Powering Cellular Networks with Renewable Energy Sources

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The Problem

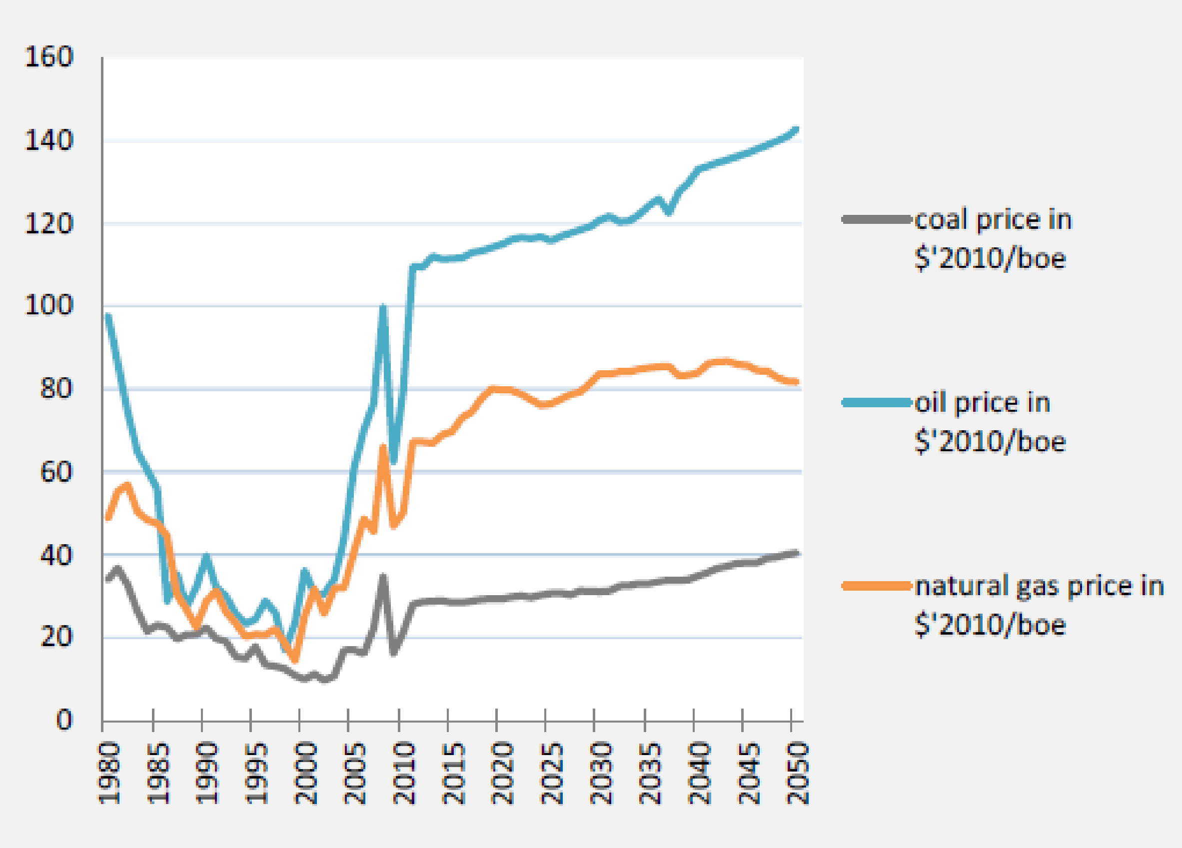
- Energy is becoming ***the issue*** of our future
  - Energy production with fossil fuels causes GHG emissions which produce *climate changes*
  - Energy is becoming *expensive*

- Energy efficiency is a goal in all sectors,

  ICT and networking included

Fossil fuel prices

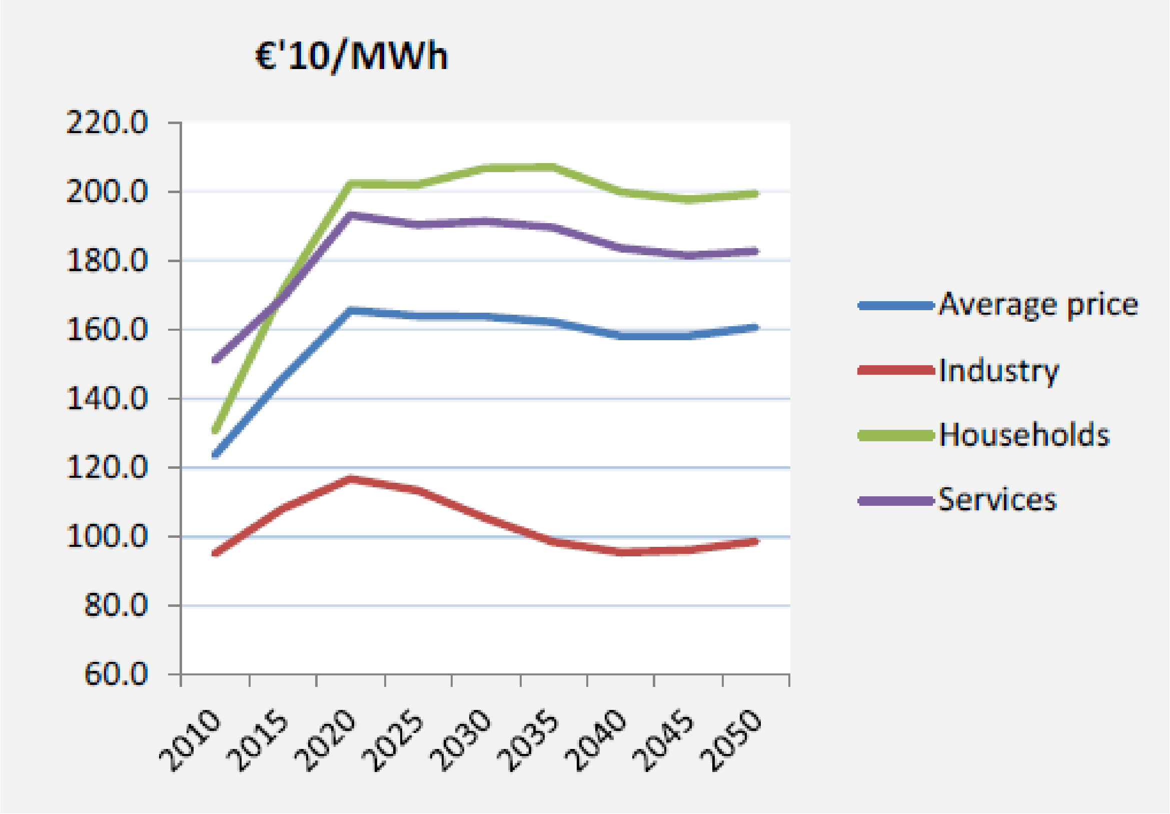
Energy price is growing



Source: Trends to 2050, European Commission.

Electricity prices

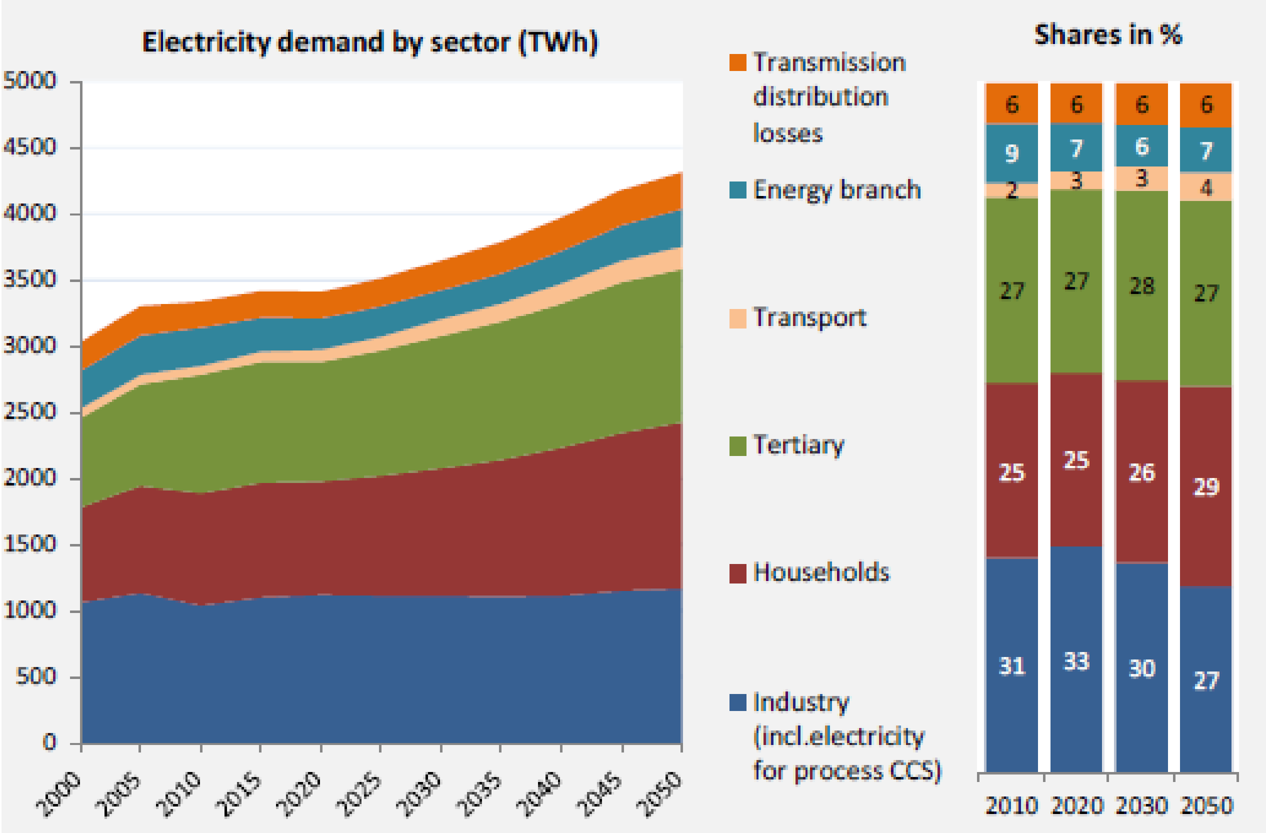
Electricity price is also growing in the next 10 years



Source: Trends to 2050, European Commission.

Electricity demand

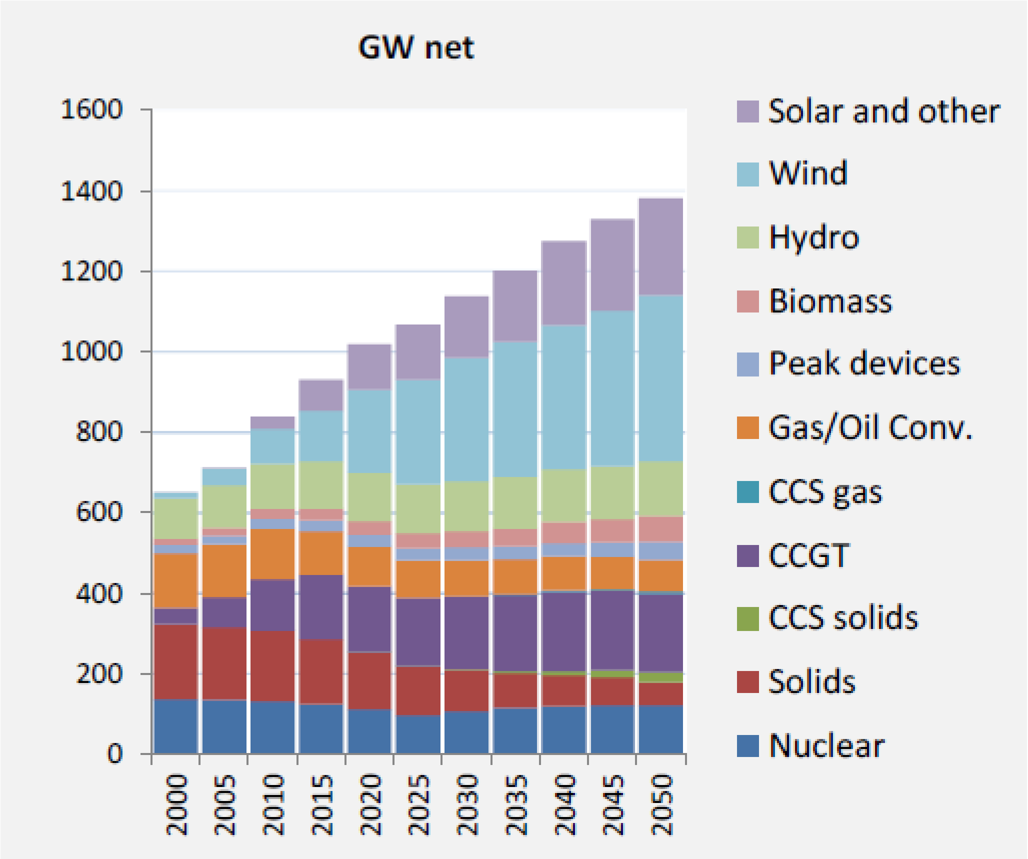
Electricity demand is growing



Source: Trends to 2050, European Commission.

Electricity generation

Energy from renewable sources will grow



Source: Trends to 2050, European Commission.

What about ICT?

- Information and Communication Technologies (ICT) play a positive role for energy efficiency:
  - *moving bits instead of atoms*
    - intelligent transport systems
    - teleworking and telecommuting
    - e-commerce
    - electronic billing
  - new manufacturing systems
  - sensors to monitor and manage our environment
    - smart buildings, neighborhoods, cities …

What about ICT?

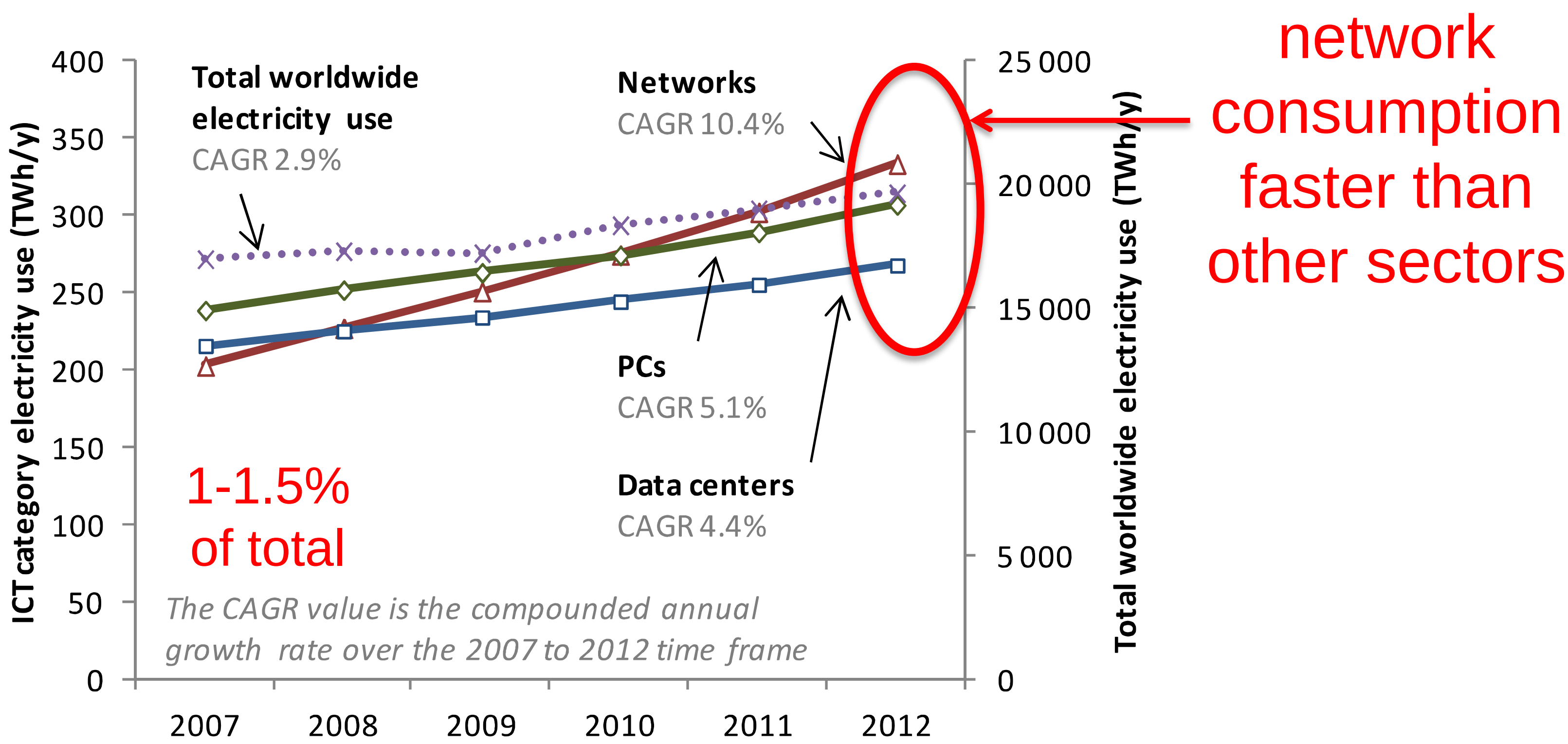
- ICT will allow savings of the order of
  - 25-30% in manufacturing
  - 20-30% in transport
  - 5-15% in buildings

  for a total of about 17-22%
- Moreover, ICT is expected to significantly improve the energy generation, transport and utilization through the adoption of *Smart Grids*

Source: Ad-hoc Advisory Group “ICT for Energy Efficiency” of the European Commission DG INFSO, 2008.

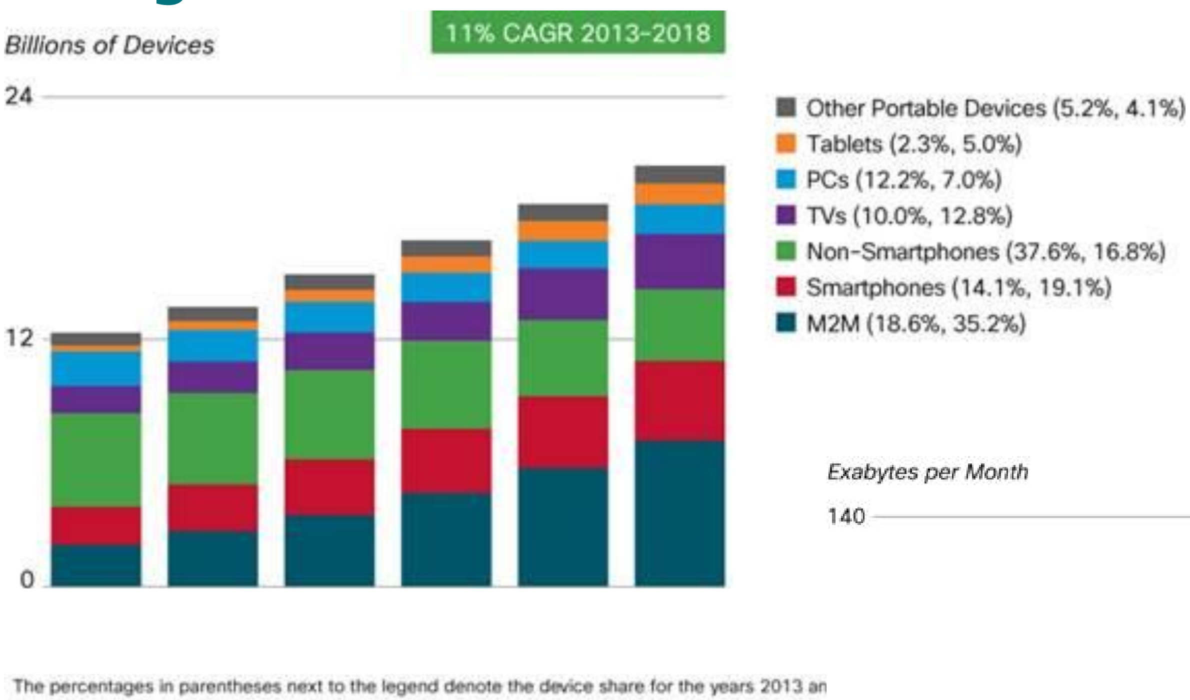
However, ICT is also part of the problem

- ICT energy consumption is huge and increasing

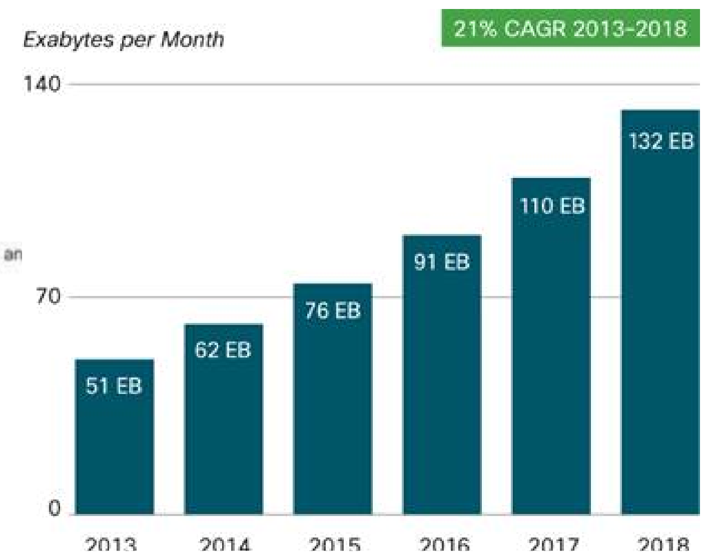


Source: **TREND** Final Deliverable on "Assessment of power consumption in ICT", 2013 and S. Lambert et al., "Worldwide electricity consumption of communication networks," Optics Express, Vol. 20, No. 26, 2012.

Traffic growth



number of devices grows (new markets)

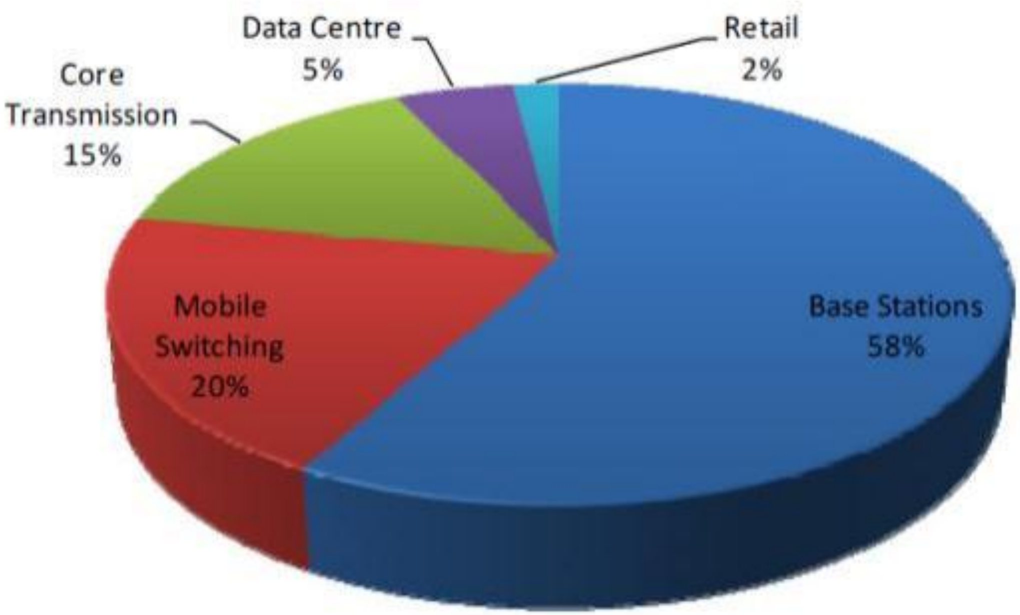


new and more traffic intensive services

Source: Cisco VNI, 2014.

The case of mobile networks

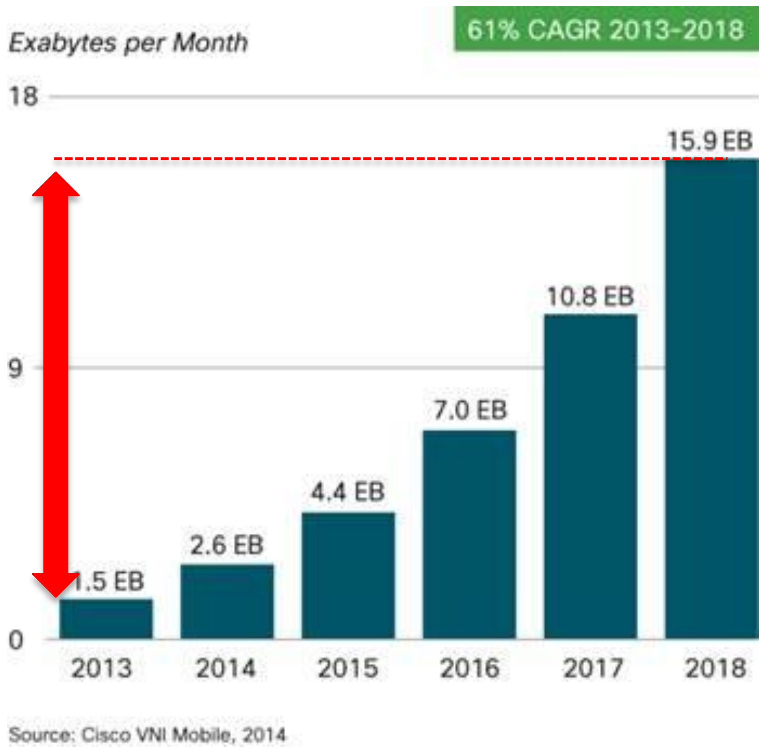
- The mobile industry sums to **0.5%** of global emissions
- Electricity cost is up to **70%** of mobile operators OPEX!



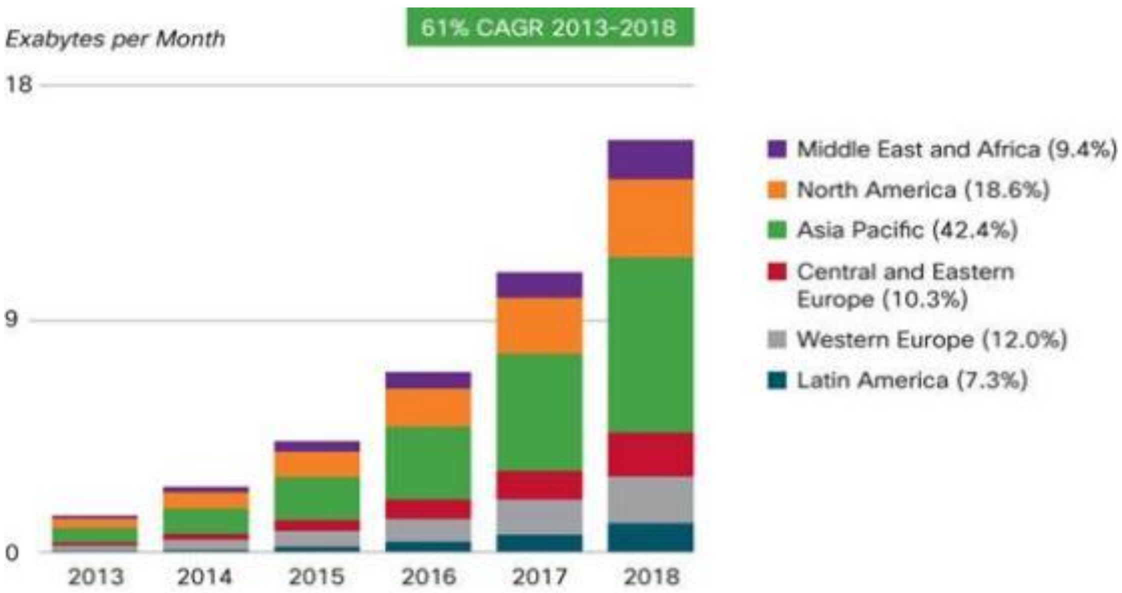
Radio access networks are the prime target for energy saving

Source: S. Vadgama and M. Hunukumbure, Trends in Green Wireless Access Networks, IEEE ICC 2011.

Traffic growth will make it “worse”



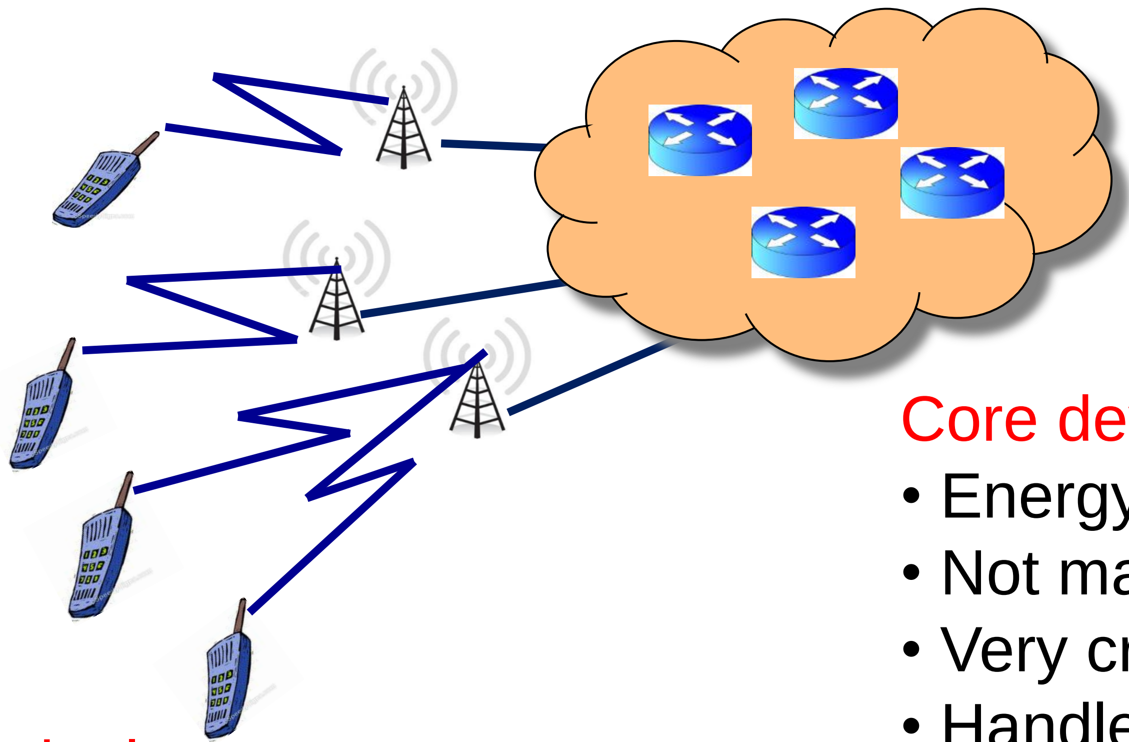
Mobile network traffic is expected to grow by an order of magnitude in 5 years!!!



- Larger no. of devices (new markets)
- More traffic intensive services

Source: Cisco VNI Mobile, 2014.

Which segment of the network?



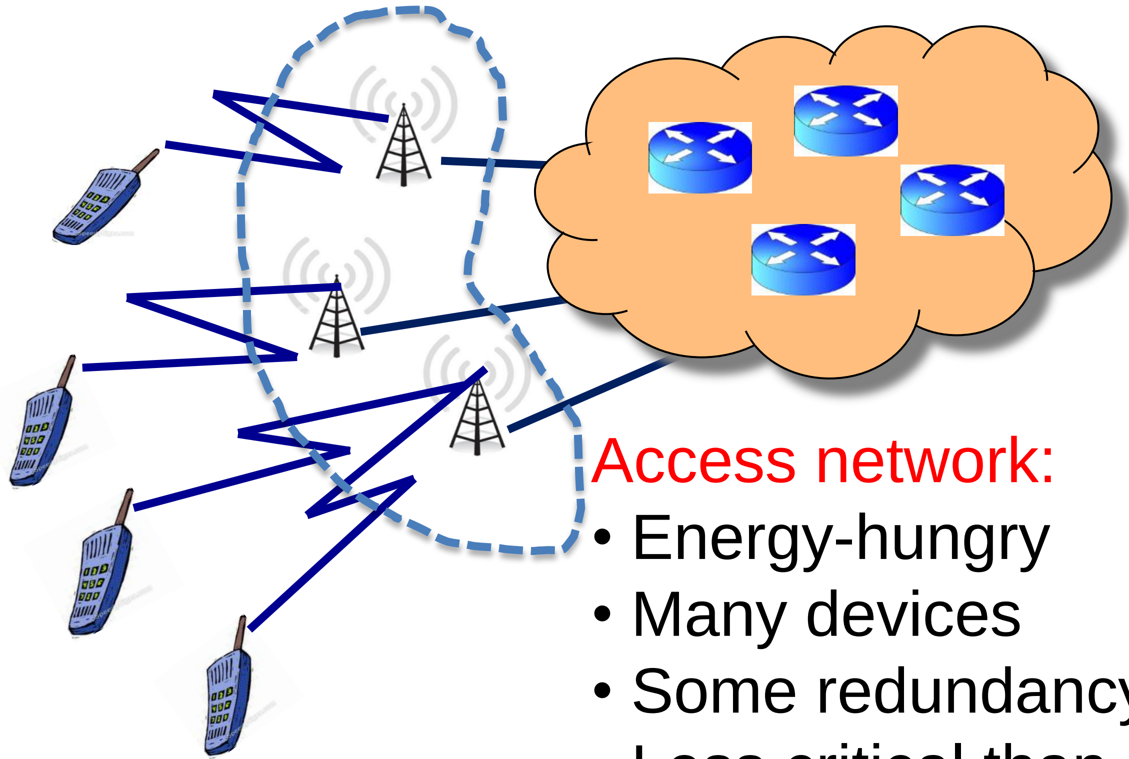
Core devices:

- Energy-hungry
- Not many
- Very critical
- Handle aggregate traffic

Terminals:

Already energy-efficient by design

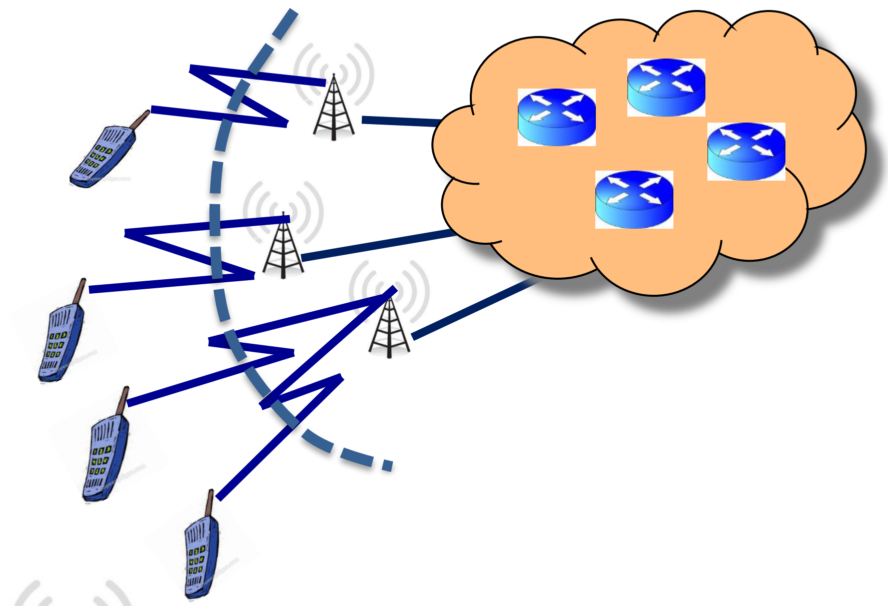
Which segment of the network?



Access network:
- Energy-hungry
- Many devices
- Some redundancy
- Less critical than core devices
- Very close to the user, hence high traffic variability

Mobile networks

According to an estimate of Nokia Siemens Networks, worldwide…



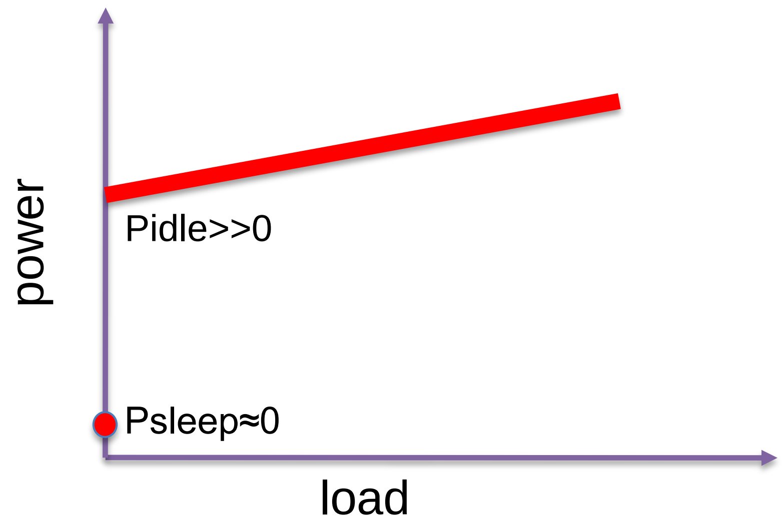
3 billion x 0.1 W =
0.3 GW

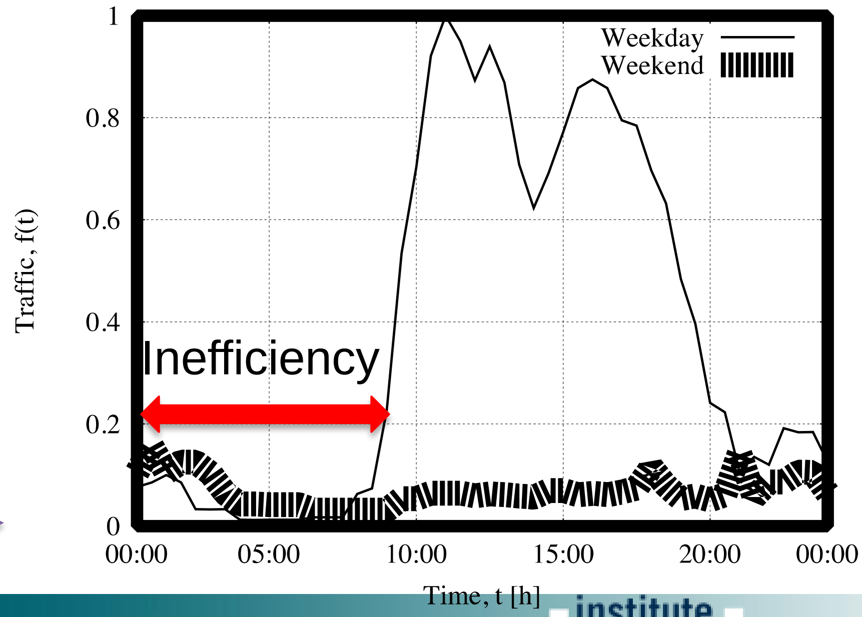
3 million x 1.5 kW =
4.5 GW

10,000 x 10 kW =
0.1 GW

Energy efficient solutions

- Traditionally, little attention to consumption in the design of the devices and of the network
- Many inefficiencies derive from the combination of
  - little load proportionality of consumption
  - due to traffic variability, long periods under low to medium load





Energy efficient solutions

- Consume energy for capacity *deployment*, not for capacity *usage*
- Many solutions try to make capacity *adaptive* to load
  - Use of sleep modes for the BSs
  - Network sharing
  - Resource on demand architectures
- Saving of up to 40% can be achieved,

is this enough?

Micro and macro effects of energy efficiency

Jevons paradox:

Increase of energy efficiency to produce a good/service

↓

reduces cost of the production and, hence, its price

↓

increases the demand

↓

increases the energy consumption

From energy efficient networking to sustainable networking

- Energy efficiency is good since, through cost reduction, it leads to
  - Higher production → better quality of life for more people
  - Reduction of price increase and energy shortage
  - Global environmental advantage if coupled with green taxes to keep the price constant

- but, for sustainability,
  it must be coupled with new energy generation principles
  (RES – Renewable Energy Sources)

Powering BSs with renewables

- **Zero grid-Electricity Networking (ZEN)**
  BSs rely purely on renewable energy sources and are not connected to a power grid
  - Can acquire limited amounts of energy from (intermittent) local generators exploiting **renewable sources**
  - Any energy surplus is stored in a **battery**
  - The BS can operate also in periods of low or no production, as long as energy is available, but it is forced to switch off when the battery is depleted

- **Hybrid** systems that, when battery is depleted, rely also on the power grid (or a secondary generator)

Powering BSs with renewables

- Power BSs with Renewable Energy Sources
  - To deploy networks where the power grid does not exist, is not ubiquitous or is not reliable
  - To achieve extremely low carbon footprints
  - To reduce operational cost
  - To survive to power grid outages or natural disasters which damage the power grid

Possible scenarios:

1. New opportunities for the deployment of networks in **emerging regions**

Possible scenarios: Emerging areas

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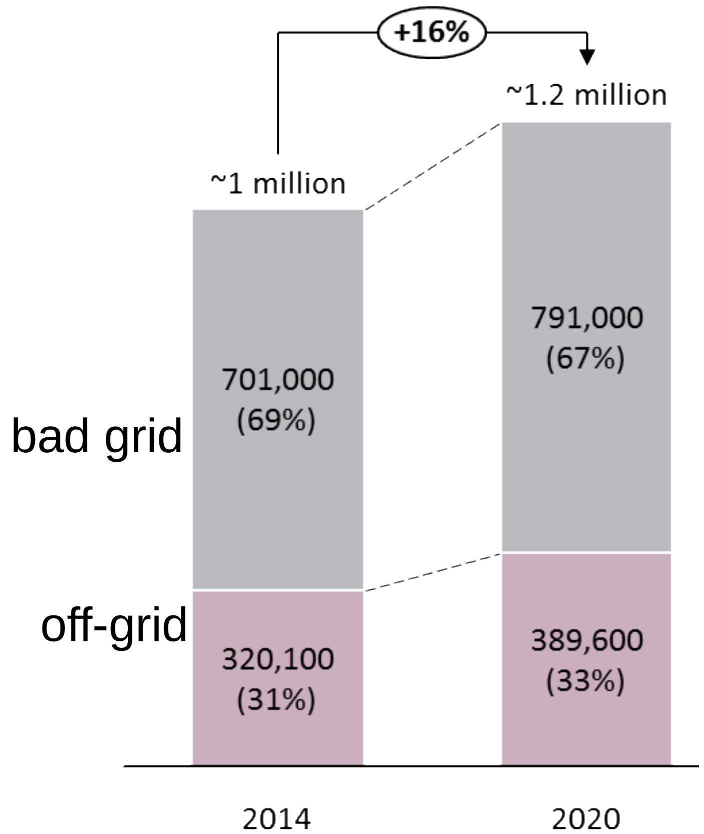
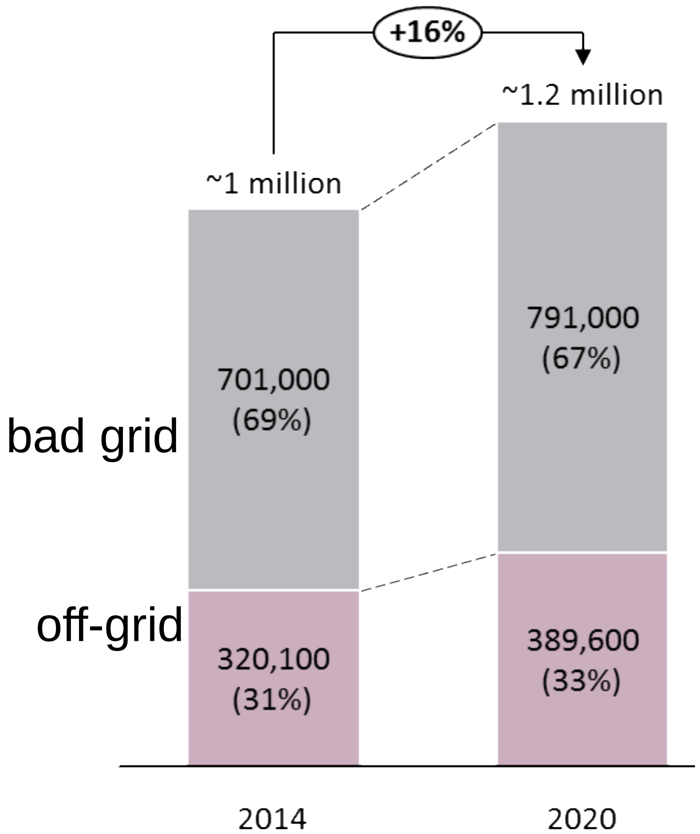


Source: "Green Power Design Approach and Feasibility Analysis," Green power for Mobile Technical White Paper, Aug. 2014.

- Expected expansion of mobile networks in rural regions in Africa and Asia
- Most of the BSs are powered with **diesel generators**
  - Costly (especially due to fuel transportation)
  - Bad for the environment

Possible scenarios: Emerging areas



Source: "Green Power Design Approach and Feasibility Analysis," Green power for Mobile Technical White Paper, Aug. 2014.

Renewables can be convenient

- Cost reduction
- Environmental concerns
- Political issues (related to energy supply)

In India,

- about 400,000 BSs
- 75% of rural sites and 33% of urban sites on RES by 2020

Source: K. Tweed, "Why Cellular Towers in Developing Nations are Making the Move to Solar Power," Scientific America, 15 Jan. 2013.

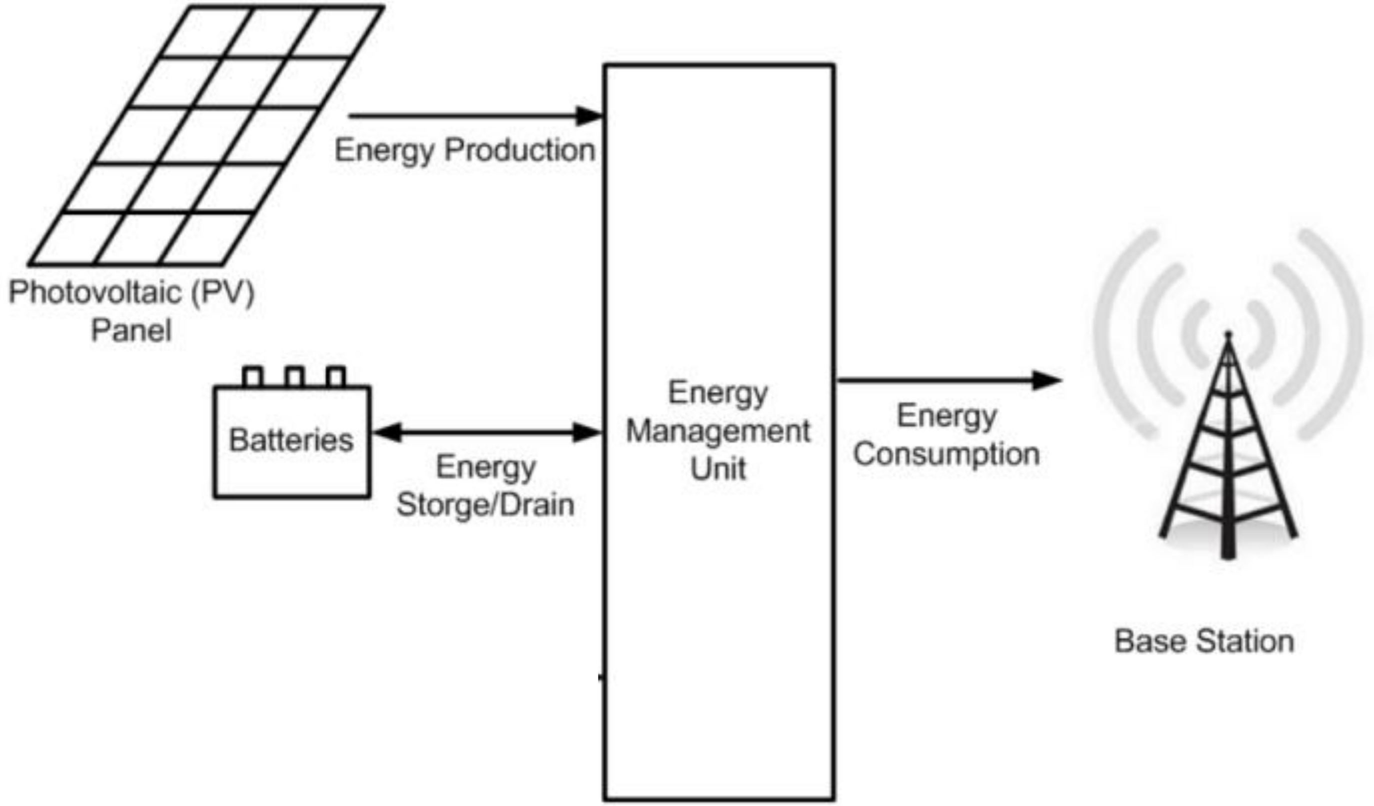
ZEN – Zero grid-Electricity Networking

- Power BSs with Renewable Energy Sources
  - To deploy networks where the power grid does not exist, is not ubiquitous or is not reliable
  - To achieve extremely low carbon footprints
  - To reduce operational cost
  - To survive to power grid outages or natural disasters which damage the power grid

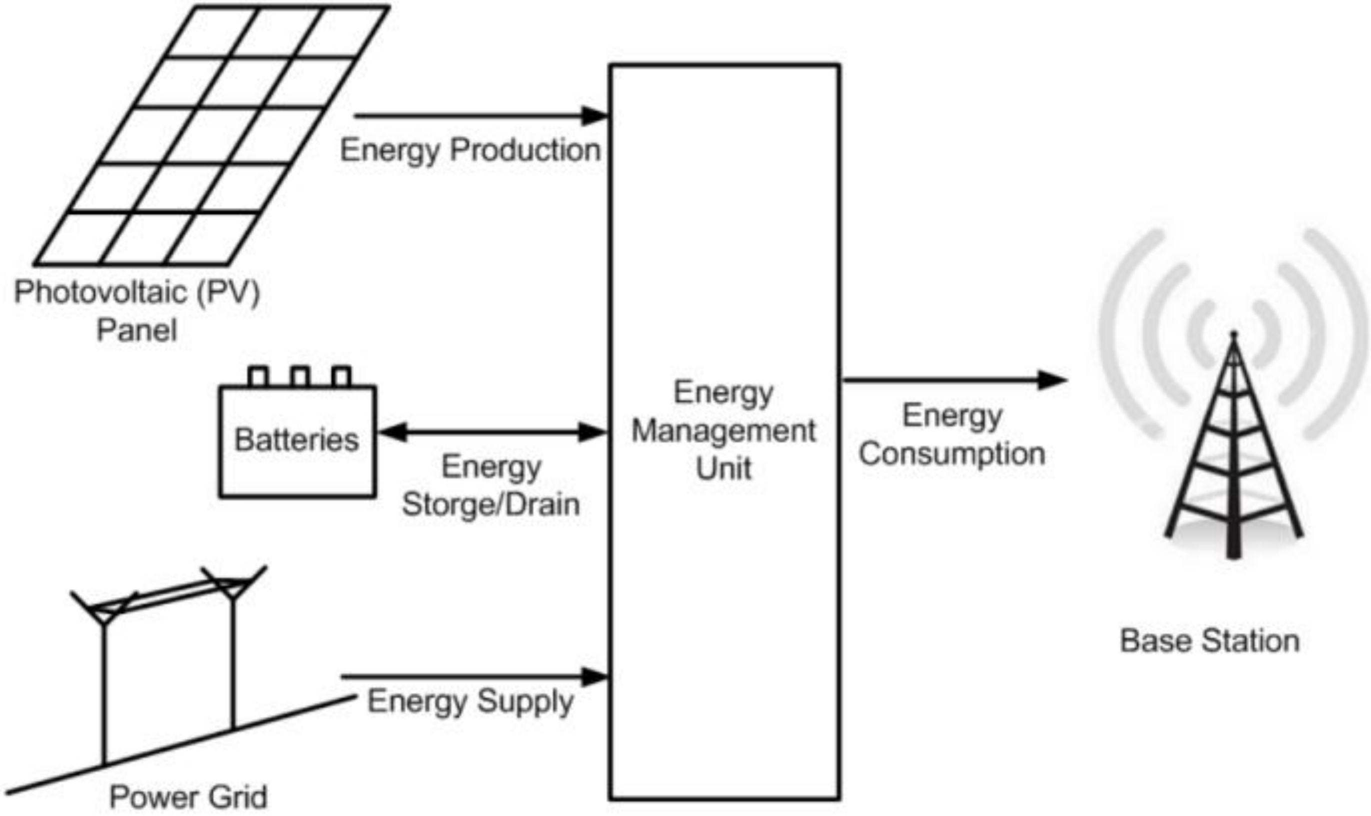
Possible scenarios:

1. New opportunities for the deployment of networks in emerging regions
2. New **business** models (high electricity price, green incentives and environmental awareness)
3. Dense urban areas where **cabling** is a problem
4. Critical infrastructure **protection**
5. …

Pure PV (ZEN)

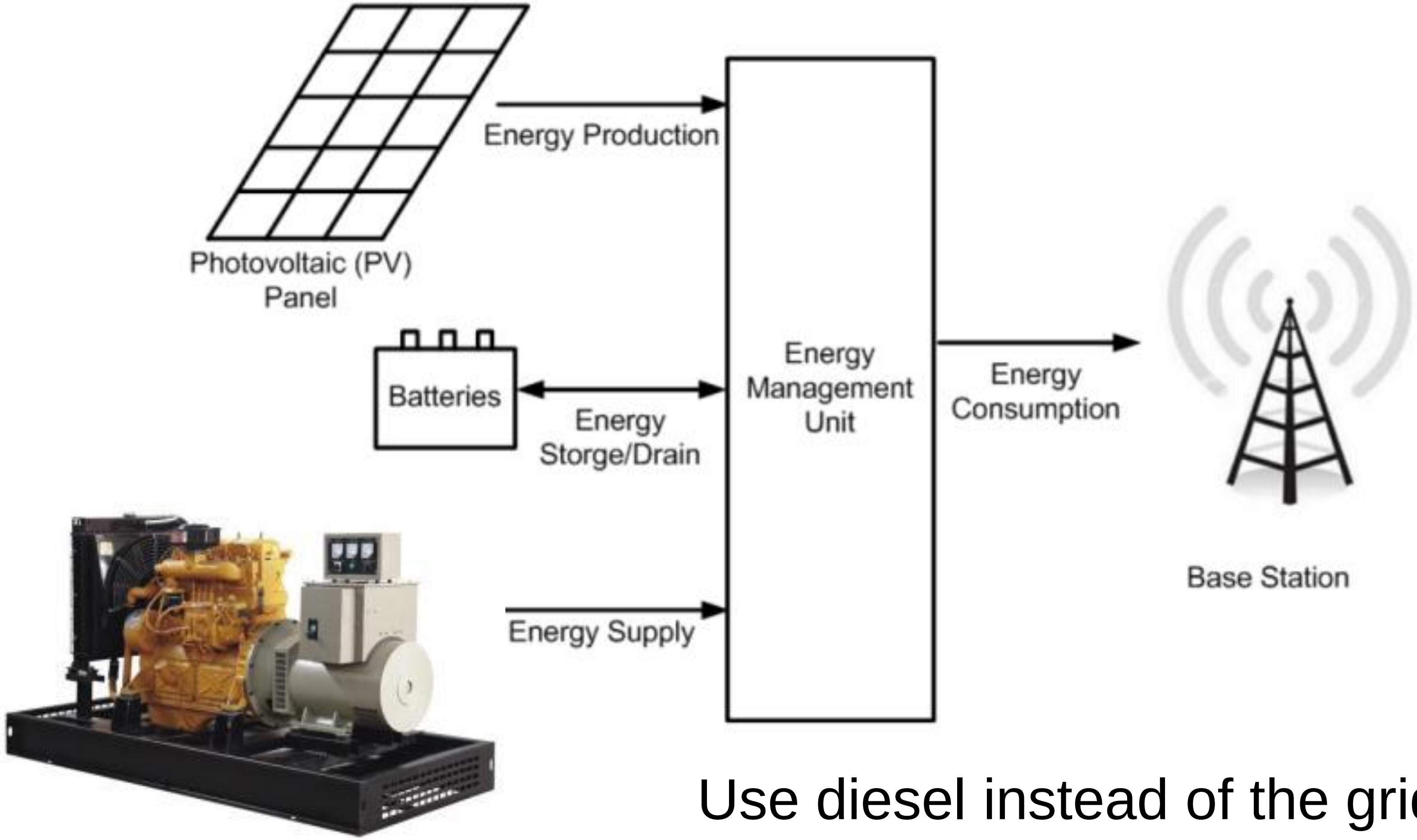

Energy Production
Photovoltaic (PV) Panel
Batteries
Energy Storge/Drain
Energy Management Unit
Energy Consumption
Base Station

Hybrid PV-Grid



Connect to the Power Grid to reduce size of PV panel & number of batteries

Hybrid PV-diesel



Use diesel instead of the grid as a backup

Hybrid systems definition

- Define parameter PT:

  percentage of time the battery charge is above 30%

- PT = 100% (ZEN, pure PV): guarantee that the battery charge is above 30% for 100% of the time in a year
- PT < 100% (hybrid system): The battery is above 30% for a percentage of time equal to PT, buy energy comes from the power grid when the battery charge becomes 0

- Lower values of PT → more energy from the grid
  – We consider PT in {70,80,90,100}%

Methodology: The scenario

- Consider 10 year period
- Choose a location
- Consider a typical BS – macro LTE
  - Energy consumption
  - Traffic (from a real network)

  } ⟶ energy need
- Consider evolution of parameters in 10 years
  - Traffic increases by 50% Compound Average Growth Rate (CAGR)
  - PV panel efficiency decreases by 1% per year
  - Electricity price increases by 3% per year

Methodology: Dimension the powering system

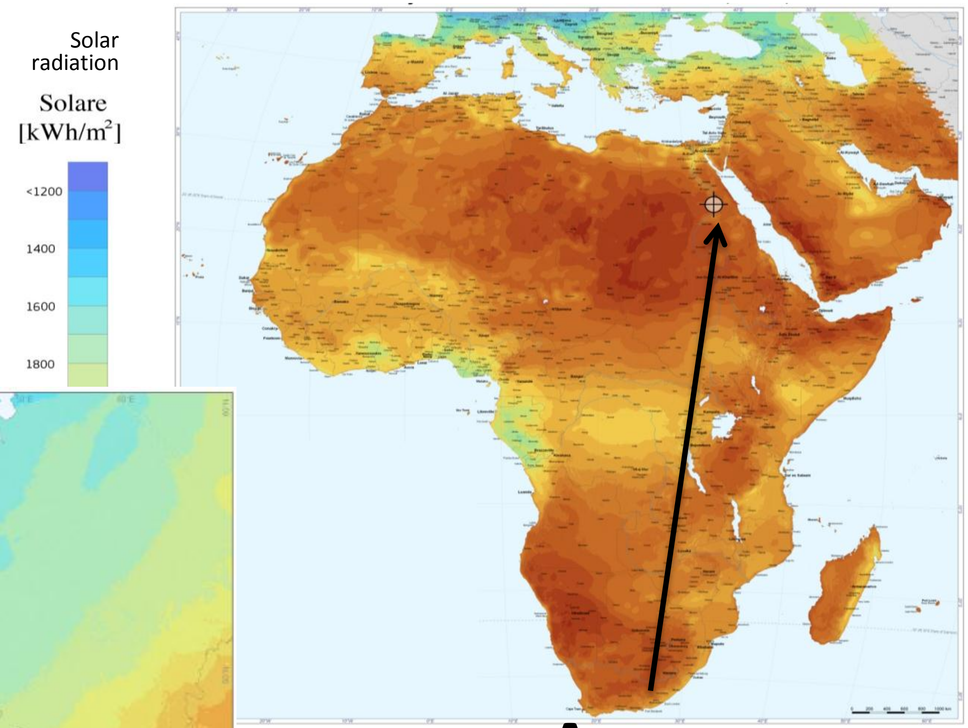
For each year of the 10 year period

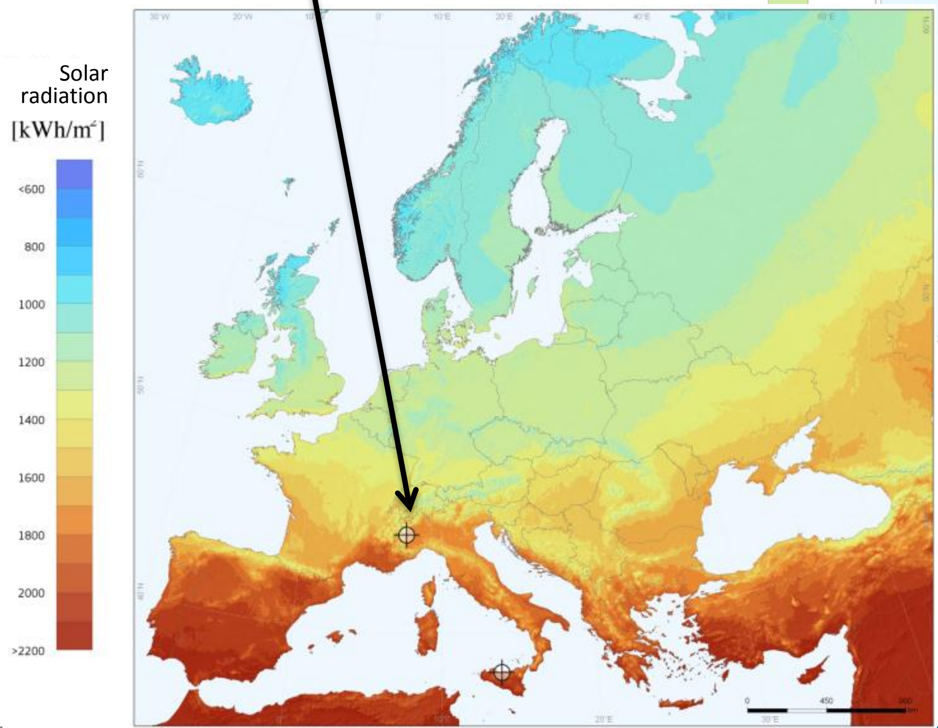
- Compute the BS energy need
- For increasing size of PV panel
  - Simulate daily energy production
  - Find the min no. of needed batteries by simulating battery charge and discharge over the whole year
  - Compute the cost of PV panels and batteries
- Choose the combination of PV panel size and no. of batteries that minimizes the cost
- Simulate 10 year, compute cost of batteries replacement
- Compute overall cost (CAPEX+OPEX)

➔ **Select the minimum cost system**

Two locations

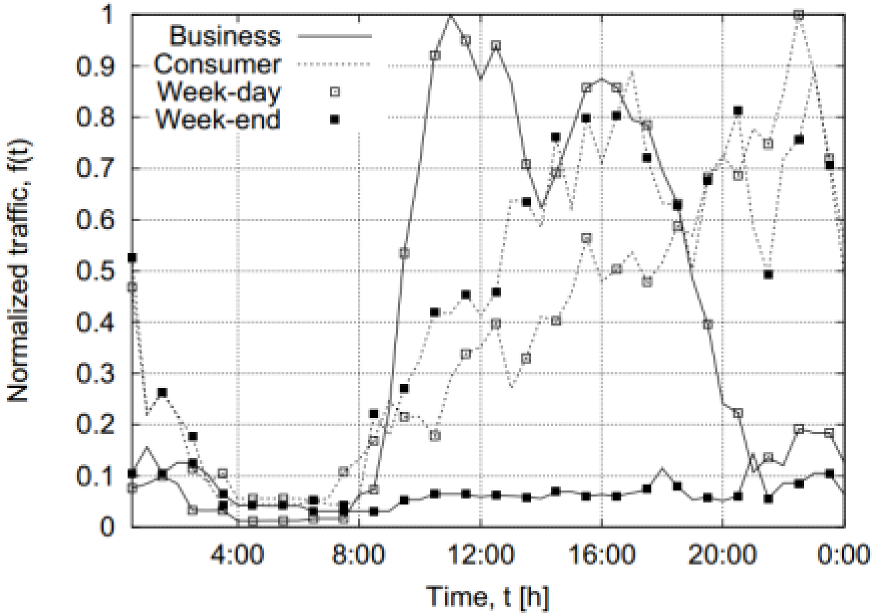
Torino
(medium: 4 kWh/m², high seasonal variations)





Aswan
(high: 6.8 kWh/m², low seasonal variations)

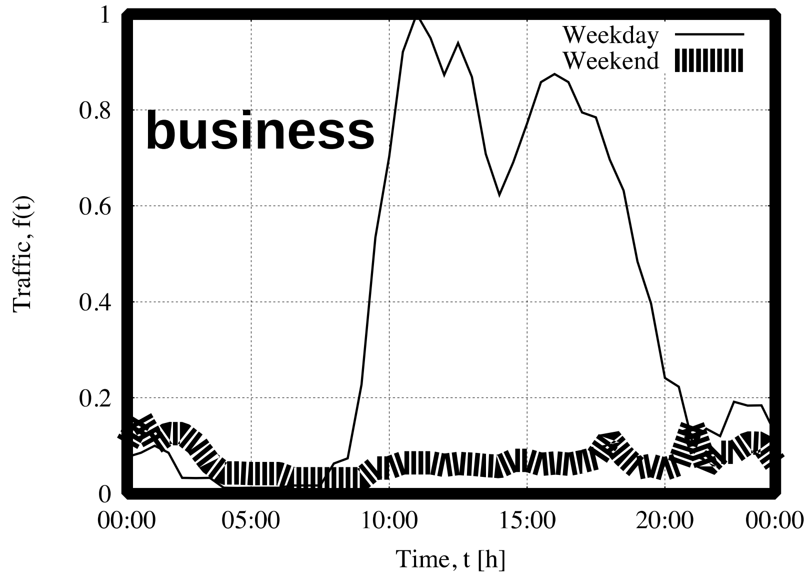
Real traffic profile

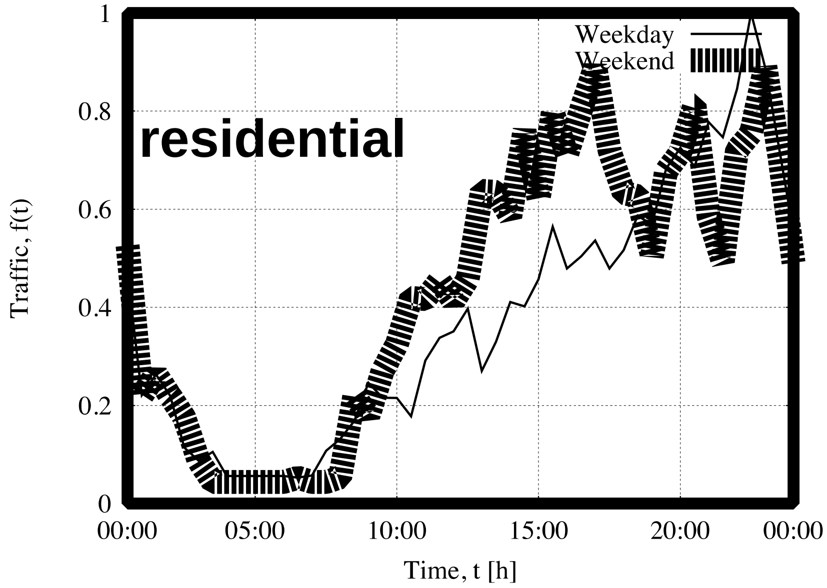


- Traffic grows according to 50% Compound Average Growth Rate (CAGR)
  - Focus on LTE, with initial low traffic load (0.02) due to start-up of the new technology and maximum (0.75) in 10 years

Source: "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013-2018," http://www.cisco.com/

Real traffic profile





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Consumption and generation models

- Model LTE BSs, with and without Remote Radio Unit (RRU)

  Source: EARTH project deliverables.

- PV efficiency that degrades of a 1% per year (i.e., energy production decreases with time)

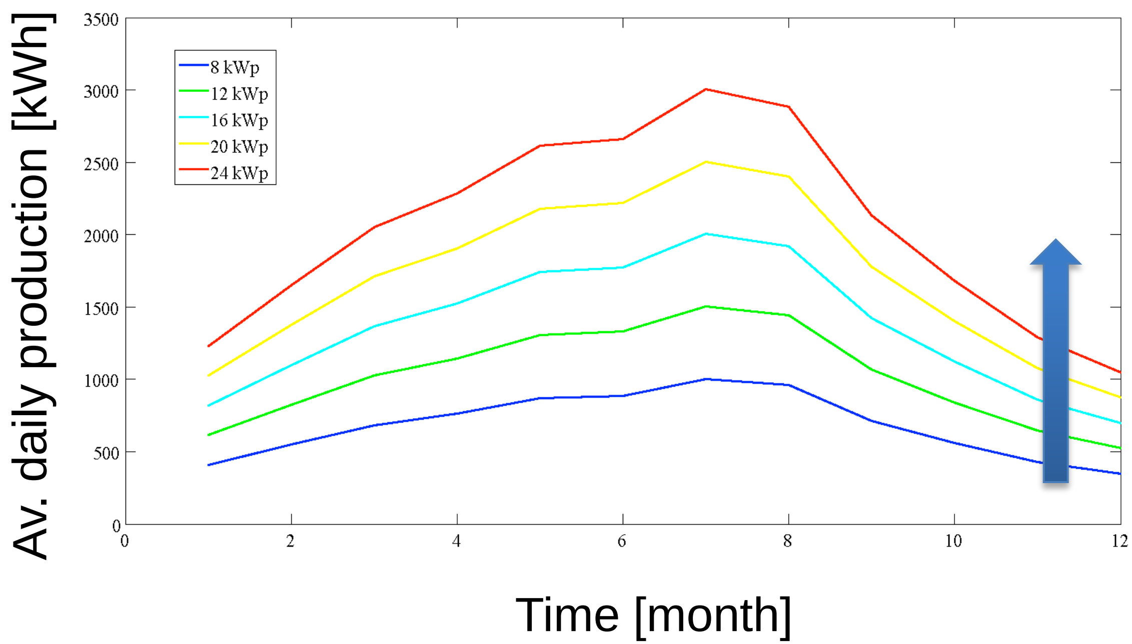
  Source: NREL, "Photovoltaic Degradation Rates - An Analytical Review," http://www.nrel.gov/docs/fy12osti/51664.pdf

- Electricity price increases by 3% per year

  Source: European Commission, "EU Energy Trends to 2030", 2009

Simulate energy production

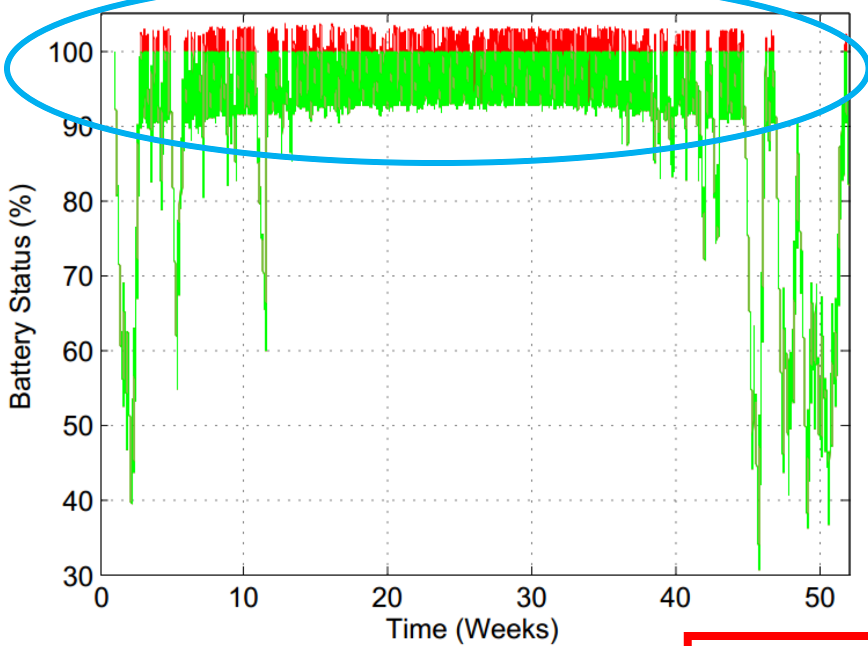
- Consider historical meteo data (typical meteorological year)
- Model the PV system and compute production



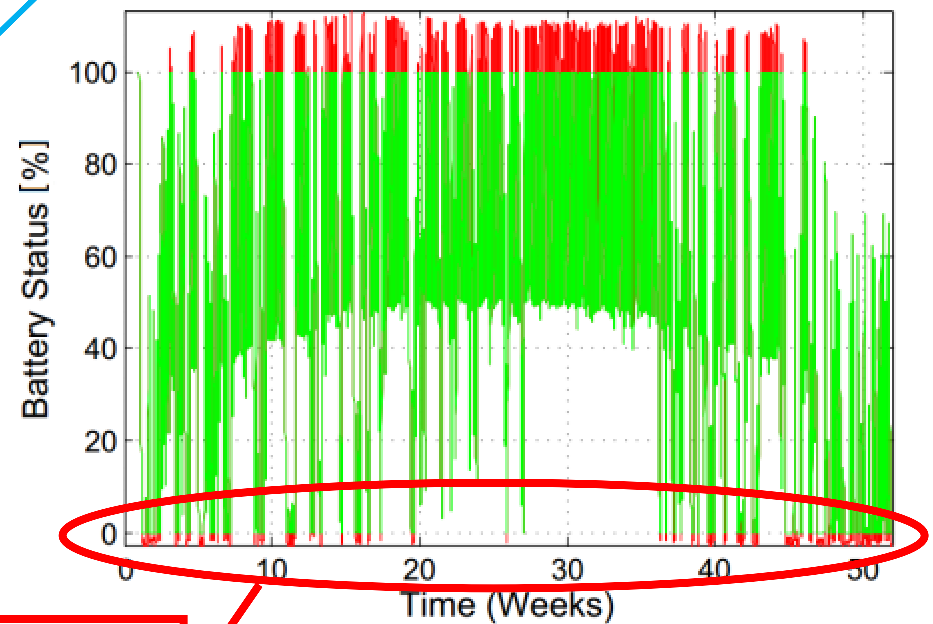
- Larger systems allow for larger production
- Production changes according to season, while BS traffic and energy consumption do not change

Battery status: Torino

Energy that cannot be stored in the batteries



(a) PT = 100%
PURE PV

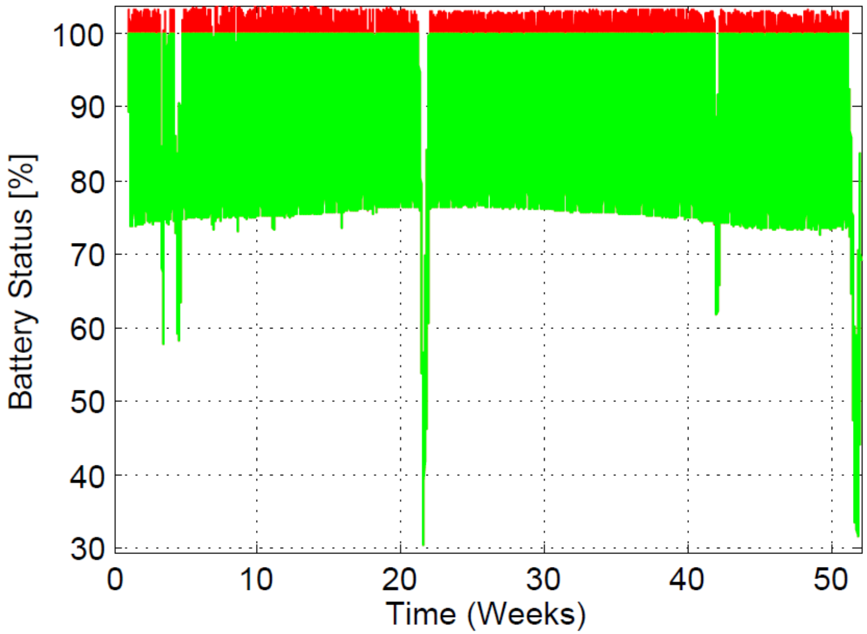


Energy bought from the Power Grid

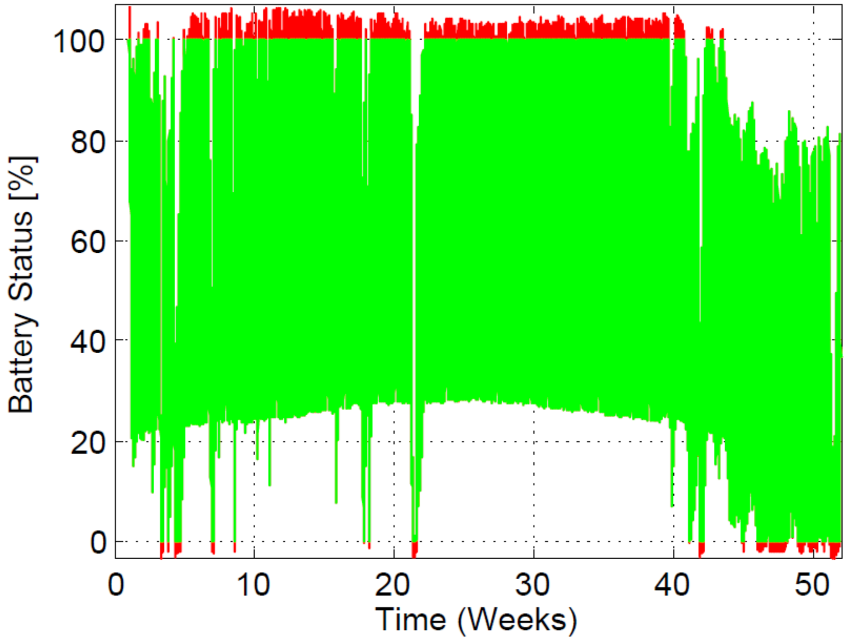
(b) PT = 70%
HYBRID

- More balanced discharge depth during the whole year in the hybrid system
- Strong bottleneck effect in winter for the pure PV case

Battery status: Aswan



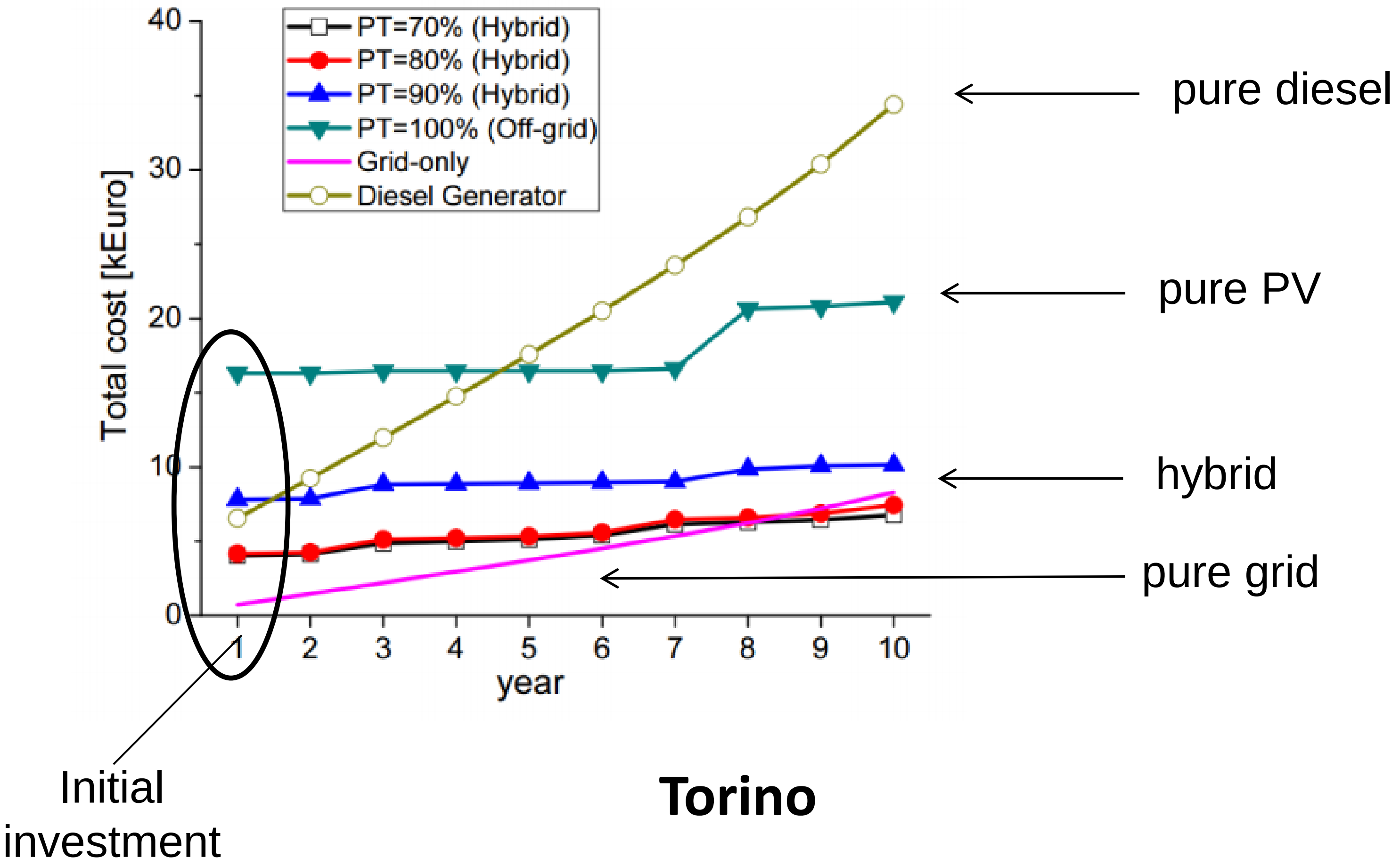
(a) PT = 100%



(b) PT = 70%

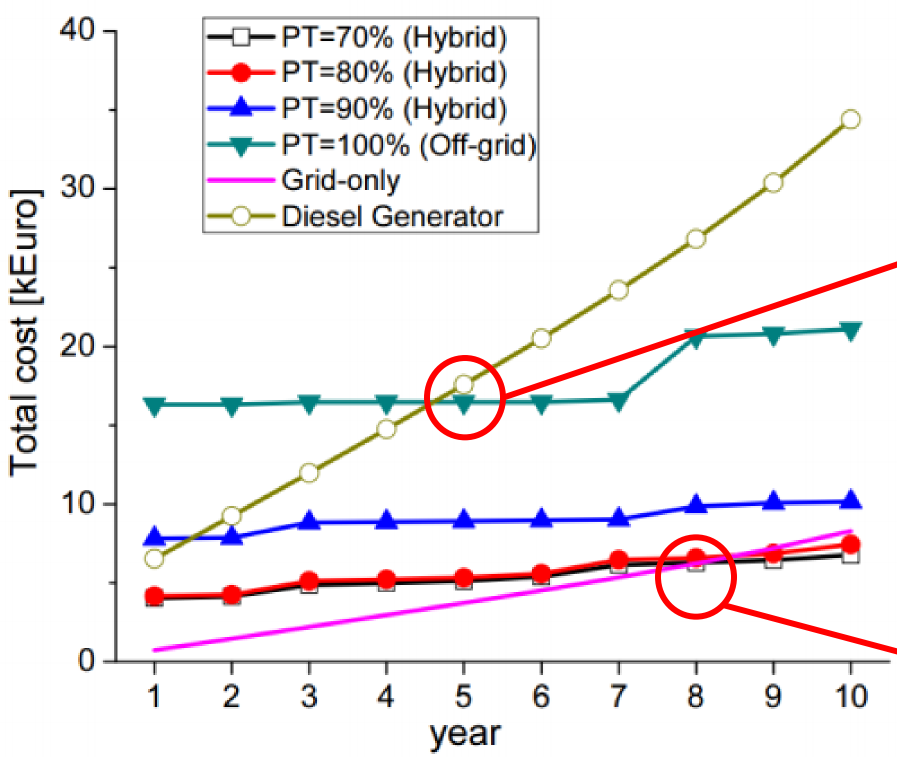
Always deeper and more balanced battery discharge than the case of Torino → more suitable dimension and no bottleneck effect in winter

Total cost in 10 years (CAPEX+OPEX)



Torino

Total cost in 10 years



Torino

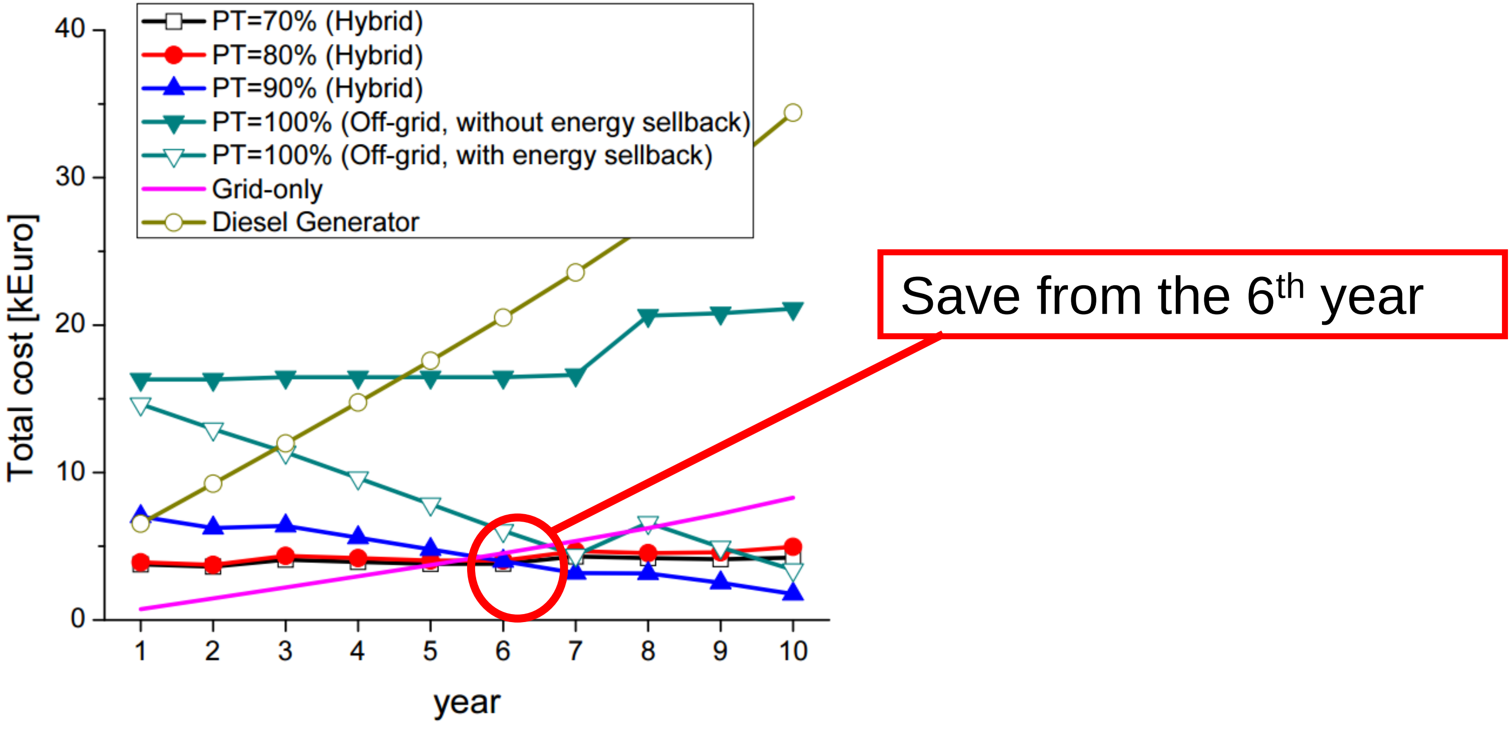
Hybrid is always cheaper than pure diesel

Pure PV saves from the 5th year wrt pure diesel

Hybrid saves from the 8th year wrt the grid-only case

Selling back energy

- Total cumulative cost, with the possibility to sell back energy



Size and cost of PV system - Torino

PT	PV size [kWp]	Number of batteries	PV+battery cost [kEuro]	Grid cost [kEuro/year]	Pay back [kEuro/year]
70%	4.3	5	4.07	0.16	0.240
80%	4.3	7	4.38	0.12	0.229
90%	9.1	7	8.07	0.05	0.850
100%	16.6	27	16.92	0	1.832

Hybrid drastically reduces PV size and no. batteries

Size and cost of PV system - Aswan

PT	PV size [kWp]	Number of batteries	PV+battery cost [kEuro]	Grid cost [kEuro/year]	Pay back [kEuro/year]
70%	3.8	5	3.69	0.019	0.017
80%	3.9	7	3.76	0.014	0.024
90%	3.9	7	3.92	0.012	0.024
100%	5	27	6.15	0	0.109

Smaller dimensioning

Very small amount from/to Grid

Evolution of BS technology

- With new BSs, consumption is reduced
- The size of PV panels and the no. of batteries reduce also

BS model	Full load [W]	No load [W]	Daily [kWh]
new 2x2 MIMO	702.6	114.5	8.65
new 4x4 MIMO	742.2	138.9	9.39
old with RRU	840.0	504.0	14.46

- Smaller consumption at low load
- Higher load proportionality

Source: GreenTouch project, 2015.

Size and cost of PV system

PT	PV size [m^2]		
	old BS	2x2 MIMO	4x4 MIMO
70%	21.5	9	10
80%	21.5	9	11
90%	45.5	13	14
100%	83.0	15	17.5

PV panel size drastically reduced!

When solar cells will achieve 50% efficiency

PT	PV size [m^2]	
	2x2 MIMO	4x4 MIMO
70%	3.6	4
80%	3.6	4.4
90%	5.2	5.6
100%	6	7

Conclusion and discussion

Awareness about the huge energy consumption of communication networks has led to development of more energy efficient solutions and technologies

However, for sustainability, energy efficiency alone is not enough

Conclusion and discussion

Networking should be combined with new energy generation principles

Powering BS with renewable sources

- is cost effective
- allows service provisioning in disadvantaged areas
- is well suited to critical infrastructure protection
- allows communications after natural disasters
- avoids cabling difficulties

Thank you!
Questions?