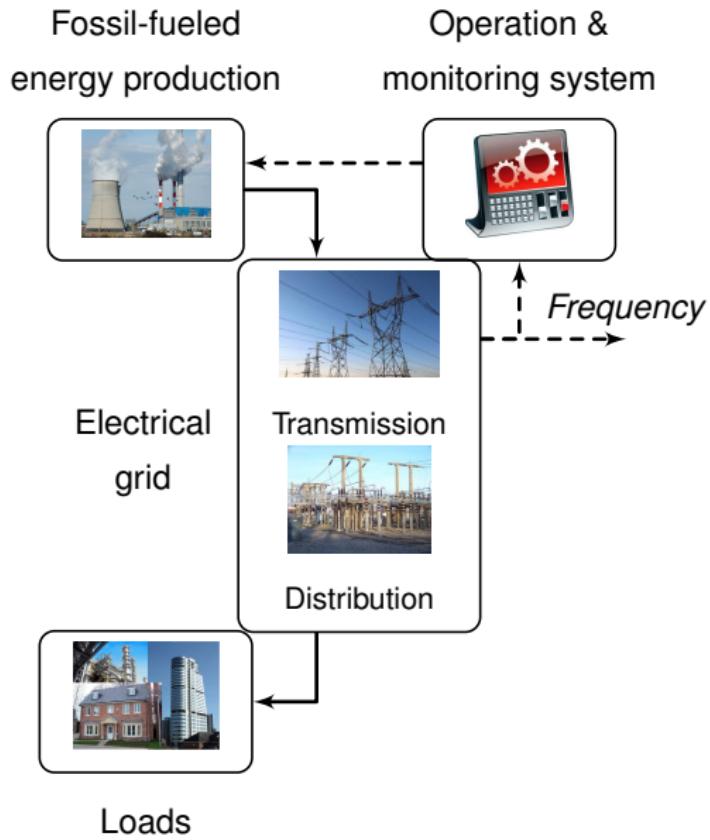


**Advantage of fossil fuels:**

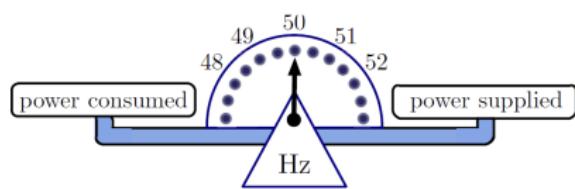
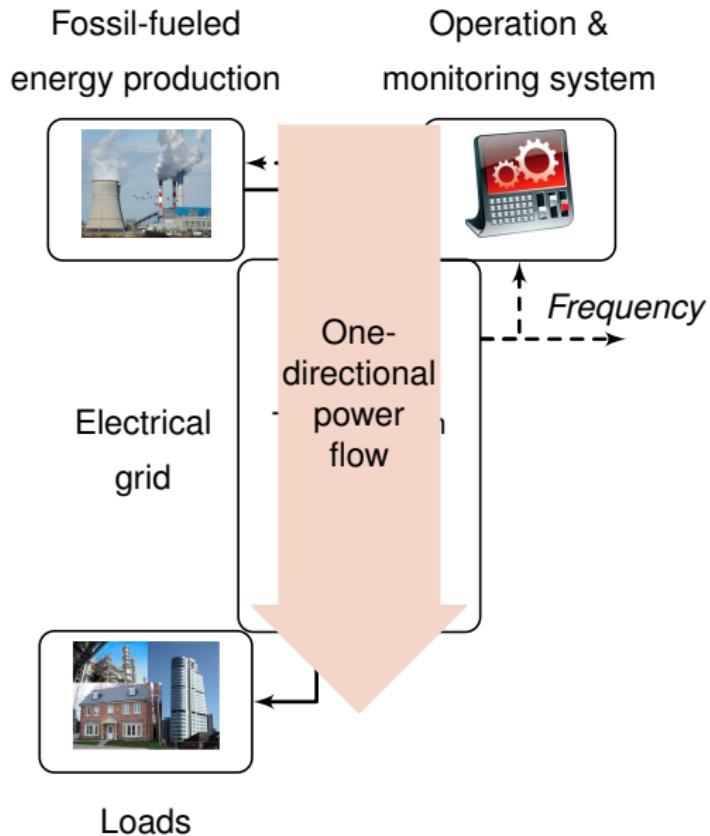
available on demand whenever required

Production follows demand

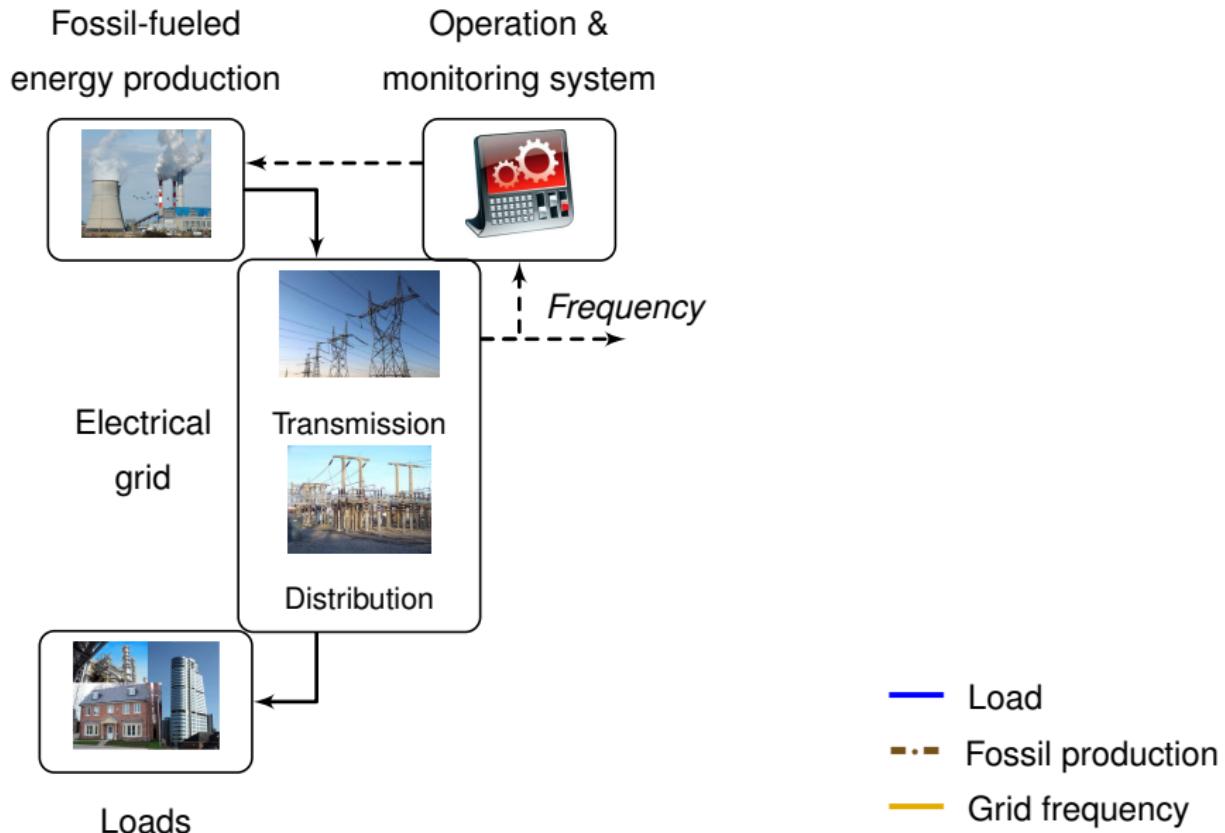
## 1 The electrical energy system: production follows demand



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## 1 The electrical energy system: production follows demand



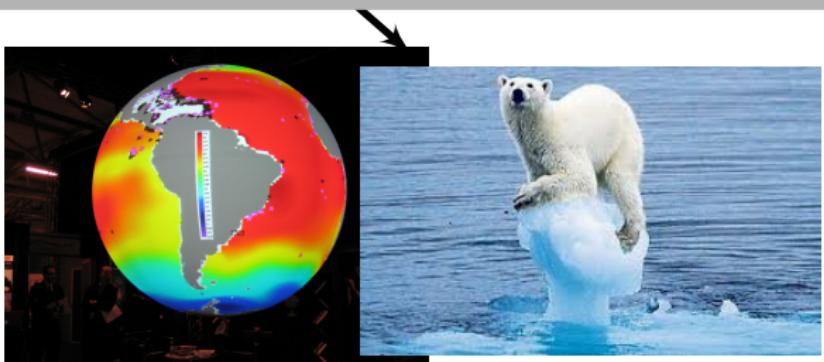
## 2 Outline

- 1 The electrical energy system: past & present (review)
- 2 **The uprise of renewable energy**
- 3 The path of the electrical energy system
- 4 The smart grid system paradigm

## 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!





Onshore wind

Solar power

Offshore wind

**Shift energy production  
from fossil to  
renewable energy sources!**



Marine power



Bioenergy

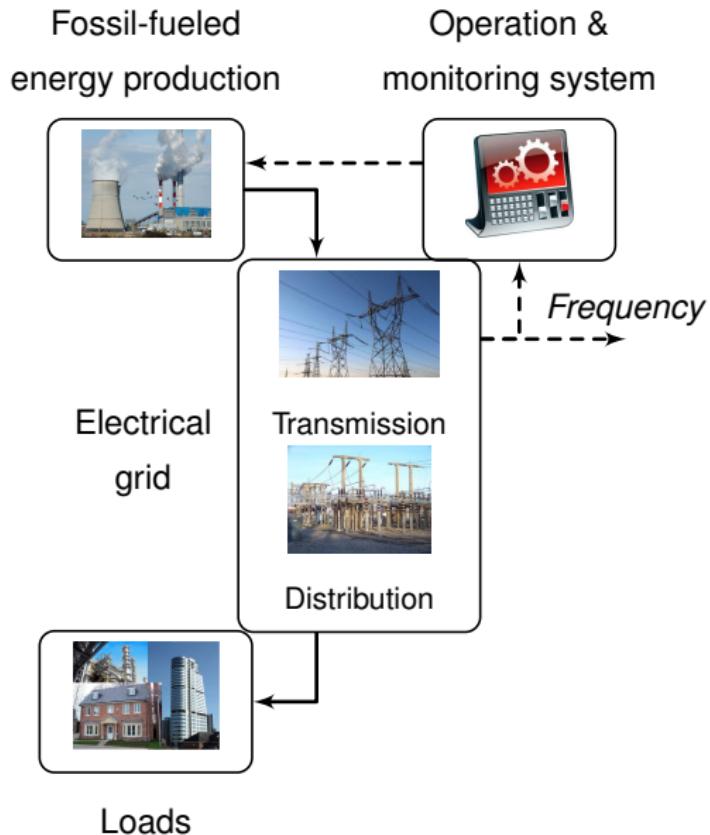


Small hydro  
power

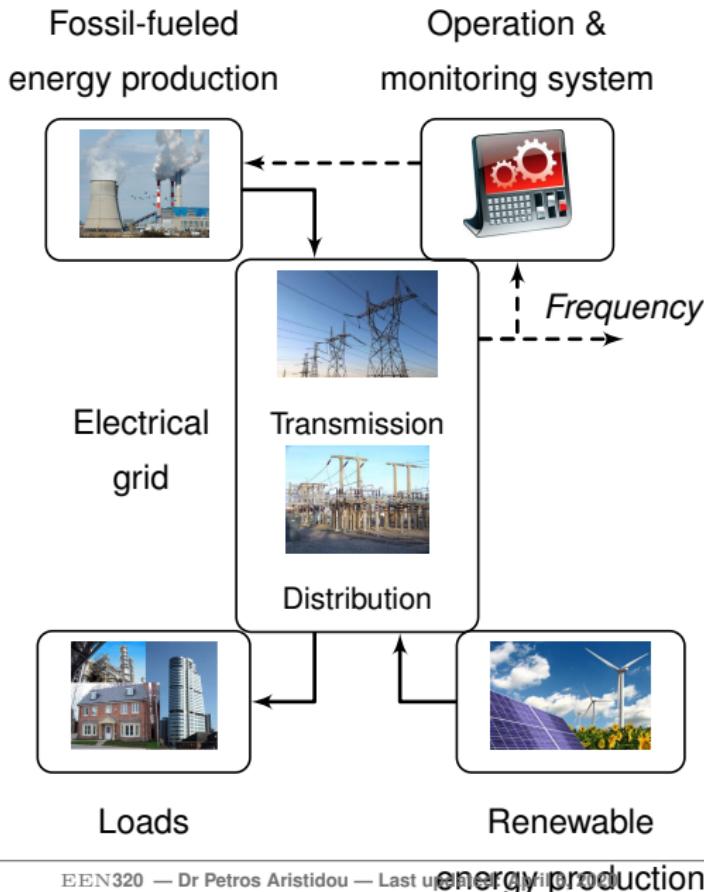
### 3 Outline

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- 2 The uprise of renewable energy
- 3 The path of the electrical energy system**
- 4 The smart grid system paradigm

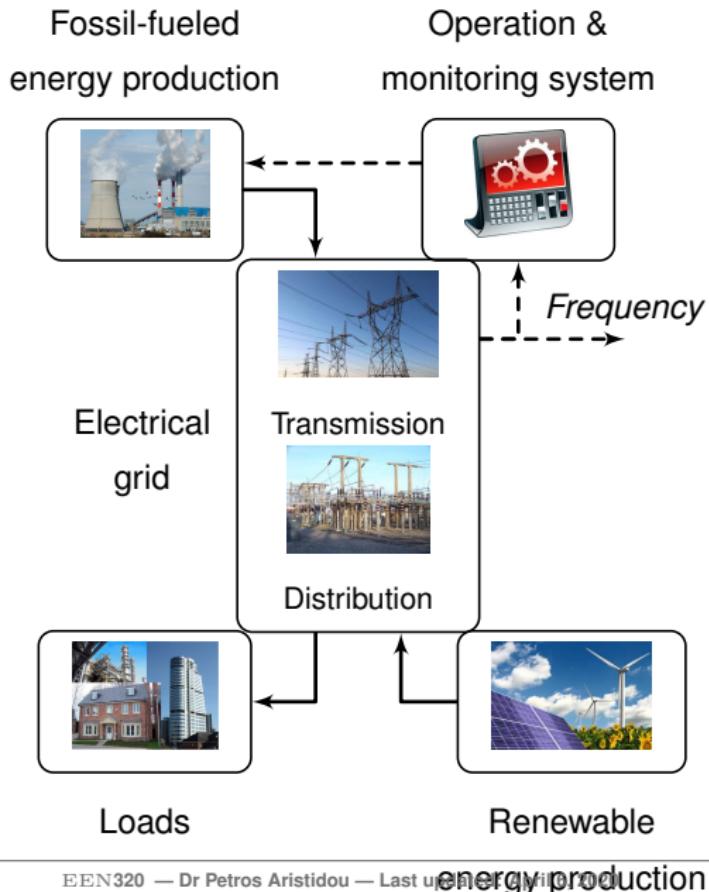
### 3 The electrical energy system: present



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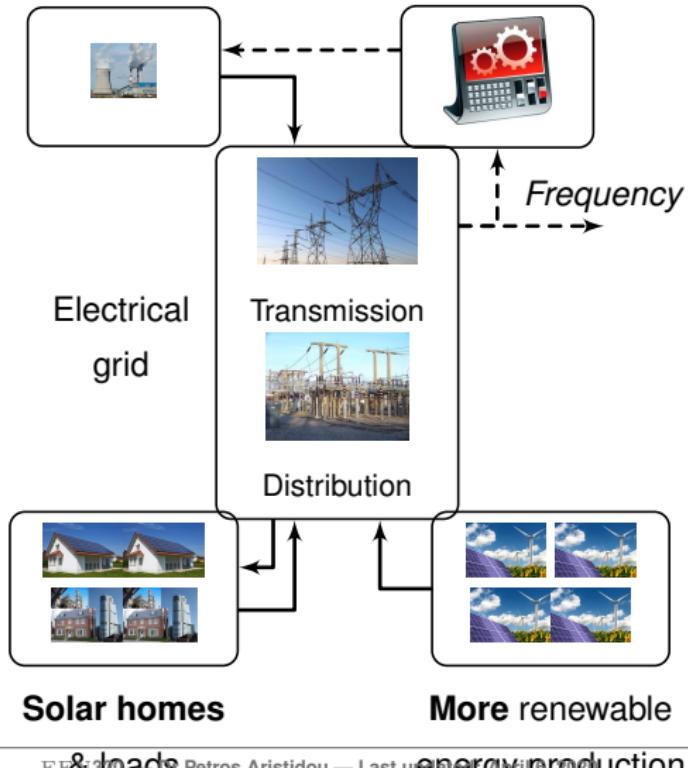


- Load
- - - Fossil production
- Grid frequency
- Renewable production

### 3 The electrical energy system: future

**Less** fossil-fueled  
energy production

Operation &  
monitoring system

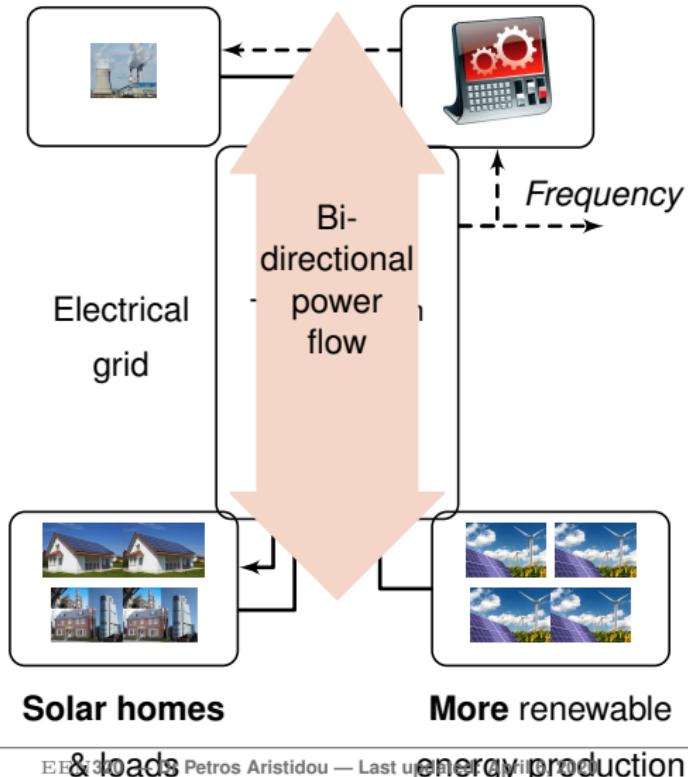


- Reduction of fossil-fueled power plants
- Increasing amount of renewable energy plants at distribution level
- Increasing amount of solar homes

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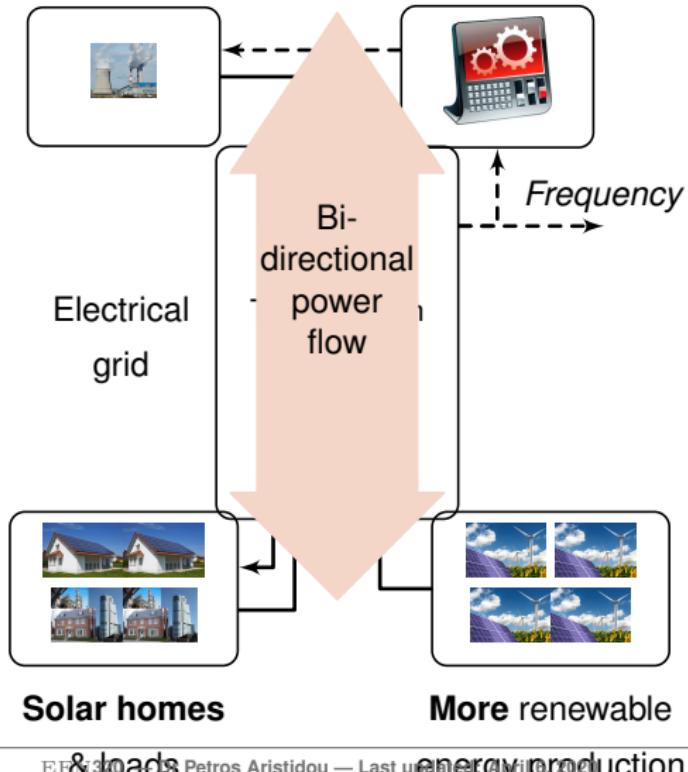


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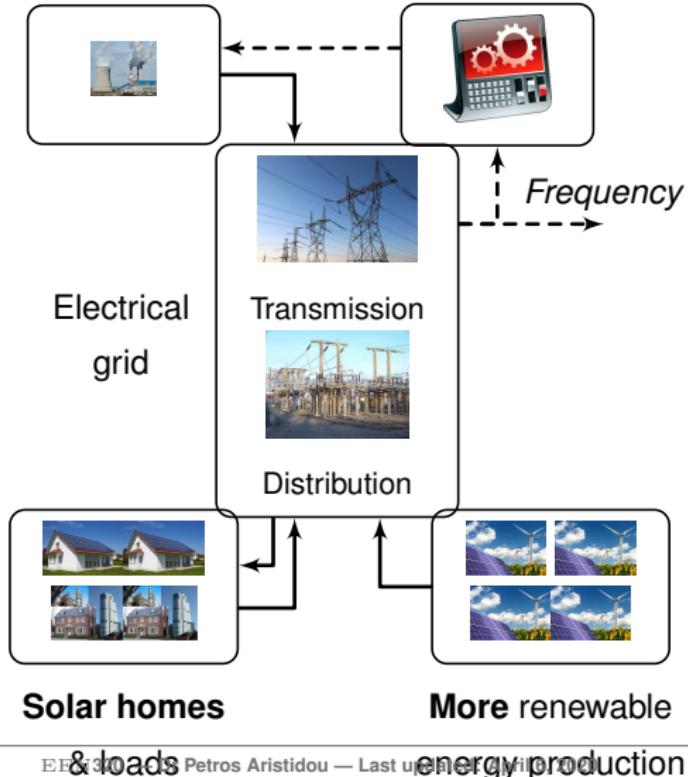
#### Renewable energies:

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

### 3 The electrical energy system: future

**Less** fossil-fueled  
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Operation &  
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- Load
- - - Fossil production
- Grid frequency
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## 4 Outline

- 1 The electrical energy system: past & present (review)
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- 3 The path of the electrical energy system
- 4 **The smart grid system paradigm**

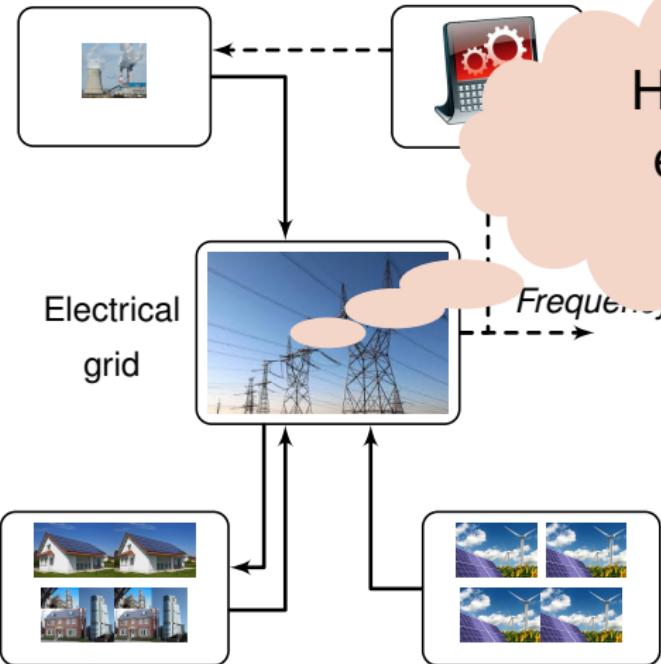
# Demand must follow production (to certain extent)

- ⇒ Energy system needs to become more flexible & intelligent

## 4 The path towards a smart grid system

Less fossil-fueled  
energy production

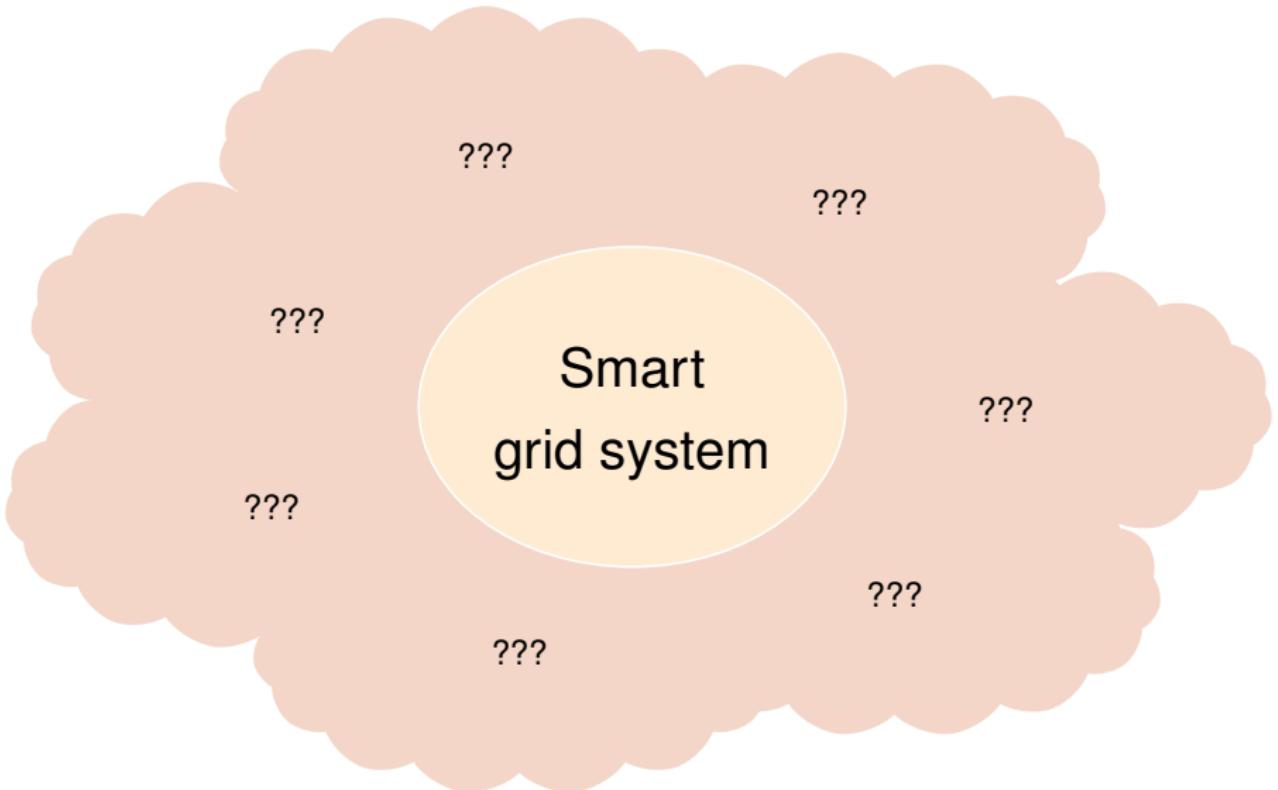
Operation &  
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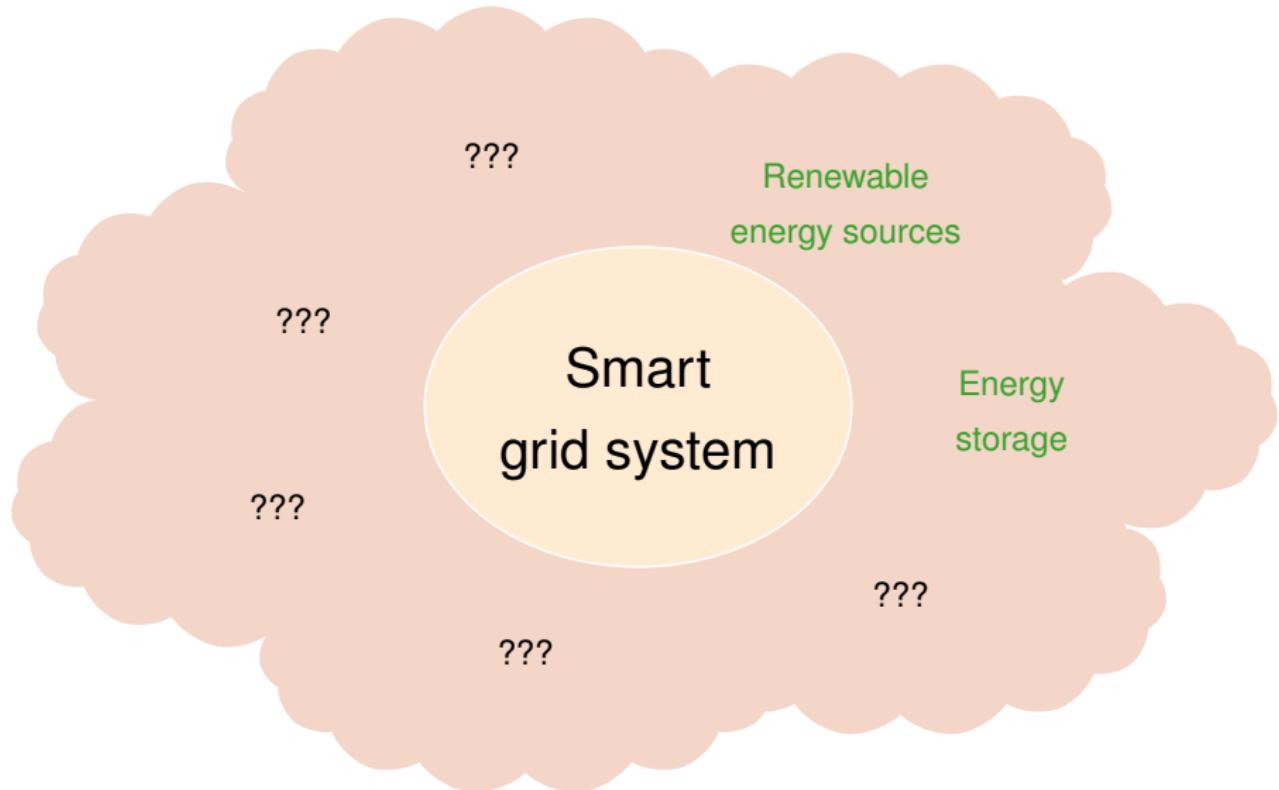


How to make the  
energy system  
***smart?***

Frequency

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





**Renewable energy**  
**sources** needed for sus-  
tainable energy supply

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

### 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



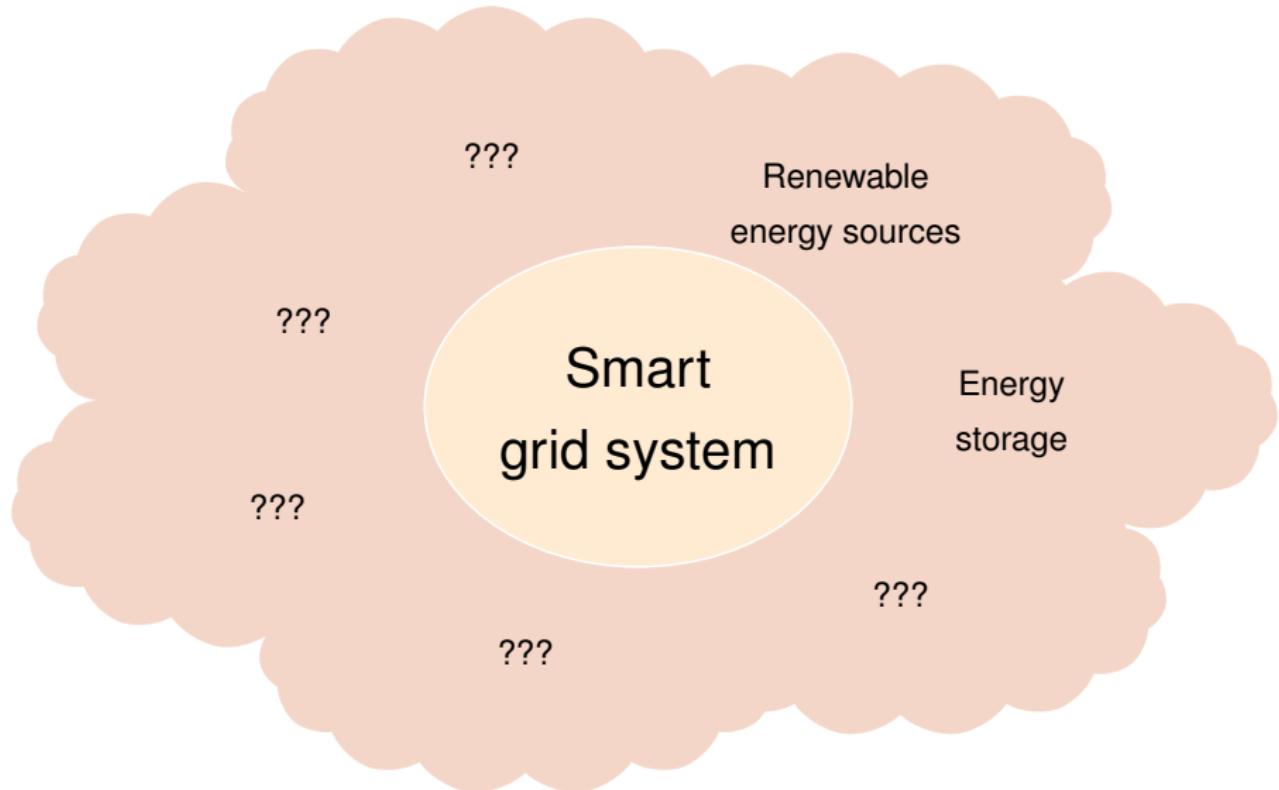
Battery technologies

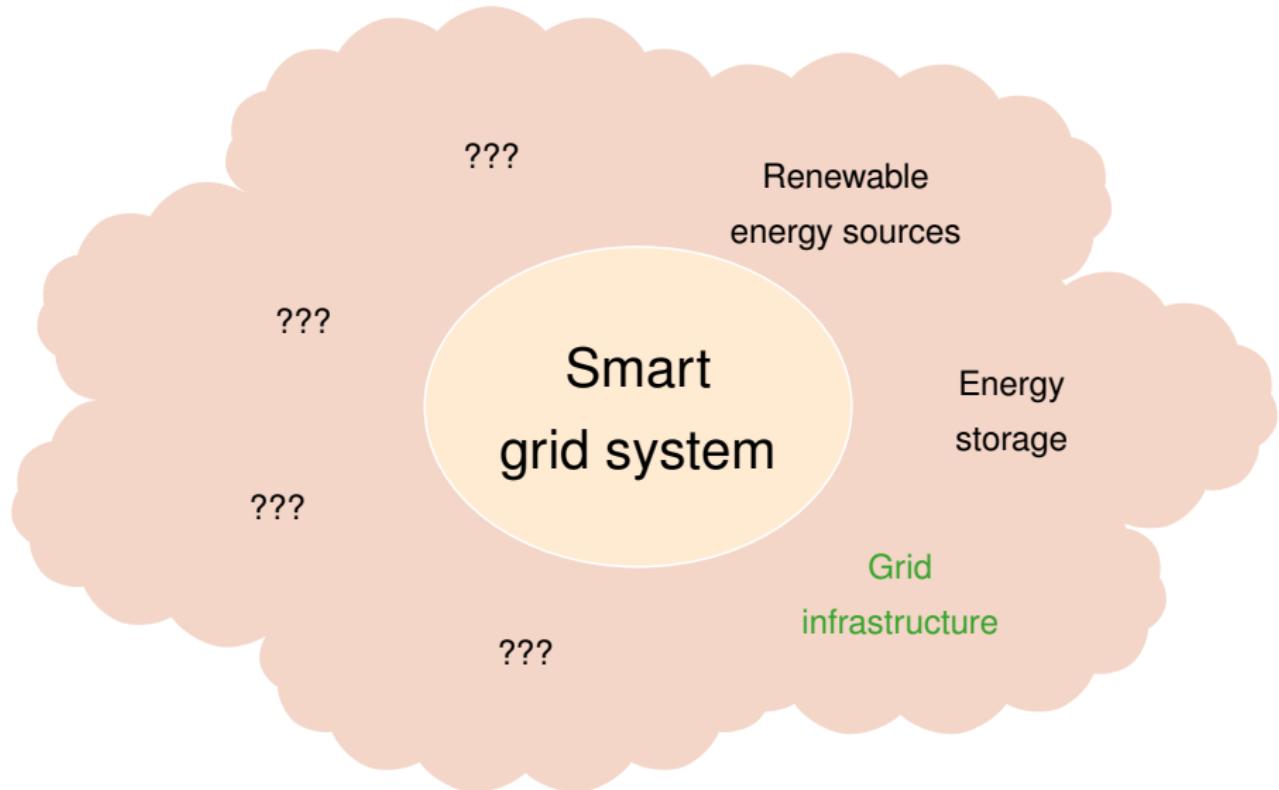


Flywheel



## 4 Key SGS ingredients





- 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

- Increasing amount of generation in distribution grids
- ⇒ Bidirectional power flow

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

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

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

Power-2-gas



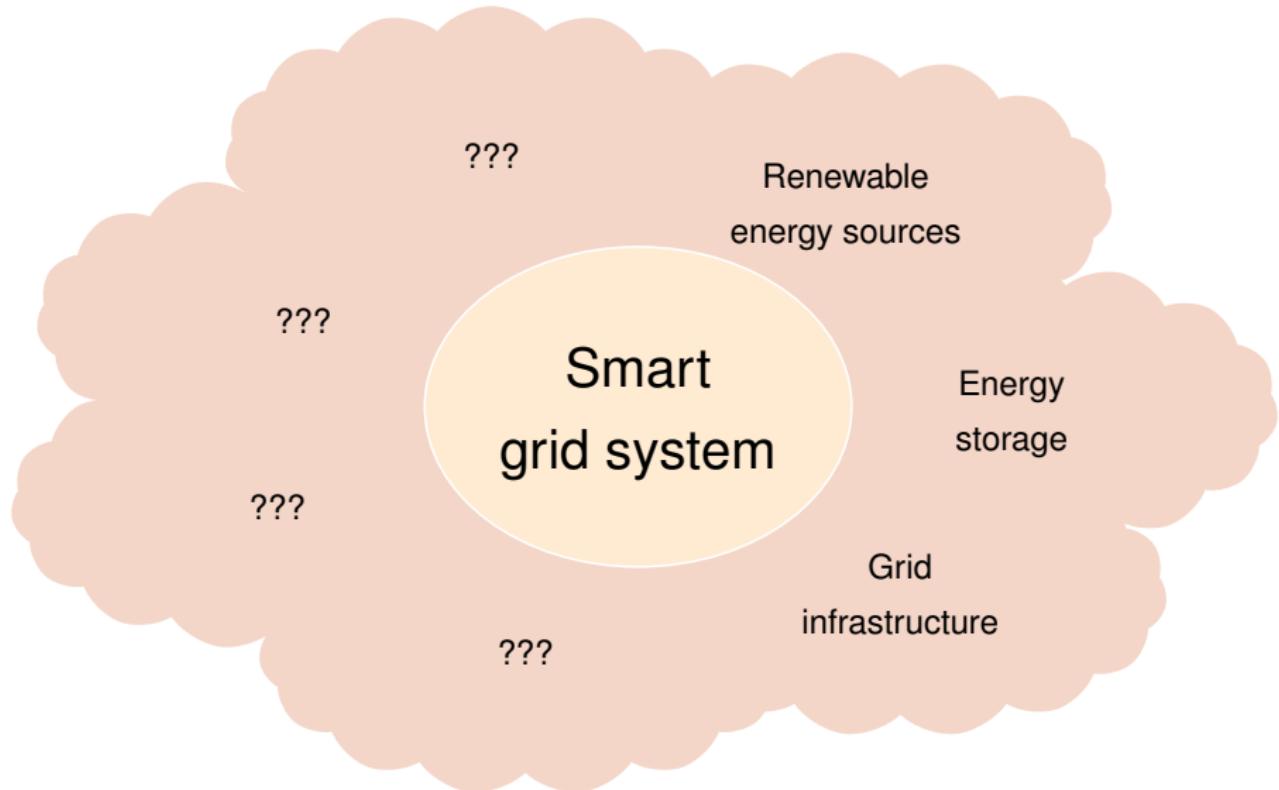
Combined heat & power (CHP) plants

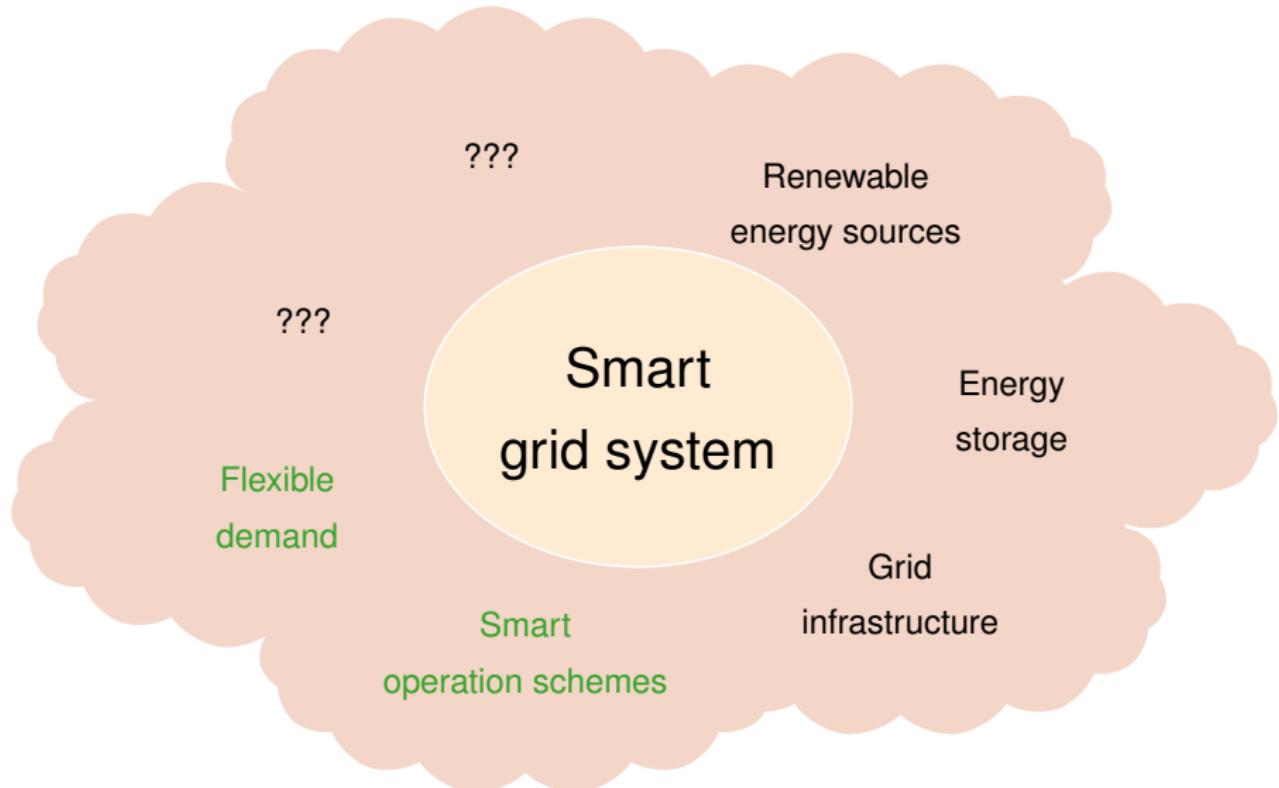


Vehicle-2-grid



## 4 Key SGS ingredients





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

Examples for agents in SGS

Energy producers



Energy retailers



End-users



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

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

Examples for agents in SGS

Energy producers



Energy retailers



End-users



Groups of agents

**Smart operation schemes**

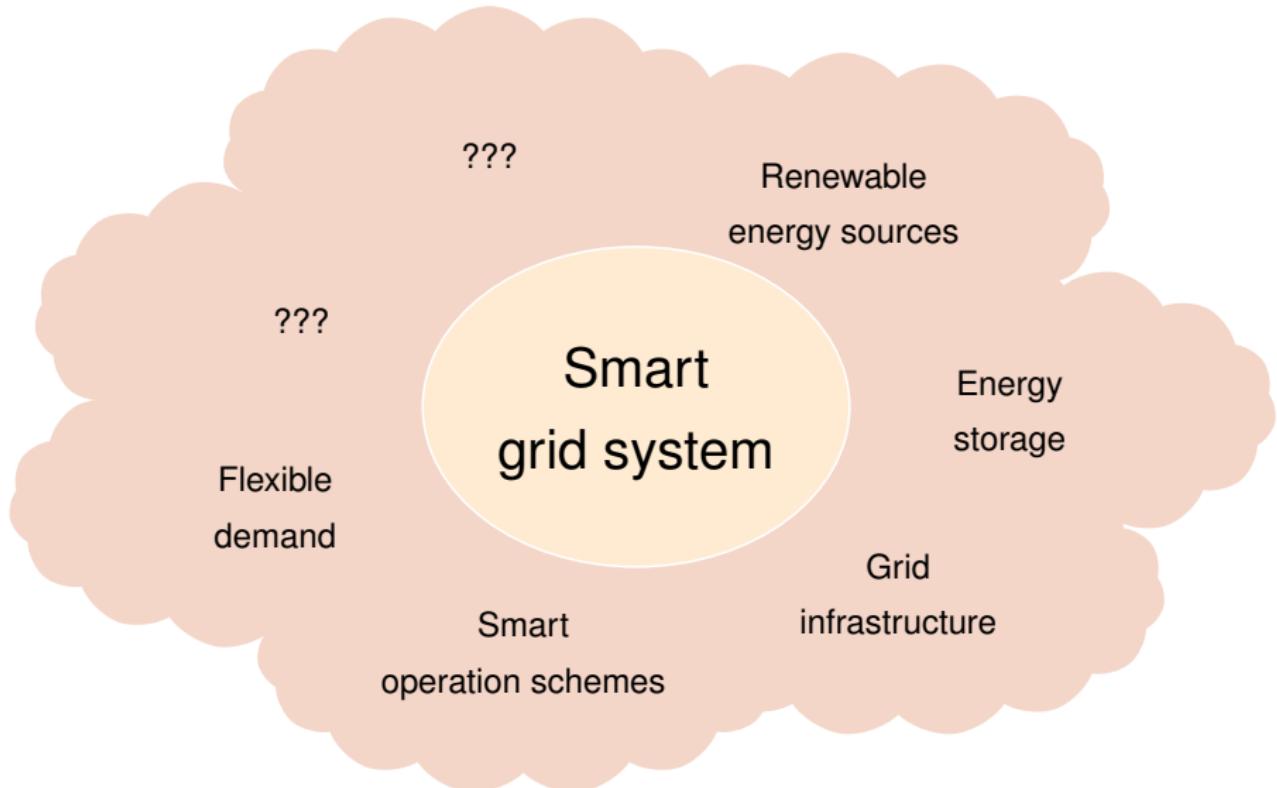
- Virtual power plants
- Microgrids

Individual agents

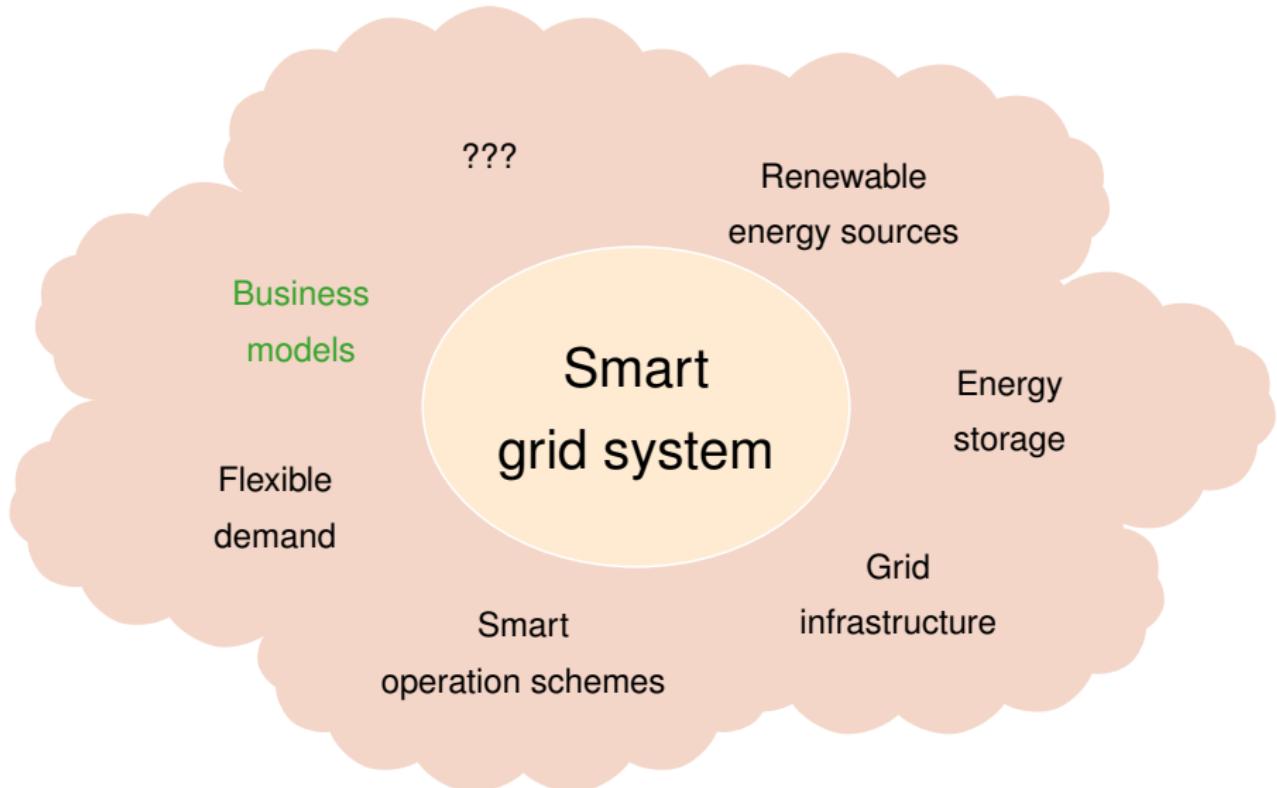
**Flexible loads**

- Demand-side management
- Smart meters & smart homes

## 4 Key SGS ingredients



## 4 Key SGS ingredients - IV. Business models

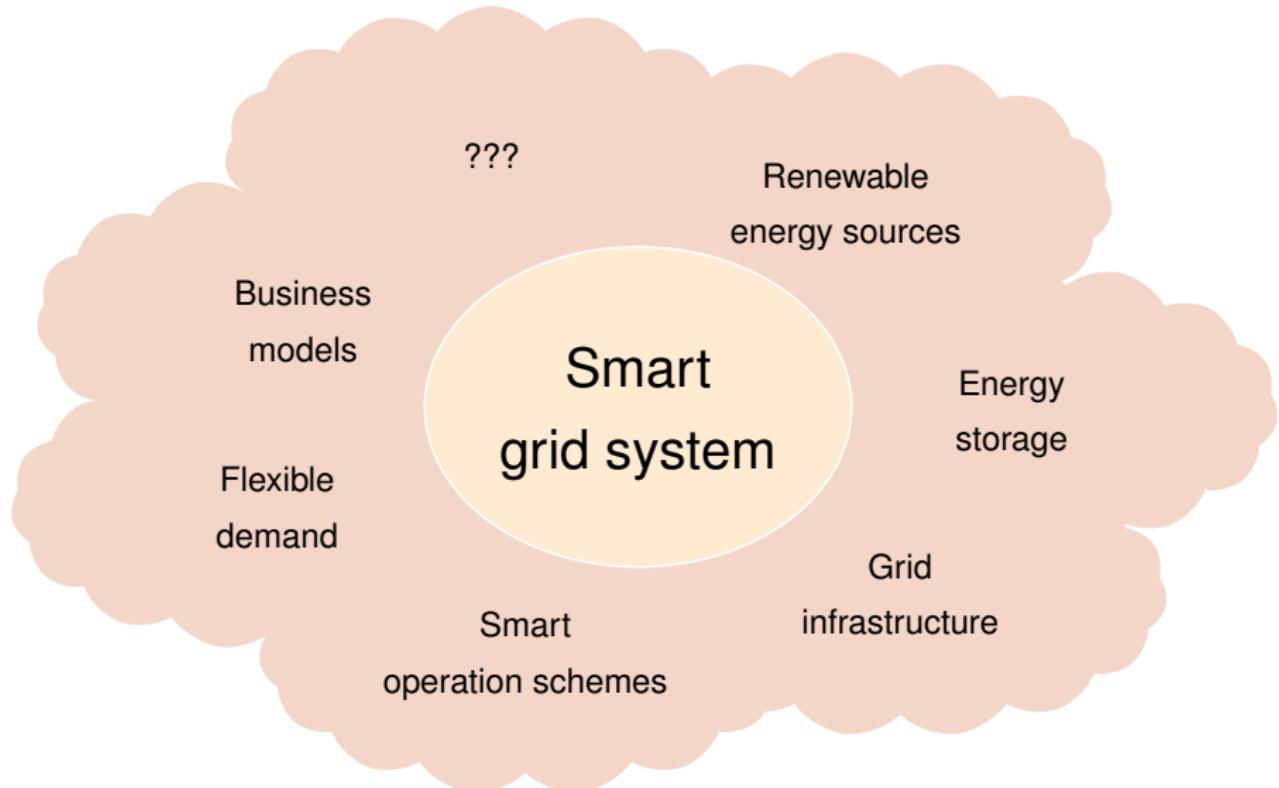


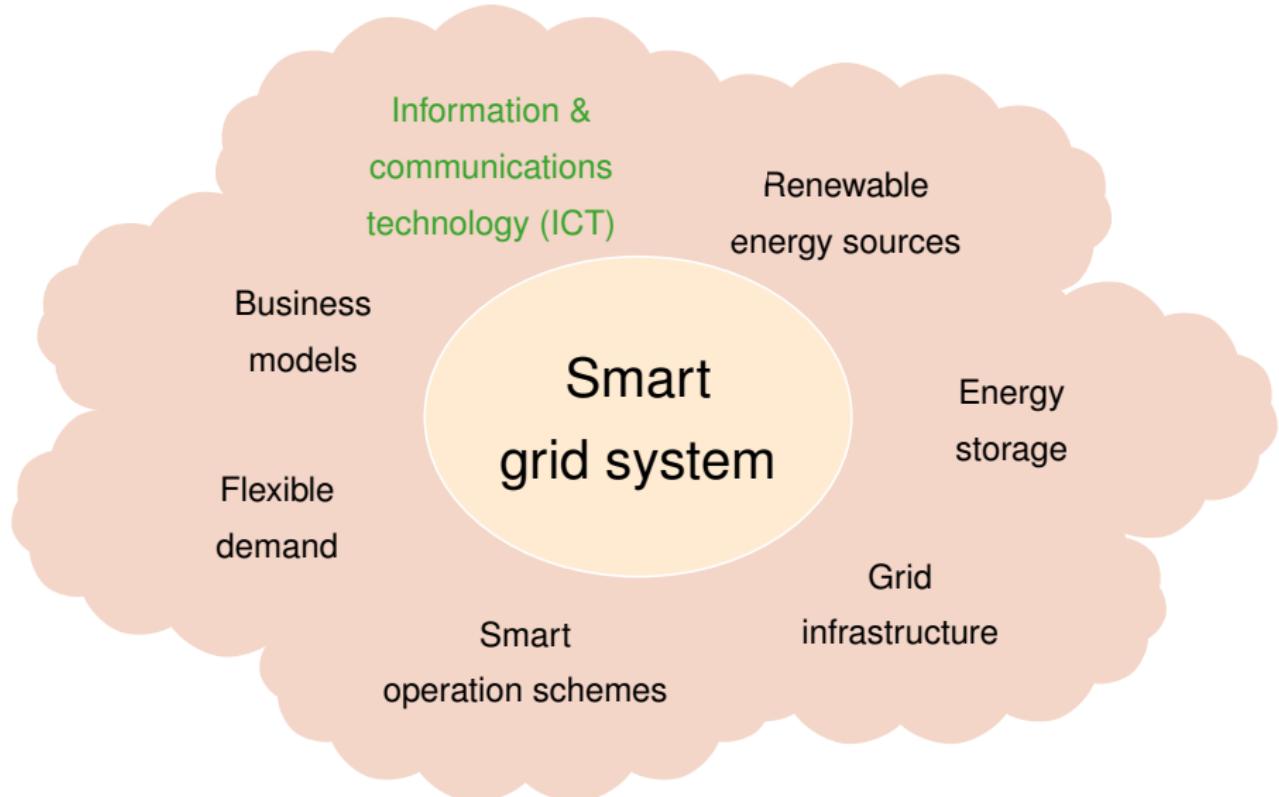
## 4 Key SGS ingredients - IV. Business models

- 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

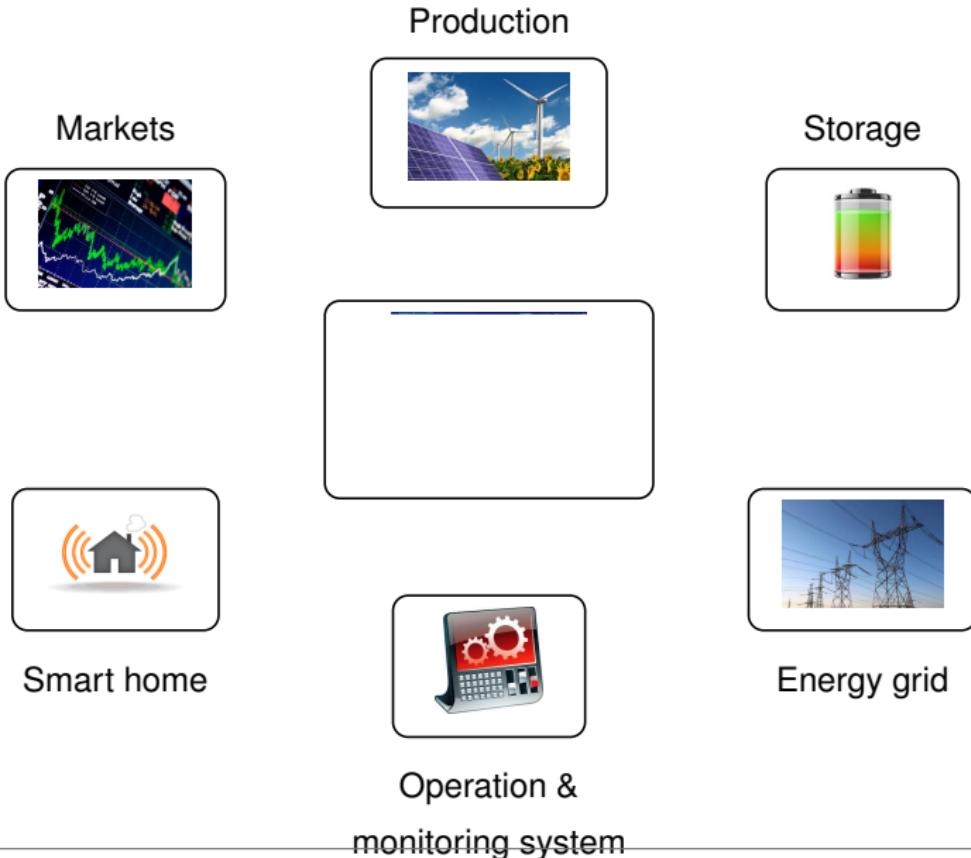


## 4 Key SGS ingredients

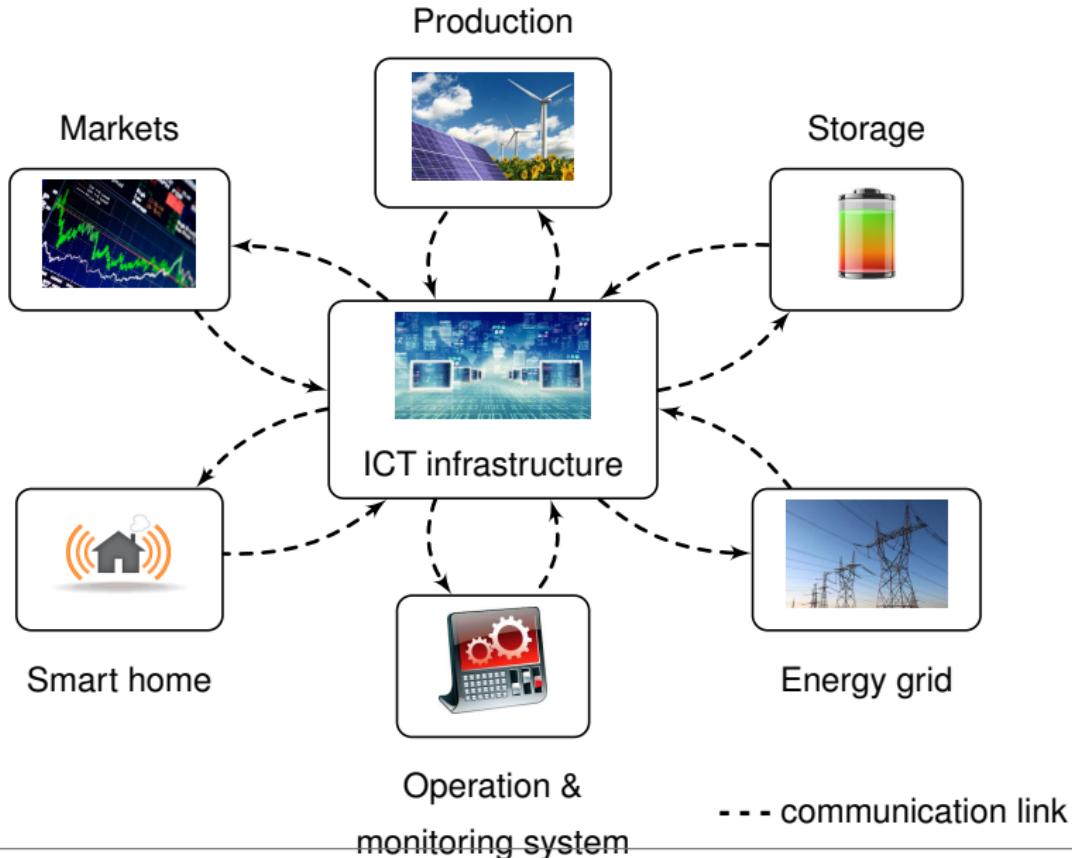




## 4 Key SGS ingredients - V. ICT



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Energy  
technology

Information & communications  
technology (ICT)

### Internet of Energy (IoE)

intelligent, information-based energy supply system

Energy  
technology

Information & communications  
technology (ICT)

reduces need of  
expanding the grid

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Data management



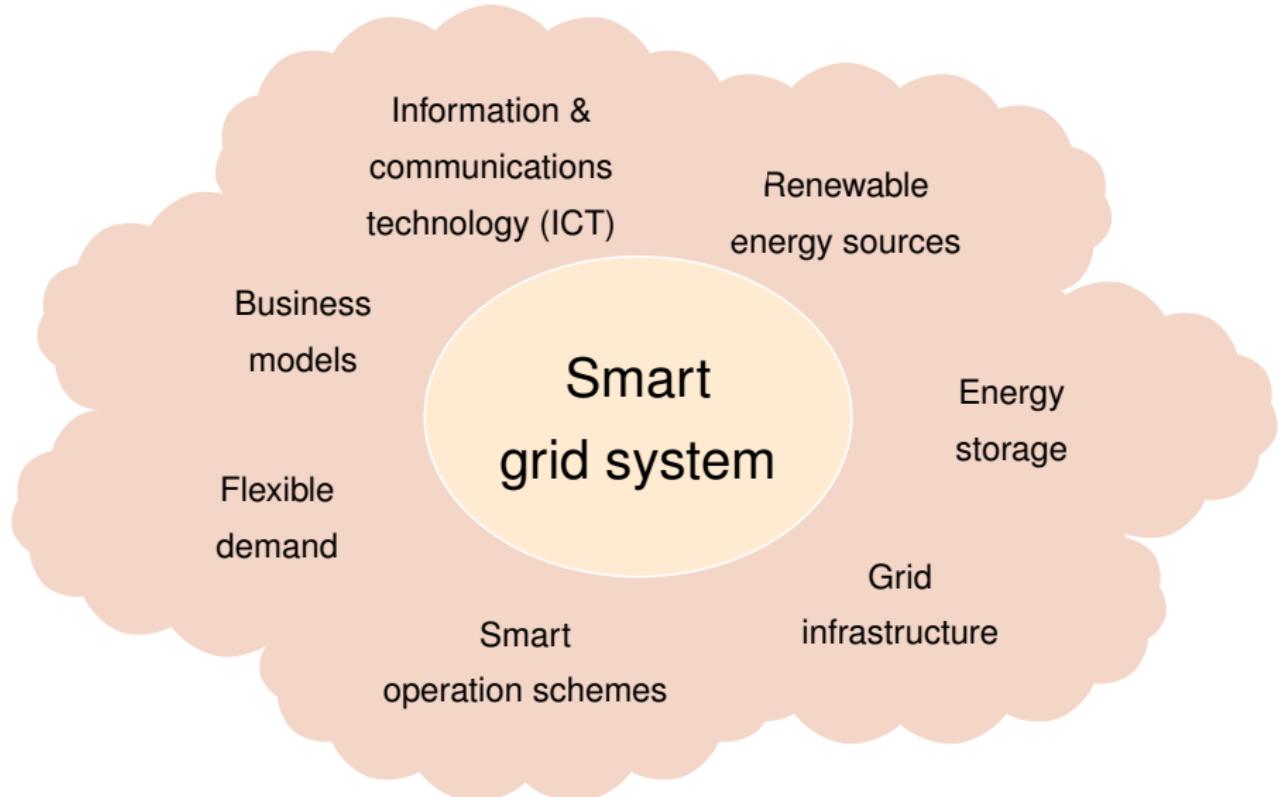
Standardisation



Data security



## 4 Key smart energy system (SGS) ingredients



### 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.eitictlabs.eu/fileadmin/studies/Joint_EIT-ICT-Labs_acatech_Study_Future-Energy-Grid.pdf)
- <http://www.energyplan.eu/smartenergysystems/>
- <http://www.nist.gov/smartgrid/>