Energy efficiency improvement of distributed data centers

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joint work with **Demetrio Laganà, Carlo Mastroianni, Daniela Renga**

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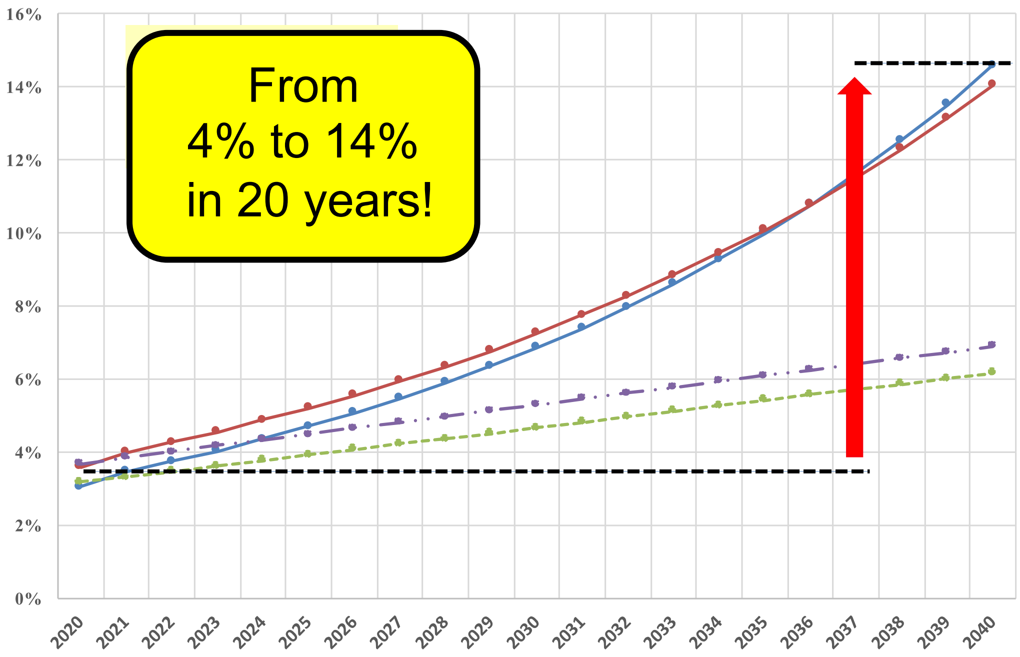
Is ICT sustainability an issue?

- According to recent estimates, ICT industry
  - generates about 3% of emissions today
  - might generate up to 14% emissions by 2040



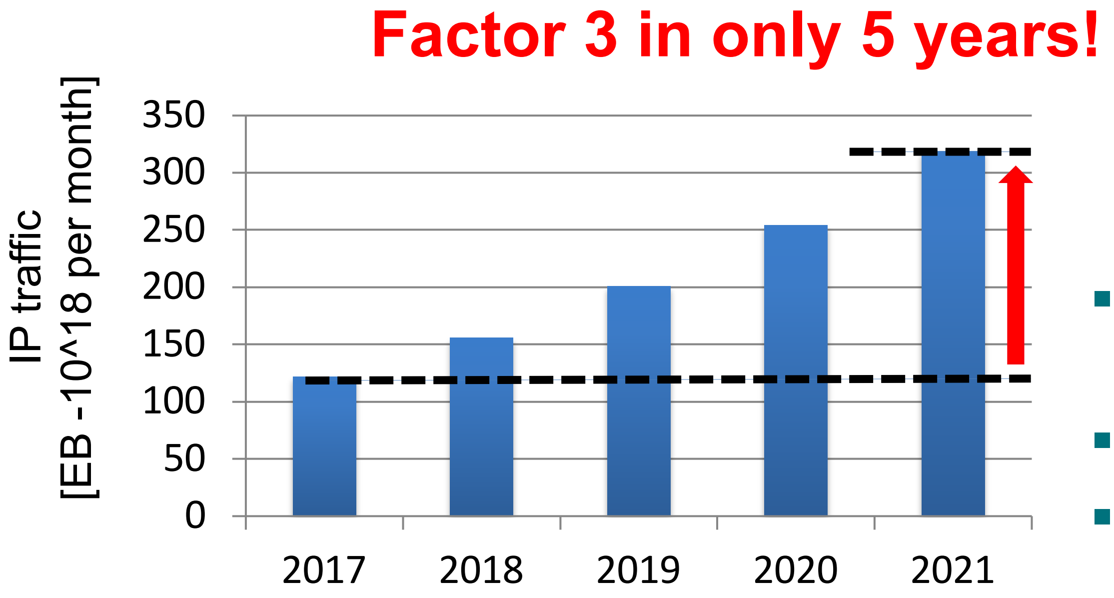
ICT Global Carbon Footprint relative to Total WW Footprint
2020 thru 2024

From
4% to 14%
in 20 years!

Source: Lotfi Belkhir, Ahmed Elmeligi, ‘’Assessing ICT global emissions footprint: Trends to 2040 & recommendations”, Elsevier Journal of Cleaner Production 177 (2018) 448-463

Where is the forecast coming from?

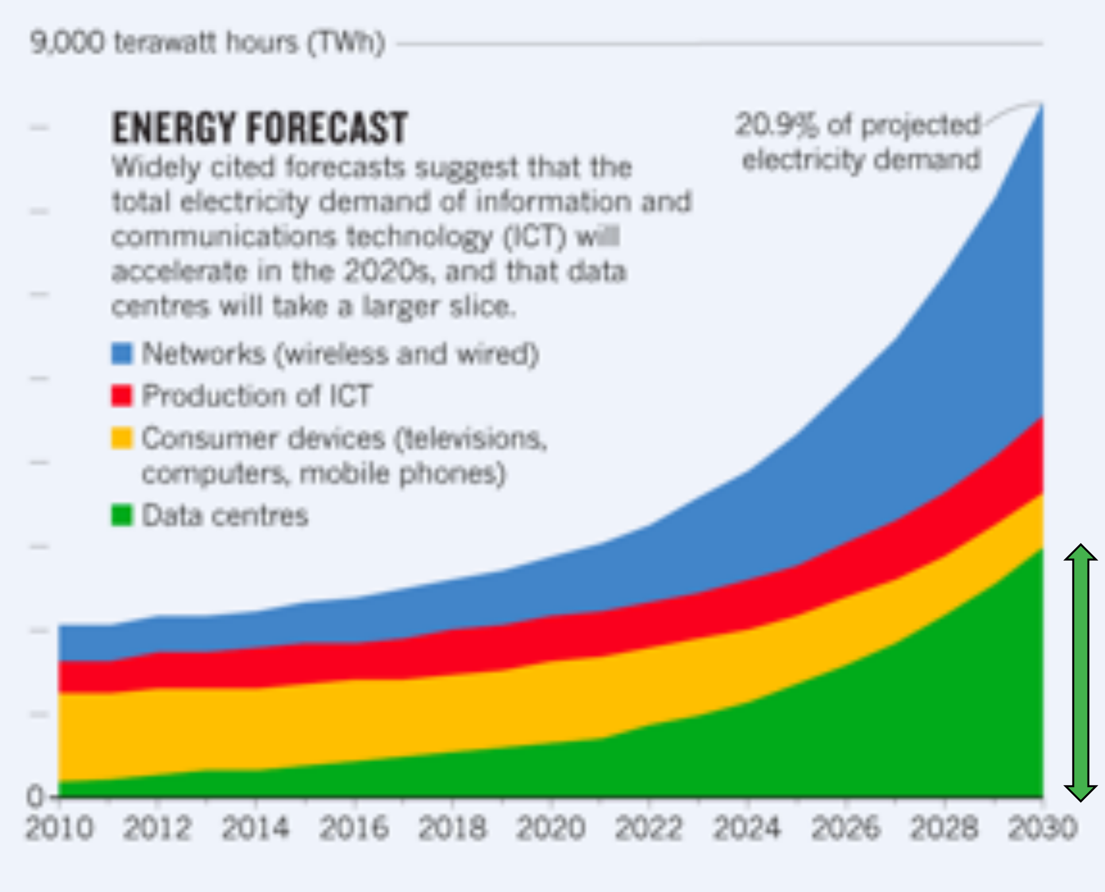
- The expected growth of electricity demand and hence emissions is due to the data tsunami



- popularity of high-rate multimedia applications
- more people connected
- traffic generated by robots, sensors, machines

Source: Cisco VNI, 2017

DC contribution to consumption



DC consumption

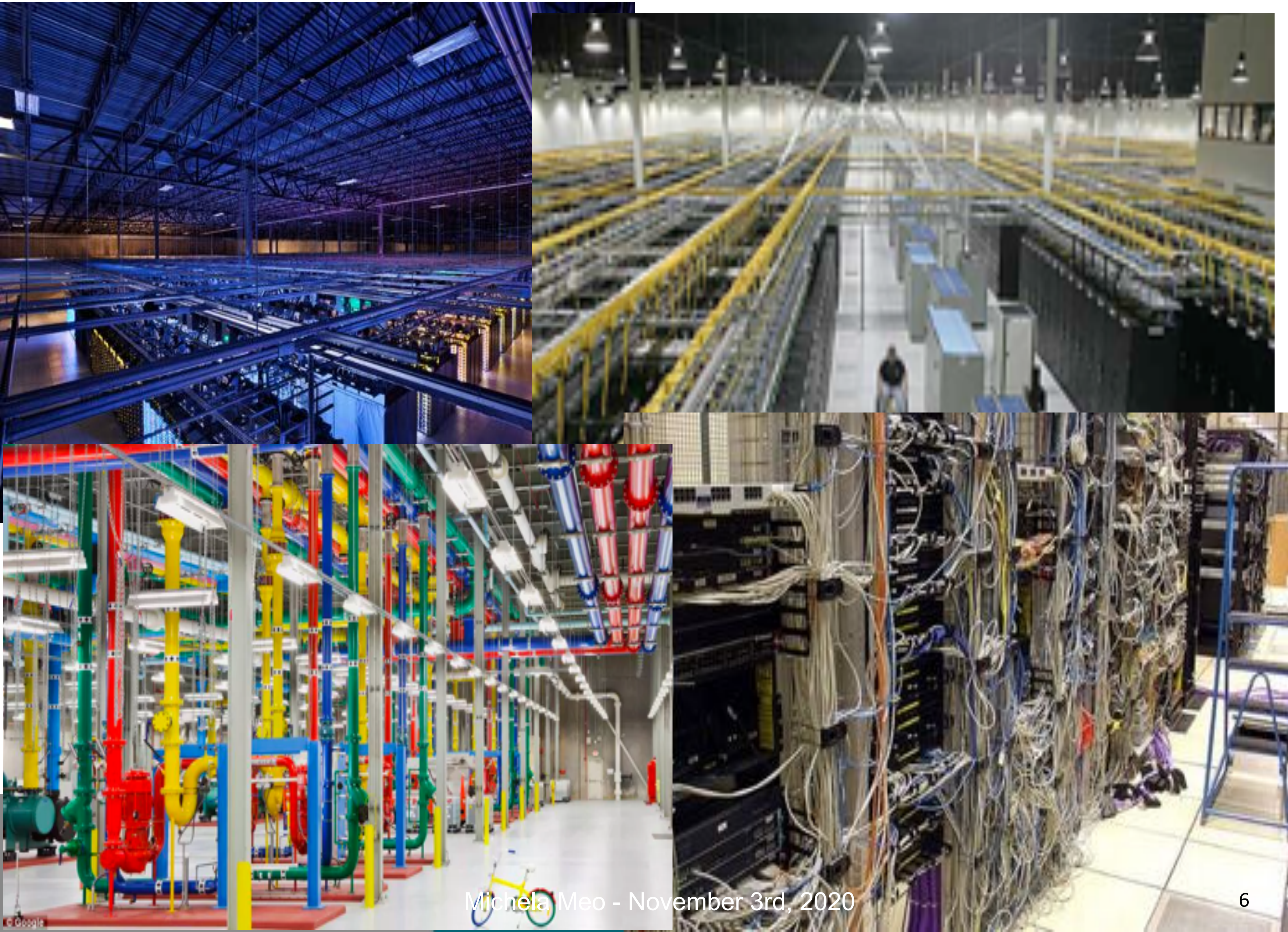
- a large fraction
- expected to grow at faster pace

Source: How to stop data centres from gobbling up the world's electricity, Nicola Jones, Nature NEWS FEATURE 12 SEPTEMBER 2018

Huge values

- In US, data centers consume **3% of total US electricity**
- The most consuming DCs in the world
  - China-Telecom inner Mongolia Information Park: 150 MW
  - China-Mobile Hohhot DC: 115 MW
  - China-Mobile Harbin DC: 150 MW

Source: http://worldstopdatacenters.com/power/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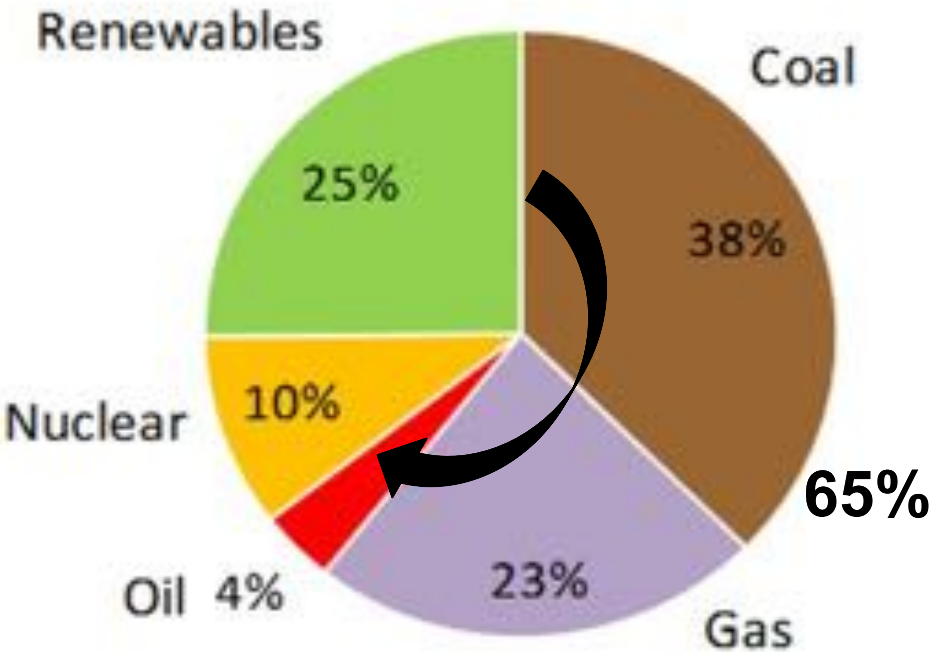
Not only a matter of consumption

- Consumption is only one side of the story
- Sustainability issues have to be evaluated by considering how electricity is generated (carbon footprint)

2017 World Electricity Production



Still a lot of fossil fuel

→ carbon emissions

Source: International Energy Agency: Electricity Statistics, www.iea.org

Awarenes

Sign in Search International edition

The Guardian

‘Tsunami of data’ could consume one fifth of global electricity by 2025

Billions of internet-connected devices could produce 3.5% of global emissions within 10 years and 14% by 2040, according to new research, reports Climate Home News

▲ A Google data centre. US researchers expect power consumption
more people come online in developing countries. Photograph: Goo

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rld Will Consume 1/5 Of Earth’s Power By

December, 2017 | **UPDATED:** 00:32, 12 December, 2017

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Power consumption in data centers is a global problem

Wayne M. Adams, SNIA Green Storage Initiative

Wayne M. Adams is the chairman of SNIA’s board of directors

The answer is global energy efficiency standards

Sustainable Development Goals

11: air pollution and efficient management practices
12: promoting resource and energy efficiency, sustainable infrastructures
13: cleaner, more resilient economies

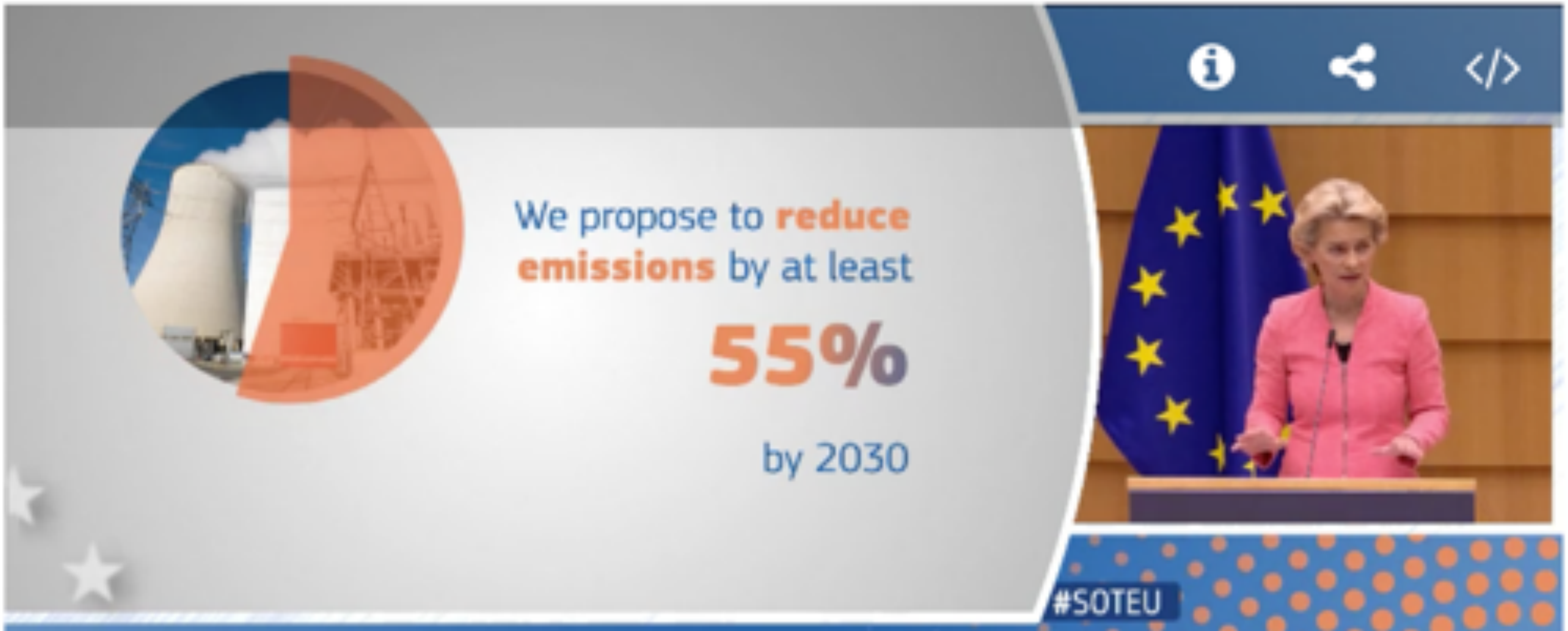
European Green Deal

Become
climate-neutral
by 2050

A plan to **make the EU's economy sustainable**

- State of the Union Address on Sept. 16, 2020

> *"the European Commission is proposing to increase the 2030 target for emission reduction to at least 55%. […]. The 2030 target is ambitious, achievable, and beneficial for Europe."*
>
> *Ursula von der Leyen, President of the European Commission*



We propose to **reduce emissions** by at least

55%

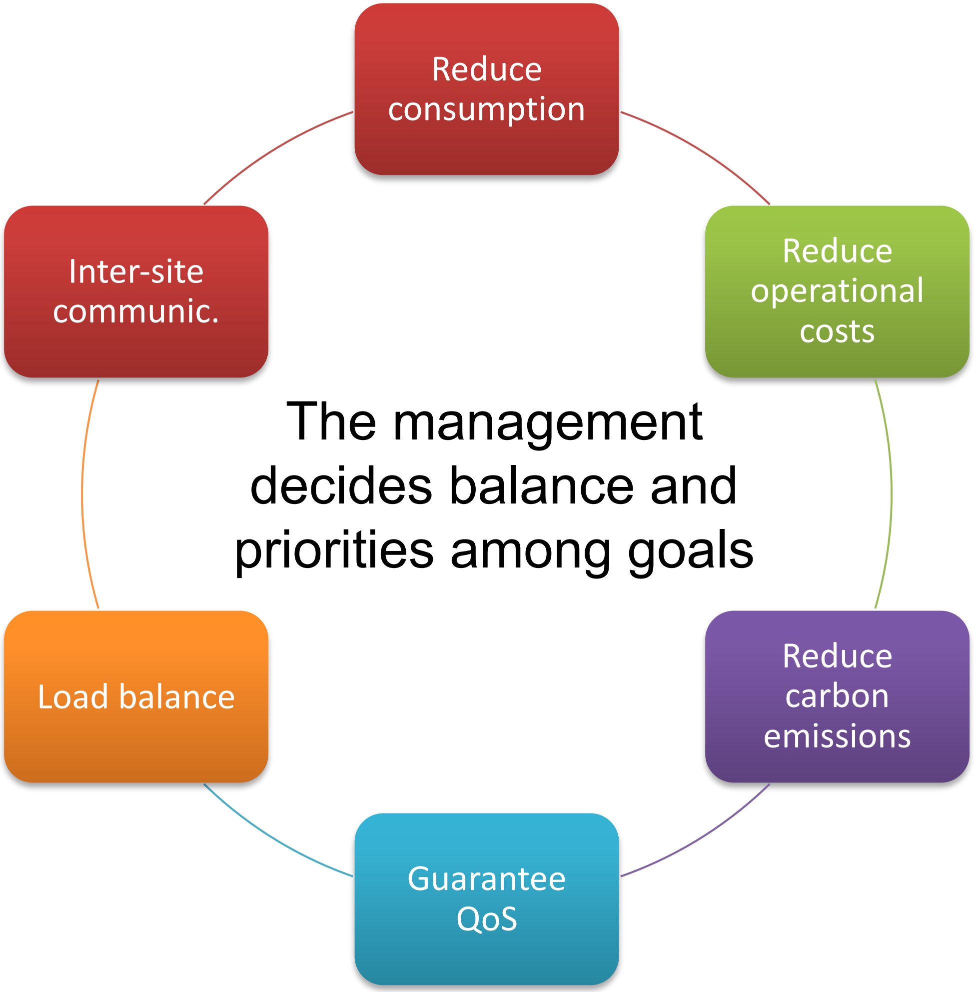
by 2030

What do these data say?

- There is and will be a significant **increase** of ICT technologies, everywhere, with more demanding services
- **Data Centers** are one fundamental component of this scenario
- Electricity generation is still mainly based on **fossil fuel**, there is a **threat to climate and environment**

- There is an issue of ICT sustainability
- Make ICT more sustainable: consume less, consume better

DC management goals



high consumption makes power supply difficult

Reduce consumption

Reduce operational costs

high OPEX reduces revenues

Reduce carbon emissions

targets by law, competitive advantage

Guarantee QoS

avoid overloads

Load balance

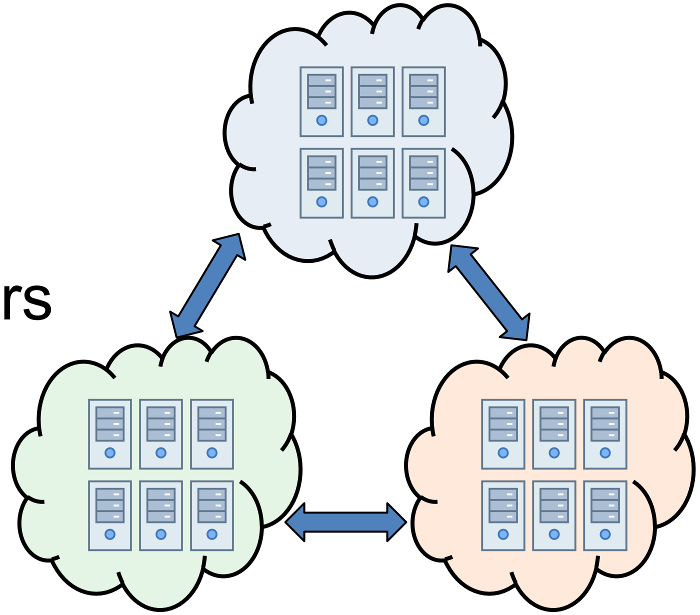
prevent overload

Inter-site communic.

it is a cost, should be carefully decided

The management decides balance and priorities among goals

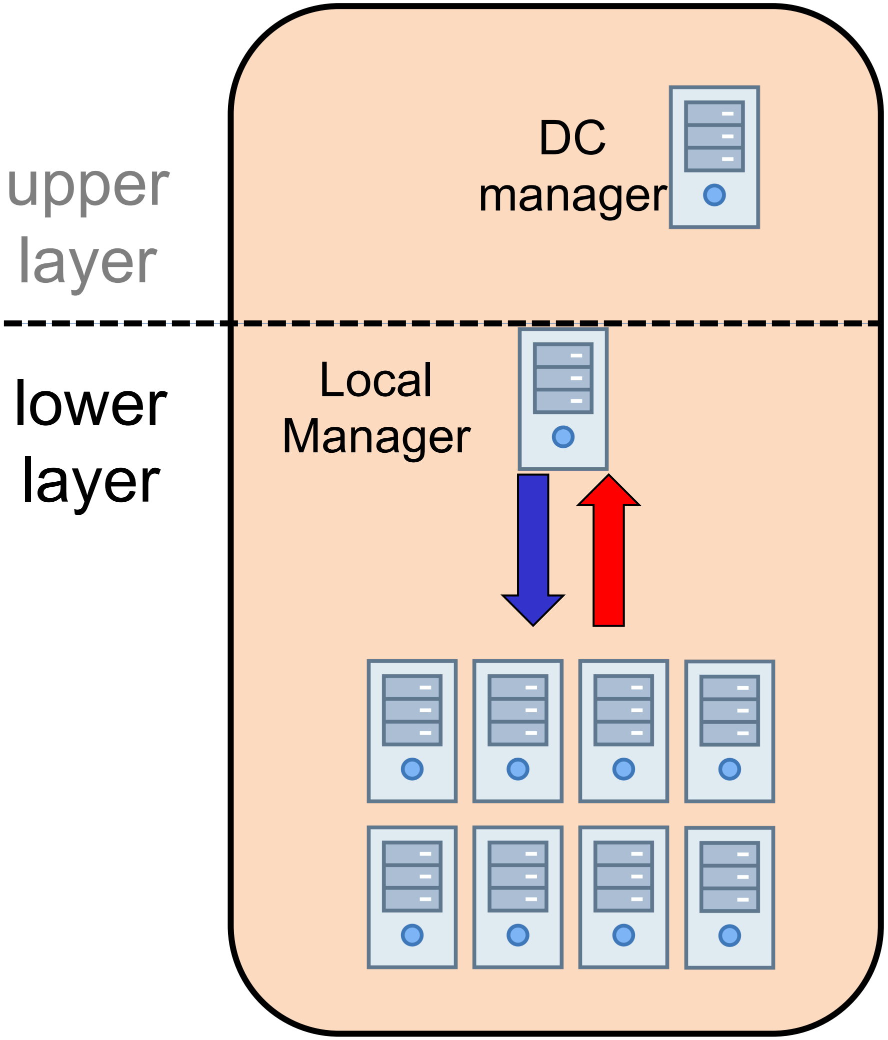
EcoMultiCloud



- For multi-site DCs
- Hierarchical architecture with two layers
  - Lower layer
    - DC monitoring and data collection
    - Intra-cloud consolidation
  - Upper layer
    - Data exchange among DCs
    - Assignment and migrations decision

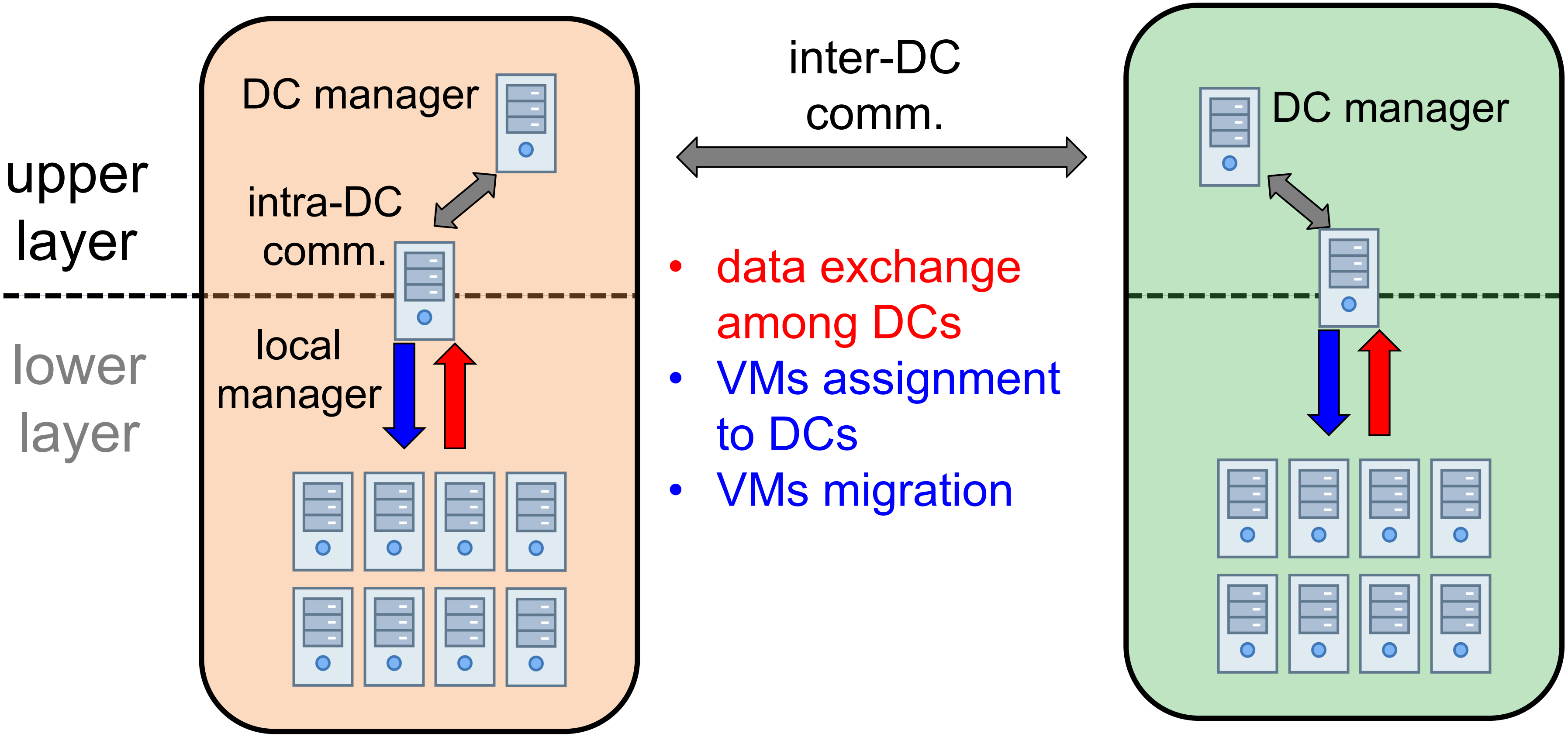
Sources:

- "Reducing the Operational Cost of Cloud Data Centers through Renewable Energy", D. Laganà, C. Mastroianni, M. Meo, D. Renga, MDPI Algorithms, Vol. 11, No. 10, 2018.
- "Hierarchical approach for efficient workload management in geo-distributed data centers", A. Forestiero, C. Mastroianni, M. Meo, G. Papuzzo, M. Sheikhalishahi, IEEE Transactions on Green Communications and Networking, Vol. 1, No. 1, 2017.
- "Probabilistic consolidation of virtual machines in self-organizing cloud data centers," C. Mastroianni, M. Meo, G. Papuzzo, IEEE Transactions on Cloud Computing, Vol.1, No.2, 2013.



collect data

intra-DC consolidation
→ assign VMs to servers



- data exchange among DCs
- VMs assignment to DCs
- VMs migration

Upper layer: assignment function

- At DC *i*, compute a cost function, *assignment function*:

Y_k at DC *i* is the component *k* of the cost

$$f_a^{(i)} = \sum_{k=1}^{M} \beta_k \frac{y_k^{(i)}}{y_k^{Max}} \qquad \sum_{k=1}^{M} \beta_k = 1$$

Weight decided by DC management

Normalization

- Assign the VMs to the DC *i* with the smallest $f_a^{(i)}$

Example: cost and load balance

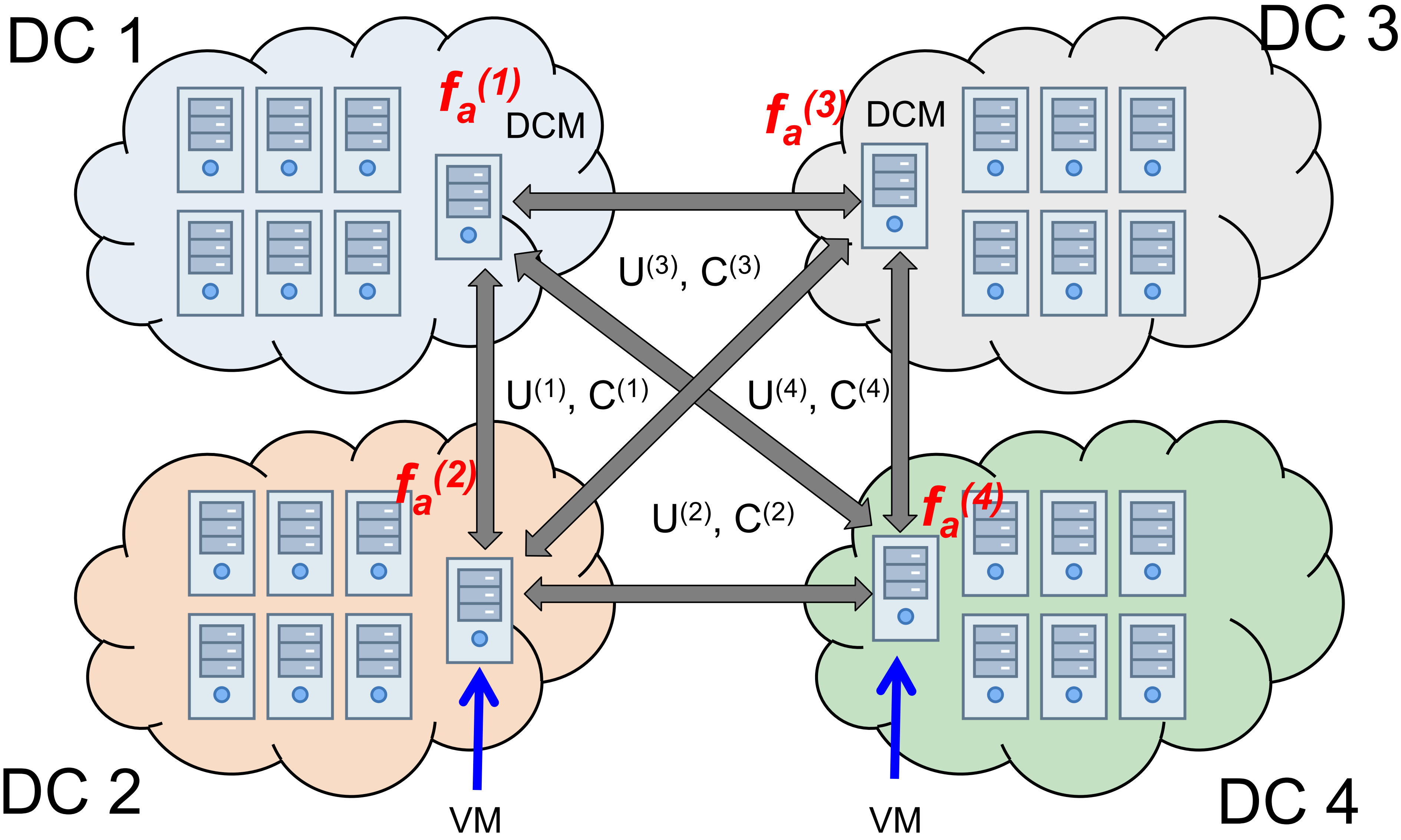
- Minimize cost, guaranteeing that the load is not too unbalanced; use
  - load, *U,* to define at load balance
  - energy cost, *C*, depends on electricity price and PUE, Power Usage Effectiveness
    - (in case of carbon footprint, it would depend on electricity footprint)

load

energy cost

$$f_a^{(i)} = \beta \frac{U^{(i)}}{U^{Max}} + (1-\beta)\frac{C^{(i)}}{C^{Max}}$$

weight that defines how important the goal of load balance is w.r.t. cost

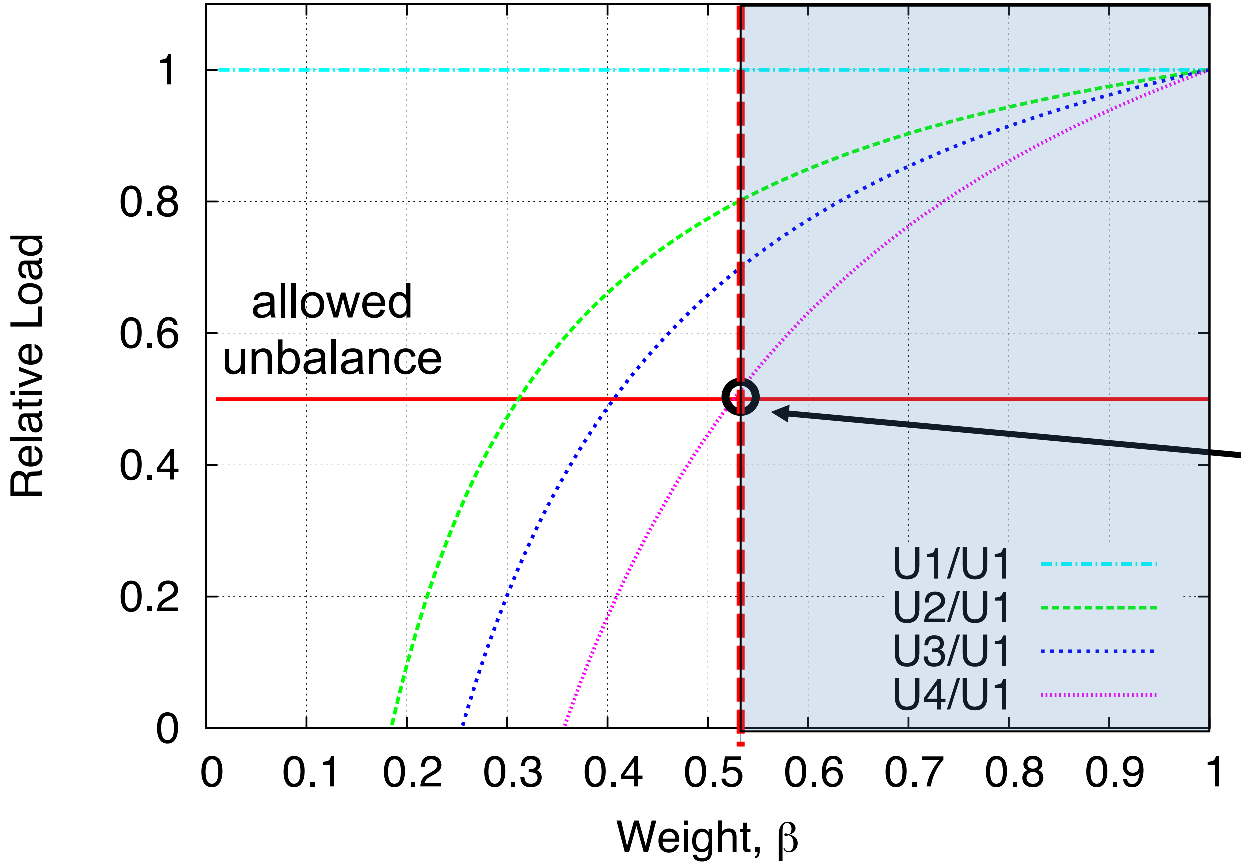

DC 1
$f_a^{(1)}$
DCM
$f_a^{(3)}$
DCM
DC 3
$U^{(3)}, C^{(3)}$
$U^{(1)}, C^{(1)}$
$U^{(4)}, C^{(4)}$
$f_a^{(2)}$
$f_a^{(4)}$
$U^{(2)}, C^{(2)}$
DC 2
DC 4
VM
VM

Assignment and migrations

- At the steady-state the values of $f_a^{(i)}$ tend to be
  - the same for all the sites
  - the lowest possible
- The geo-distributed DC adaps to variations, in a self-organizing way
- To speed up adjustments to changes in the scenario (e.g., electricity price variations) VM *migrations* are needed
  - Periodically check if differences among $f_a^{(i)}$ values is larger than a given threshold
  - If so, migrate VMs from DC with the largest f_a to DC with the smallest

Cost and load balance

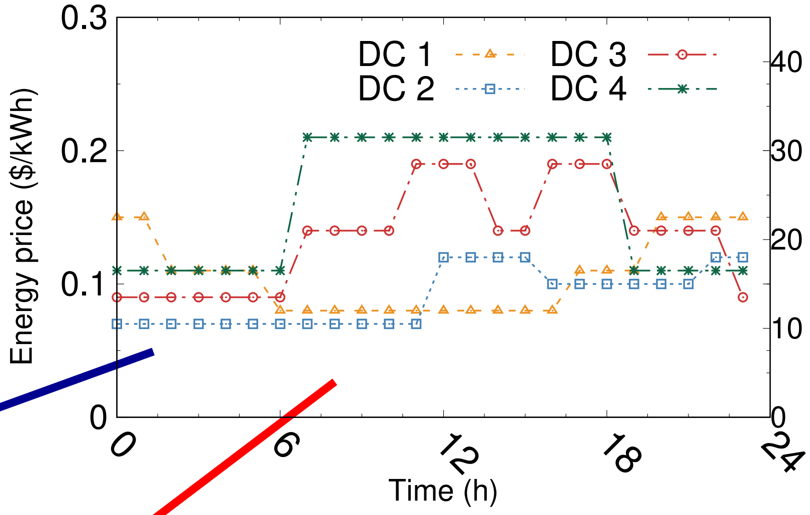
$$f_a^{(i)} = \beta \frac{U^{(i)}}{U^{Max}} + (1-\beta)\frac{C^{(i)}}{C^{Max}}$$



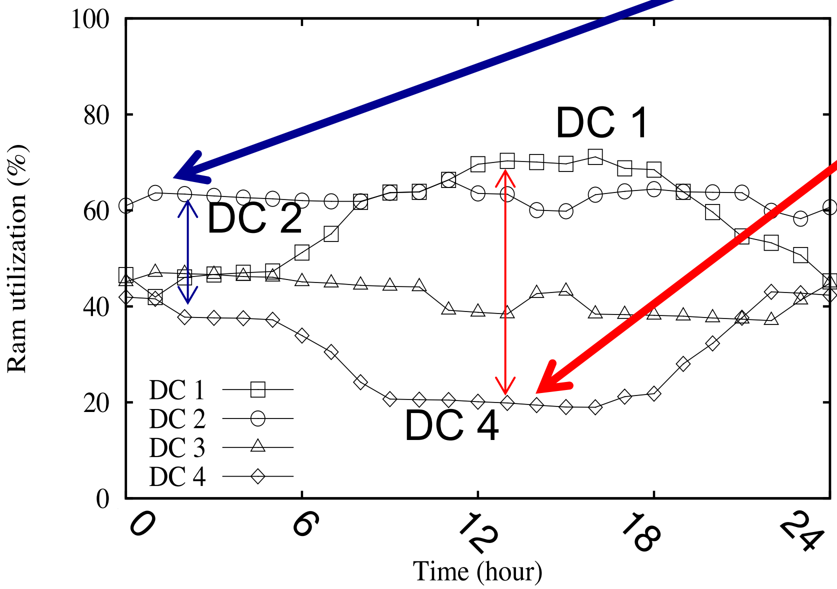
requirement on load balance is satisfied

min value β that satisfies requirement and minimizes cost

Adapt to price variations



- low price in DC 2
- high price in DC 1 and DC 4

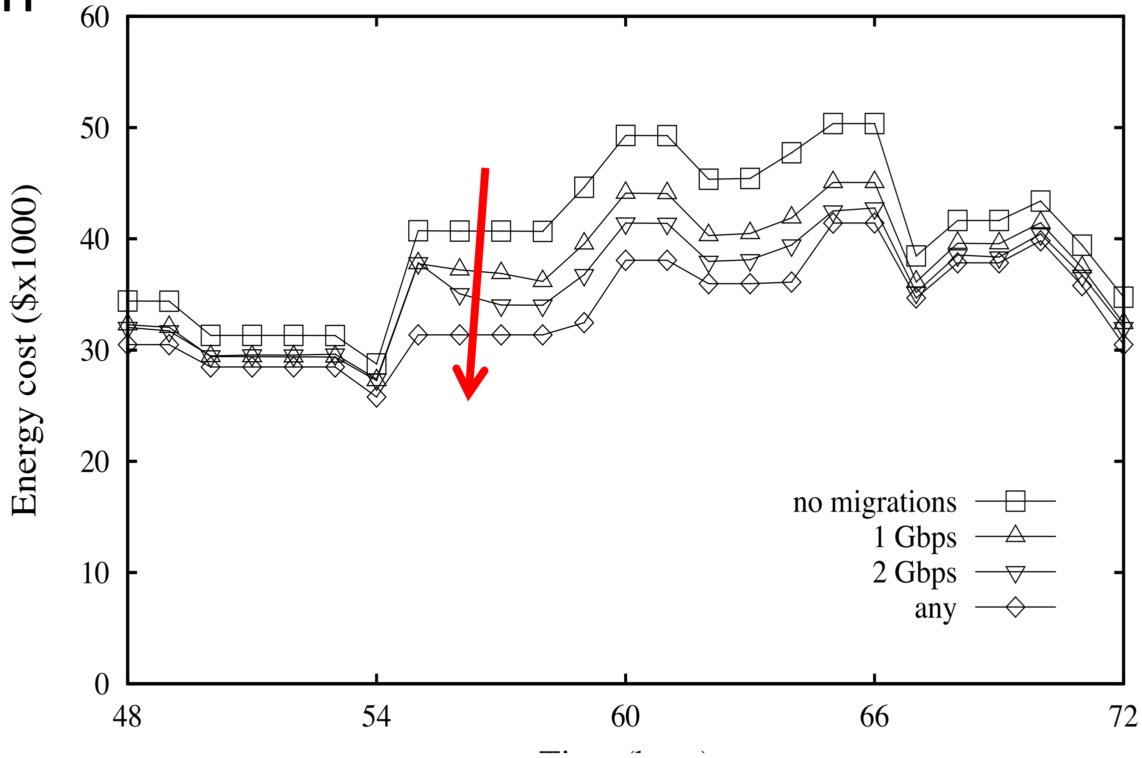


- low price in DC 1
- high price in DC 4

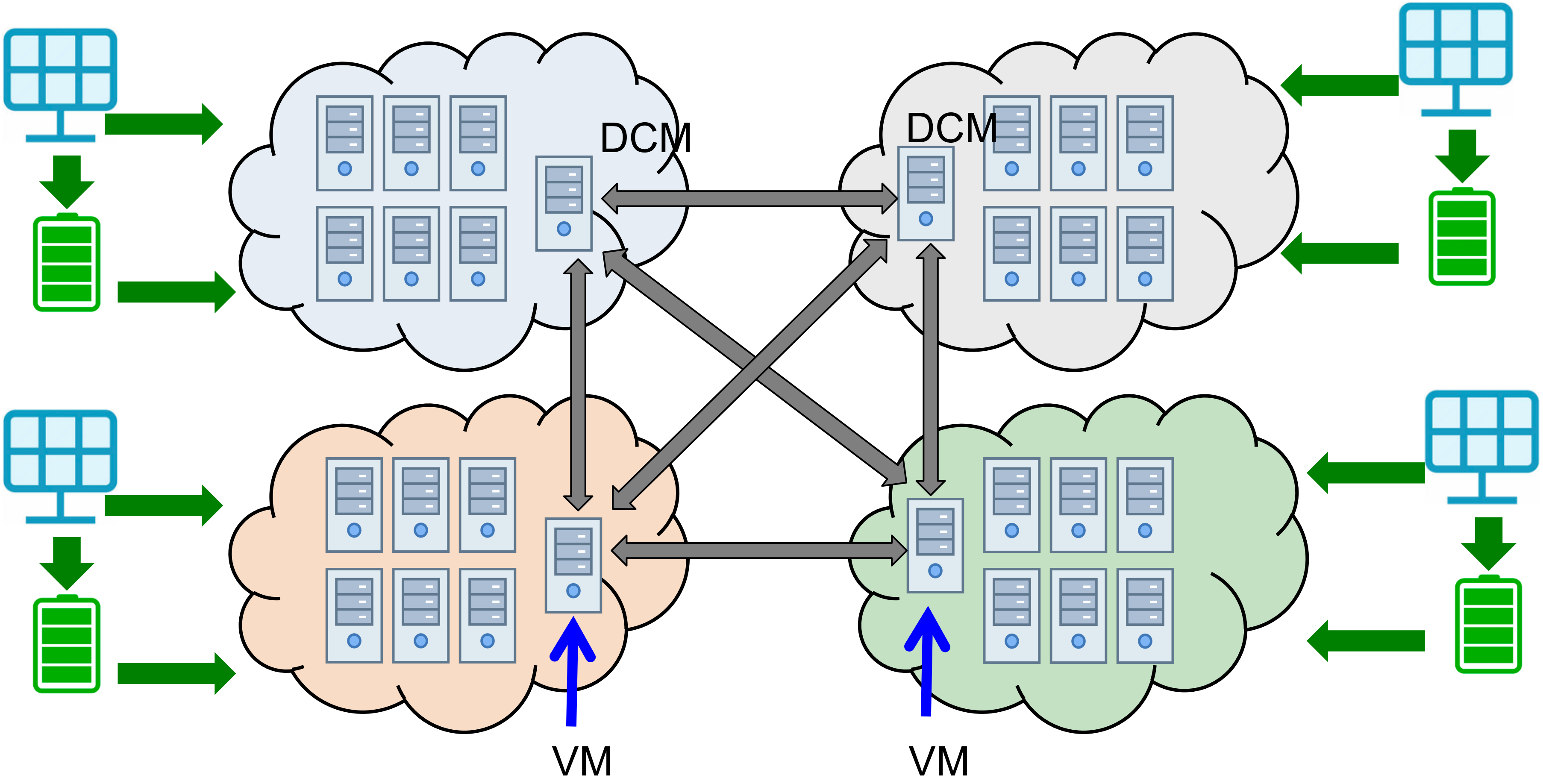
Effect of migrations

Migrations allow a higher
- capability to adapt
- level of consolidation

→ reduce costs

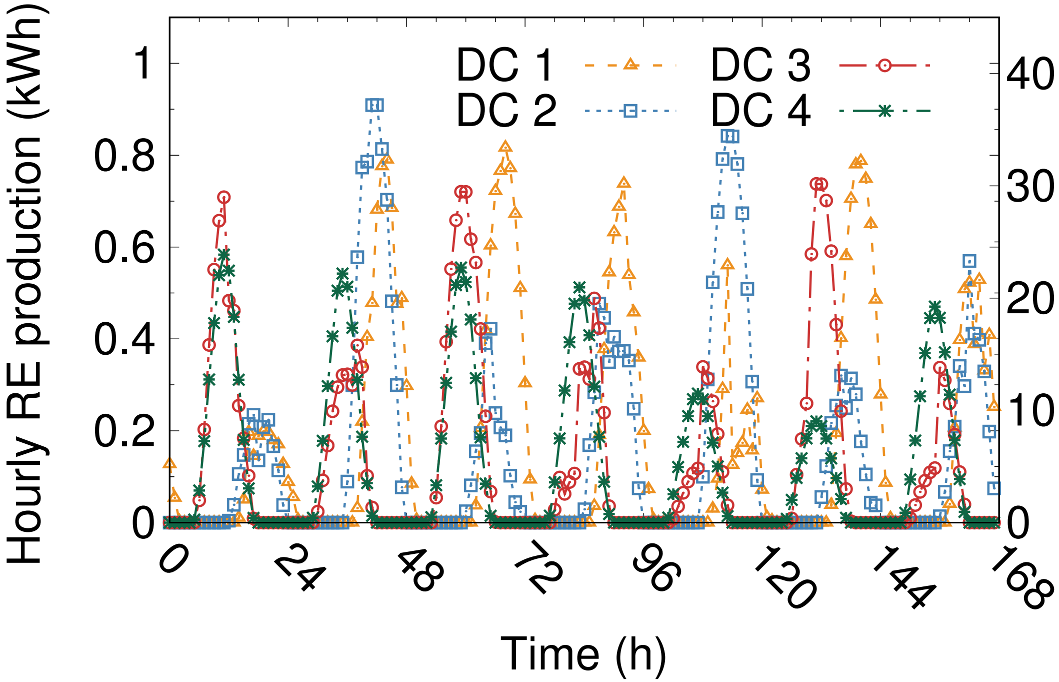


Introduction of renewable energy



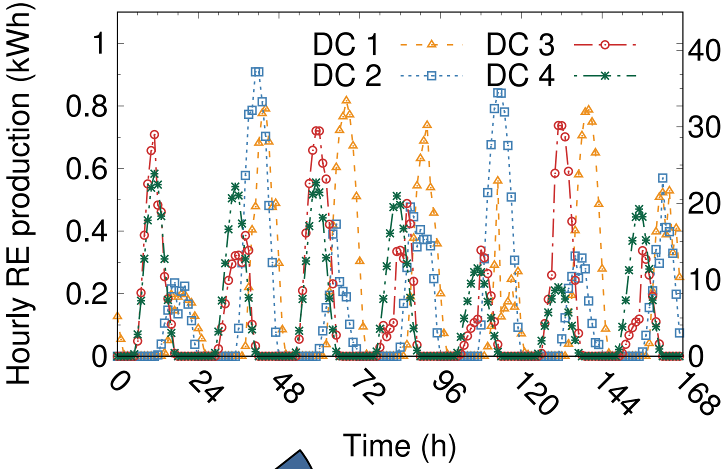
Energy production

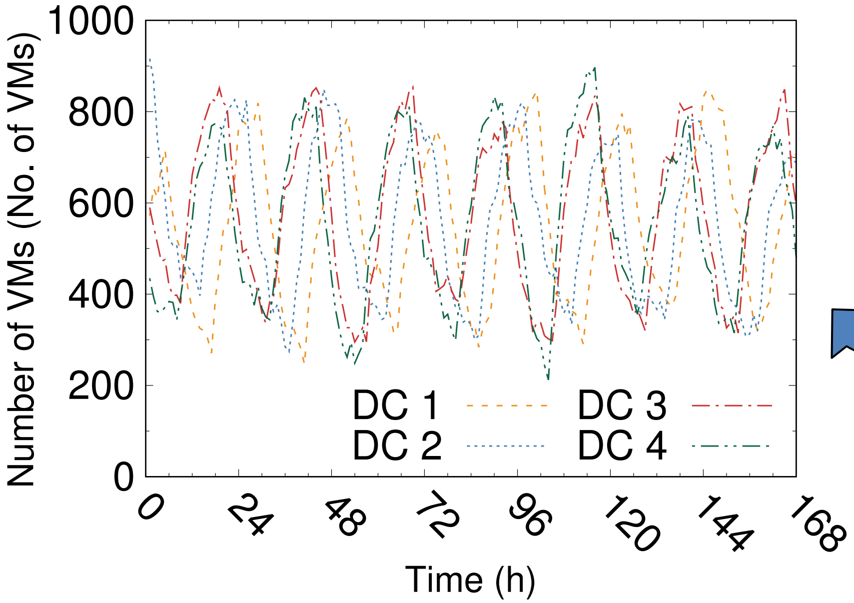
- Energy production depends on time zones
- Take advantage of geographical diversity



Energy production

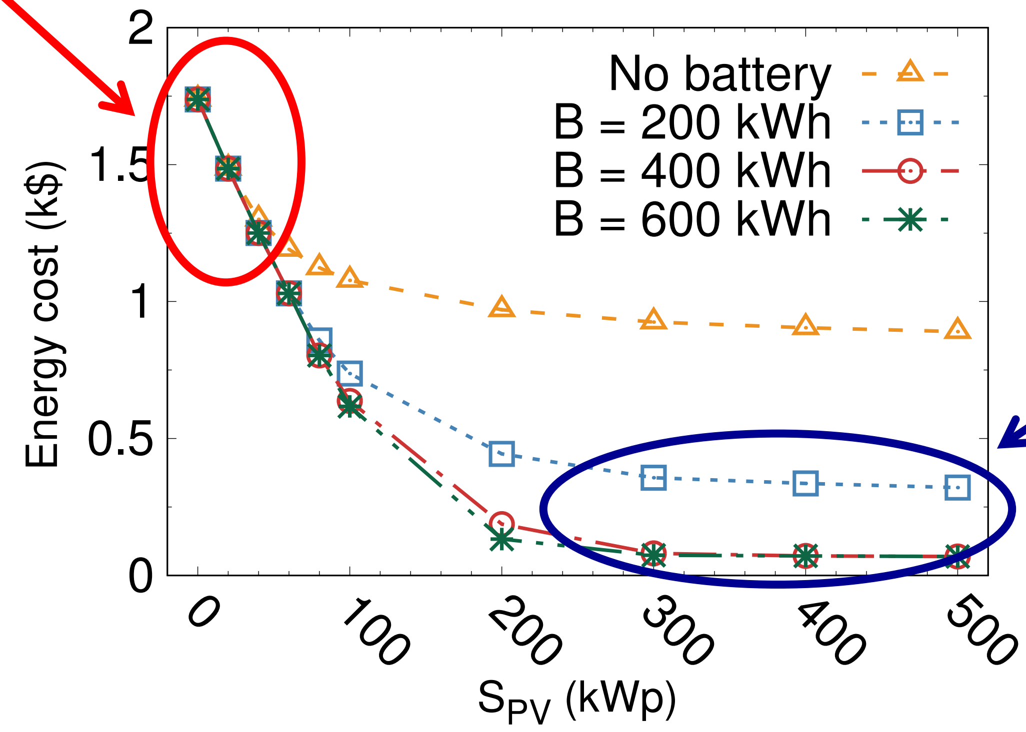
Adapt VM allocation to energy production





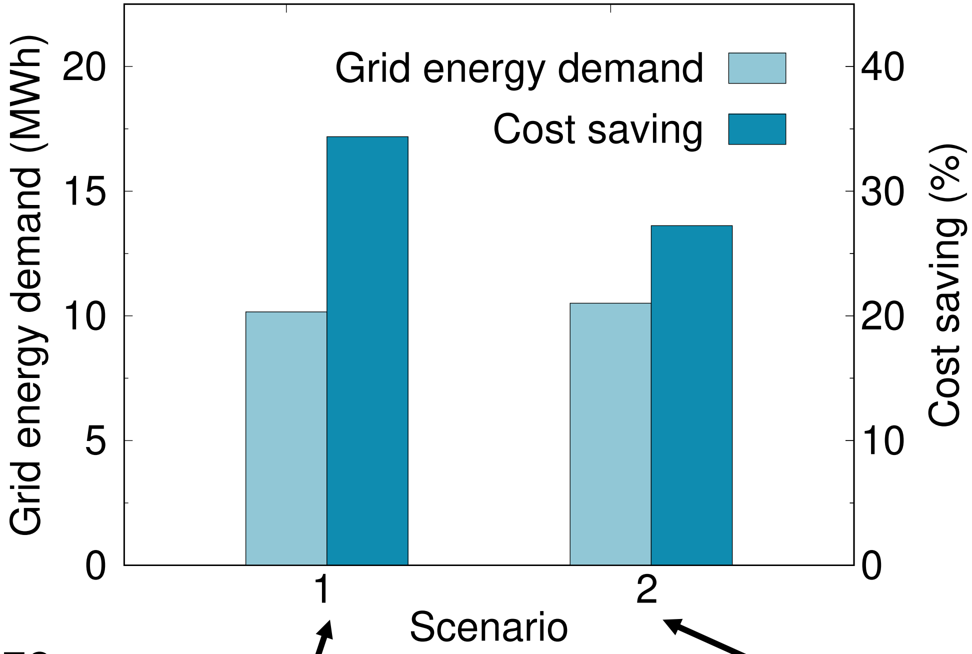
Reduce cost, reduce emissions

- Small PV panels
- Need to buy



- Large PV panels
- Need storage for night power supply

CAPEX and OPEX



cost saving depends on electricity price also

PV panel size

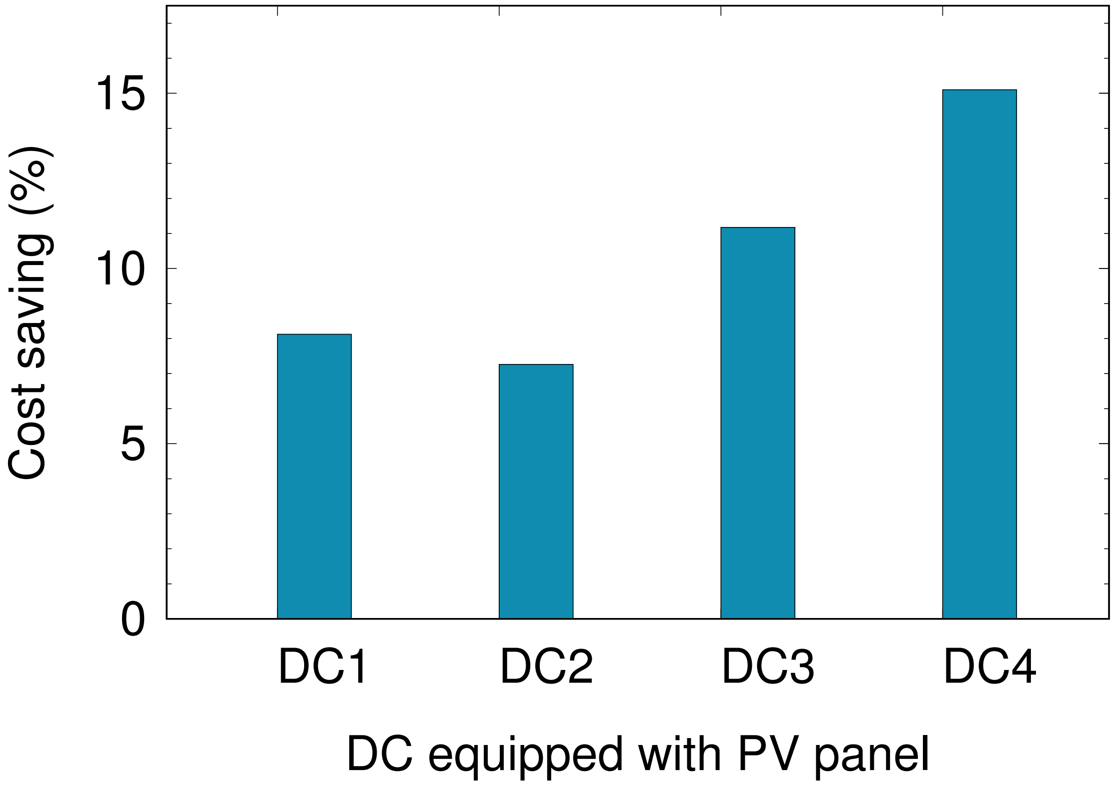
DC 1	DC 2	DC 3	DC 4
20	40	60	80

[kWp]

DC 1	DC 2	DC 3	DC 4
80	60	40	20

CAPEX and OPEX

One 80 kWp panel only



preferentially produce where electricity is more costly

Conclusions

- ICT sustainability is a key challenge that requires the adoption of
  - energy consumption strategies
  - renewable energy sources
- Joint network and energy management strategies are needed
- Through assignments and migrations, strategies should adapt load to
  - energy production
  - consumption
  - cost

Thanks!