Energy Adaptive Infrastructure for Sustainable Cloud Data Centres

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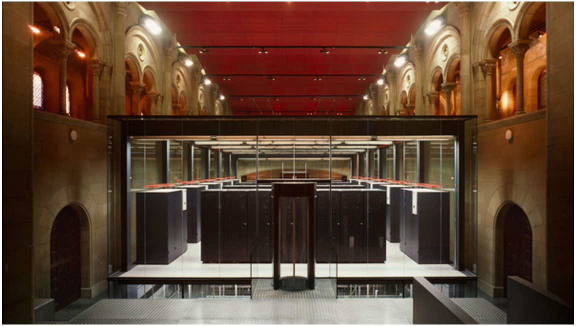
Data centre energy consumption

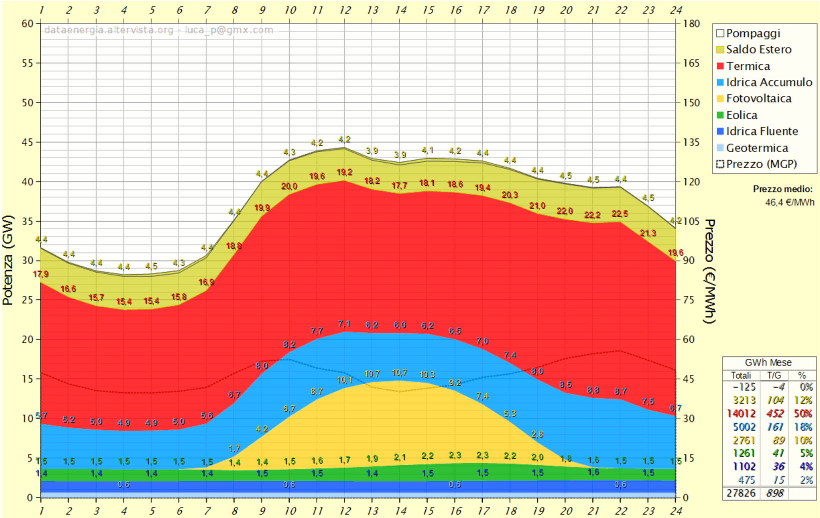
- Between 1.1% and 1.5% of electricity consumed worldwide in 2010
- Google uses 37% of renewables, Apple uses 87%



Energy & data centres

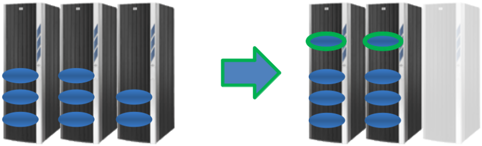
- Renewable energies are very variable
- Data centres are heterogeneous:
  - Computing environments: IaaS, PaaS
  - Virtualization techniques: Virtual machines, containers
  - Applications: task oriented, service oriented
  - Constantly evolving

Electricity production in italy 2014



Reducing Energy Consumption

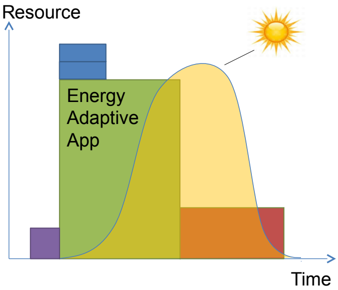
Consolidate application/services and turn unused servers off:



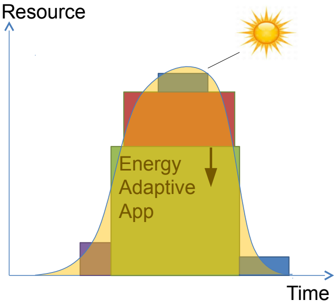
Relocate application/services to efficient servers:

Scheduling Renewable Energies

Not scheduling the renewable energies:



Scheduling the renewable energies:



IaaS, PaaS and applications optimizations

At IaaS level

- consolidate virtual machines (VMs) on the most efficient servers
- switch off unused servers

At PaaS level

- scale up or down applications, following renewables
- common energy interface

At application level

- task-oriented applications
- service-oriented applications

Plug4Green

We present Plug4Green, an energy aware VM manager based on Constraint Programming (CP).

- 23 VM placement constraints
- 2 objectives: reduce overall energy consumption or greenhouse gas emission

EASC

The EASC controls one application, making it “energy adaptive”, and responsive to external energetical requests.

- scheduling algorithms for task-oriented and service-oriented applications
- PaaS and IaaS paradigms
- Energetical model for shared infrastructure

Related Work

- Heuristics for VM positioning
- Energy aware extensible frameworks
- Server power models
- renewable energy scheduling systems
- IaaS/PaaS optimizations and energy models

Outline

Objectives

Objective: reduce the consumption of brown energy from data centres.

This goal is two-fold:

- Reduce the overall energy consumption of the data centre.
- Increase the ratio of renewable energies used in the data centre.

Research problems

- Optimize the placement of virtual machines,
- Cope with a great number of constraints,
- Cope with the extensibility needed to include new constraints,
- Optimize the workload of applications in order to maximize the usage of renewable energies in DCs,
- Use the opportunities offered by PaaS and IaaS data centres for the usage of renewable energies,
- Evaluate the energy consumption of applications in a shared infrastructure.

Outline

Problem formulation

- CPU level is limited:

$$\sum_{j=1}^{k_i} v_j.rVCpu * v_j.aURate \leq k * s_i.nrCore$$

- The vRAM cannot exceed the physical RAM:

$$\sum_{j=1} v_j.aRam \leq s_i.nrRam$$

- Limit the VCPU per physical CPUs:

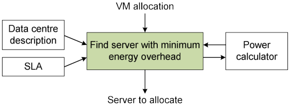
$$\sum v_j.rVCpu \leq s_i.nrCore * maxVCpuPCore$$

- Maximum number of VMs per servers:

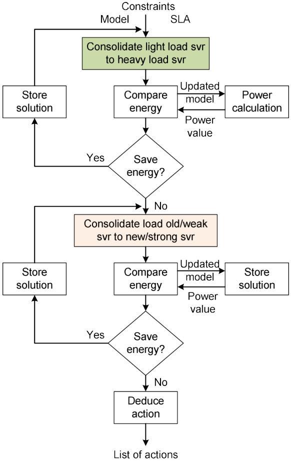
$$k_i \leq maxVmPServer$$

Algorithms

Single Allocation algorithm:

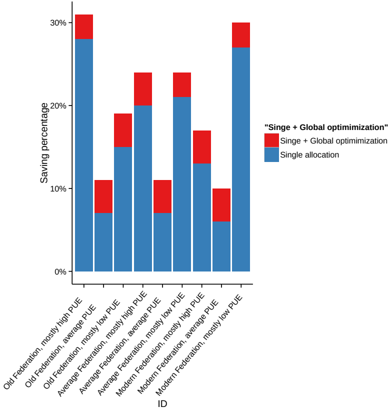


Global Optimization algorithm:

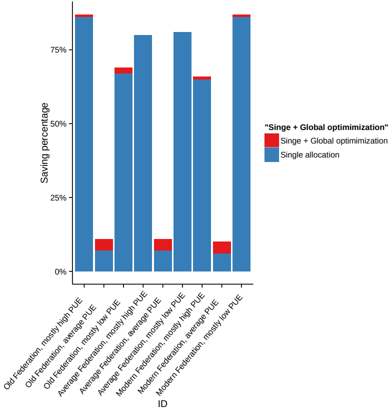


Results

Energy savings:



CO_2 savings:



Performance comparaisons

Performance comparison simulation result:

Algorithm	Power
Round robin	61.23 KW
Round robin + GO	47.64 KW
Load balance	60.46 KW
Load balance + GO	46.56 KW
Greedy	50.74 KW
Greedy + GO	45.67 KW
SA	46.58 KW
SA + GO	44.76 KW

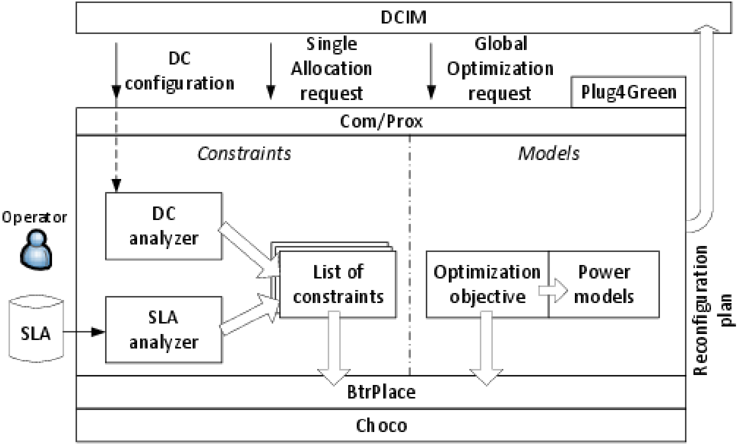
Conclusion: from heuristics to meta-heuritics

- Simple heuristics can be fast and efficient: from 10% to 31% of energy saving
- However, they fail to capture complex and evolving environments

Introduction

- Plug4Green is an energy-aware VM placement algorithm
- Easily specialized and extended to fit the specificities of the data centres
- 23 SLA constraints and 2 objectives

Plug4Green Architecture

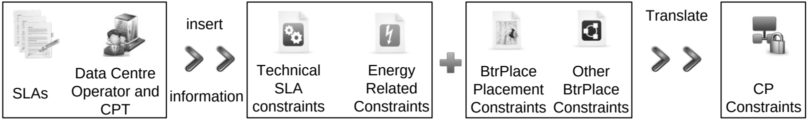


SLA Constraints

Category	Constraint	The Constraint enforces...
Hardware	HDDCapacity	minimum amount of hard disk space available for a VM
	CPUCores	minimum number of CPU cores available for a VM
	CPUFreq	minimum CPU frequency available for a VM
	MemorySpace	minimum amount of memory space available for a VM
	GPUCores	minimum number of GPU cores available for a VM
	GPUFrequency	minimum GPU frequency available for a VM
	RAIDLevel	minimum Raid level available for a VM
QoS	MaxVMperServer	maximum number of VMs per server
	MaxCPULoad	maximum load of CPUs for a server
	MaxVLoadPerCore	maximum virtual load associated to a CPU Core
	MaxVCPUPerCore	maximum number of virtual CPU associated to a physical CPU
	MaxVRAMperPhyRAM	maximum amount of virtual RAM per physical RAM
	MaxServerAvgVCPUperCore	same as MaxVCPUPerCore but averaged for all cores of a server
	MaxServerAvgvRAMperPhyRAM	same as MaxVRAMperPhyRAM but on a server basis
	Bandwidth	minimum network bandwidth available for a VM
Security	DedicatedServer	a VM will be hosted on a server with no other VMs
	Access	a certain secure access possibility for a VM (e.g. VPN)
Energy	MaxServerPower	maximum power consumption for a server
	DelayBetweenVMMigrations	minimum delay between two successive VM migrations
	DelayBetweenServerOnOffs	minimum delay between two state changes for a server
	VMPaybackTime	VM migration only if the energy spent for migration is 'paid back'
	SpareNodes	minimum amount of servers that are kept free in the data centre
	SpareCPUs	minimum amount of CPUs that are kept free in the data centre

From SLAs to Constraints

Translation of the SLA contract into technical SLAs and then to Constraints:



Plug4Green model

	Energy related variables
P	Future global power consumption of the data centre federation
$P(s)$	Future power consumption of a server s
P_{net}	Power consumption of the network
E_{reconf}	Energy spent by the reconfiguration plan
$E_{move}(v)$	Energy spent for the migration of VM v
$E_{onoff}(s)$	Energy spent for switching on or off a server s
	Variables used from BtrPlace model
$hosters$	Association array VM/Server of the resulting configuration
$card(s)$	Number of VMs that a server s will host
$n^{CPU}(s)$	Future CPU load of a server s
$n^{RAM}(s)$	Future RAM usage of a server s
$n^{HDD}(s)$	Future HDD usage of a server s

Constraint example *MaxServerPower*

MaxServerPower constraint definition:

```
public void injectMaxServerPower(VRSP model, int maxServerPower) {
    model.post(eq(P, plus(mult(card, β), α)));
    model.post(leq(P, maxServerPower));
}
```

Power Objectives

- Power of the servers:

$$P(s_i^k) = X_i \times \alpha_k + \sum_{j=1}^{p} h_{ij} \times \beta_{kl}$$

- Power of the full federation:

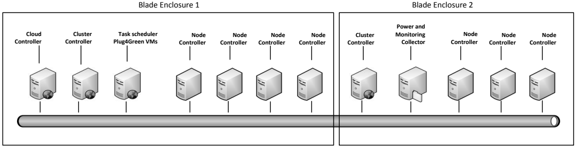
$$P = \sum_{d=1}^{D} (PUE_d \times \sum_{i=1}^{n} P(s_i^k))$$

- Energy consumed by applying the reconfiguration plan:

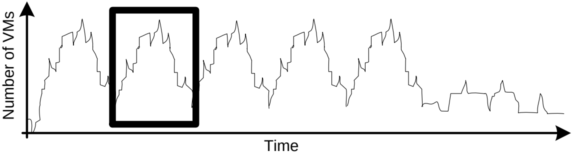
$$E_{tot} = (P_{bef} - P_{aft}) \times T_{reconf} - \sum_{i=1}^{p} E_{move}(i) - \sum_{j=1}^{n} E_{onoff}(j)$$

Plug4Green Evaluation Setup

Testbed setup:

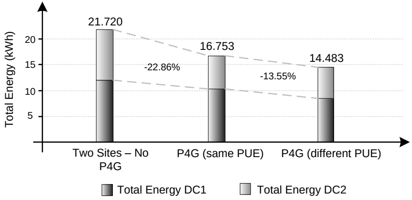


Synthetic workload used:

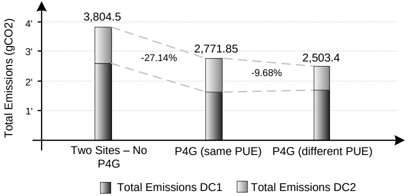


Efficiency of Plug4Green

Energy consumption of two data centres with different PUE values:

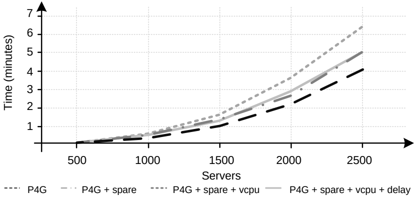


Energy consumption of two data centres with different CUE values:

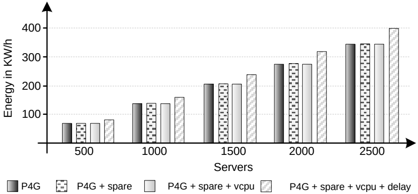


Scalability of Plug4Green

Solving duration to compute the improved configurations:



Energy consumption of the improved configurations:



Conclusion

- Reduction of power consumption by 27%
- Reduction of greenhouse gas by 23%
- Improved placement for 7,500 VMs running on 1,500 servers in a minute

Outline

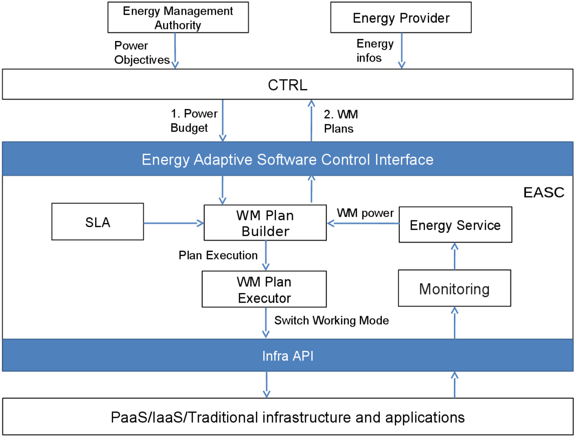
Introduction

Schedule applications workload in order to increase the usage of the renewable energies.
The EASC allows to:

- Describe applications flexibility
- Schedule task-oriented and service-oriented applications
- Benefit from IaaS and PaaS paradigms

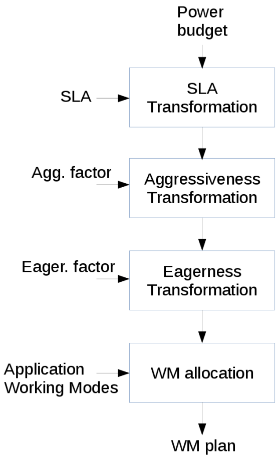
EASC has been evaluated in Trento and Milan testbeds.

Architecture

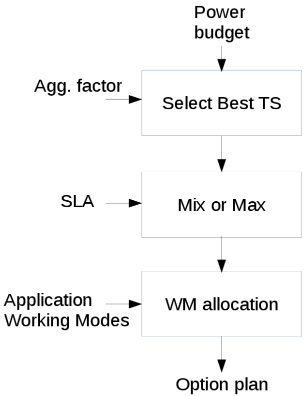


Algorithms

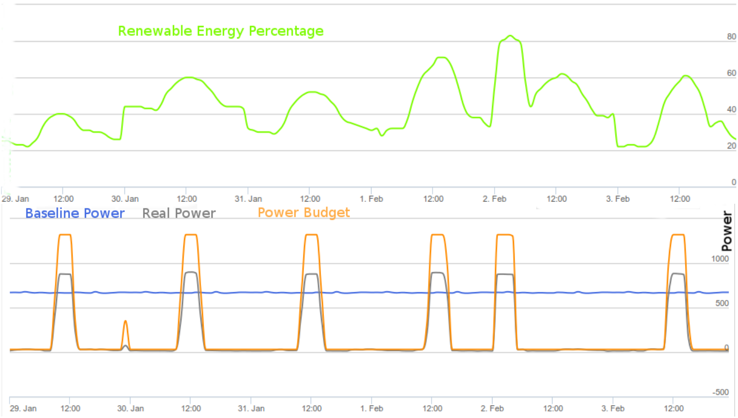
EagerAgg algorithm:



MinMaxAgg algorithm:



Trento trial

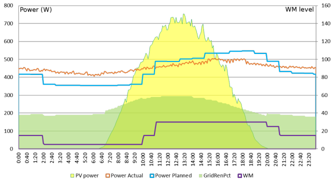


Trento trial

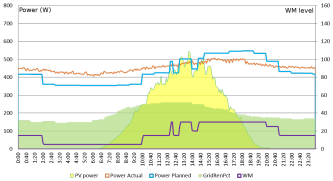
Trento trial results:

Profile	**Baseline Ren%**	**Final Ren%**
Day 1	30.03%	37.65%
Day 2	49.24%	58.30%
Day 3	39.19%	49.73%
Day 4	45.98%	66.56%
Day 5	57.27%	77.94%
Day 6	37.06%	56.29%
All days	43.13%	57.88%
A year	37.39%	48.22%

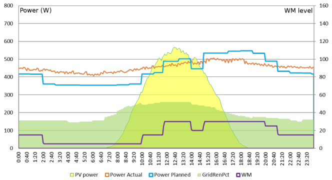
HP trial



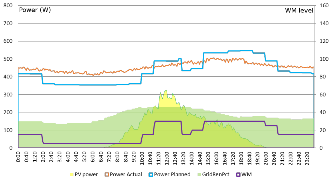
(a) Day 1



(b) Day 2



(c) Day 3



(d) Day 4

HP trial

HP experiment trial results:

Profile	Ren% baseline	Ren% EASC	Ren% inc. (pp)	Ren% inc. (%)
Day 1	68.20%	70.34%	2.14pp	3.13%
Day 2	61.85%	64.68%	2.83pp	4.57%
Day 3	58.57%	61.65%	3.08pp	5.25%
Day 4	53.99%	57.26%	2.27pp	6.05%
Trial Days	60.65%	63.52%	2.87pp	4.73%

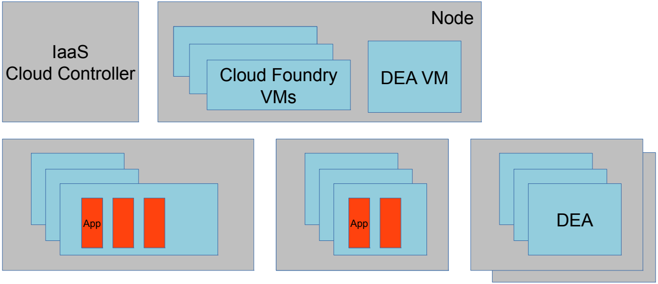
Introduction

EASC has been enhanced to support IaaS/PaaS hybrid infrastructure:

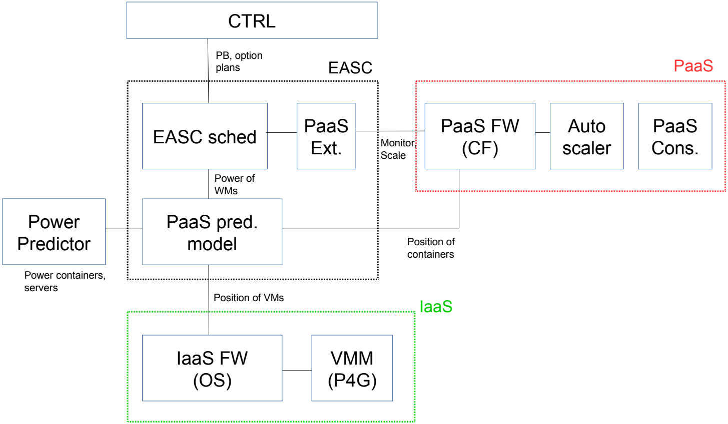
- Auto-scaling full infrastructure
- Power model for shared infrastructure
- Evaluation in Trento trial

IaaS/PaaS hybrid data centre

Typical IaaS/PaaS hybrid infrastructure:



IaaS/PaaS architecture



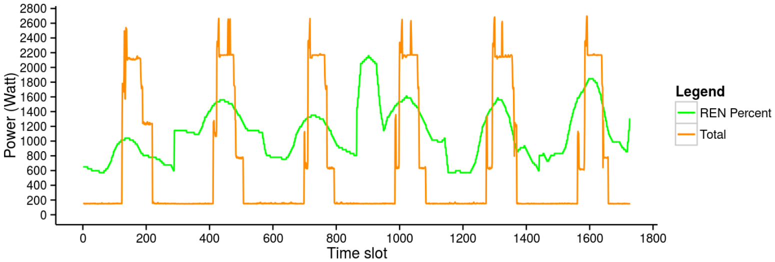
Application power model

Power of an application in a shared infrastructure:

$$P_{totApp} = P_{dynNode} * \frac{CPU_{App1}}{\sum CPU_{Apps}} + P_{idleNode} * \frac{RAM_{App1}}{\sum RAM_{Apps}}$$

Evaluation

Total energy consumption of the trial:



Evaluation

Trial results:

Profile	Baseline Ren%	Final Ren%
Profile 1	30.19%	35.37%
Profile 2	49.24%	55.75%
Profile 3	39.41%	47.24%
Profile 4	47.00%	61.28%
Profile 5	56.49%	58.02%
Profile 6	37.68%	50.19%

Full year projection: 7.07pp increase of renewable energies consumption.

Outline

Conclusion

We presented two contributions to reduce brown energies consumption in DCs:

- Plug4Green
- EASC

Evaluation of Plug4Green in HP Milan test bed:

- *Efficiency*: reduce the overall energy consumption up to 33% and the gas emission up to 34%, while respecting the SLAs
- *Scalability*: compute the improved placement of 7,500 VMs on 1,500 servers under one minute, while respecting their SLA.

Evaluation of EASC in Trento testbed: increase of renewables usage of 7.07pp.

Discussion

- Heuristics vs meta-heuristics
- Analytical power models vs black-box power models
- Technology transfer
- Renewable energies adoption

Future works

- Usage of energy accumulators in DCs
- Energy management with Unikernels
- Warm data centres
- Service migrations & edge computing

Publications

- Sonja Klingert, Florian Niedermeier, Corentin Dupont, Giovanni Giuliani, Thomas Schulze, and Hermann de Meer. *Introducing Flexibility into Data Centers for Smart Cities.*
  Communications in Computer and Information Science, 2016
- Corentin Dupont, Mehdi Sheikhalishahi, Federico M. Facca, and Fabien Hermenier. An energy aware application controller for optimizing renewable energy consumption in cloud computing data centres.
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  In *2015 EAI International Conference on Smart Grids for Smart Cities*, Toronto, Canada, 2015
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- Corentin Dupont. Renewable energy aware data centres: The problem of controlling the applications workload.
  In Sonja Klingert, Xavier Hesselbach-Serra, MariaPerez Ortega, and Giovanni Giuliani, editors, *Energy-Efficient Data Centers*, volume 8343 of *Lecture Notes in Computer Science*, pages 16–24. Springer Berlin Heidelberg, 2013

- Corentin Dupont, Thomas Schulze, Giovanni Giuliani, Andrey Somov, and Fabien Hermenier. An energy aware framework for virtual machine placement in cloud federated data centres.
  In *Proceedings of the 3rd International Conference on Future Energy Systems: Where Energy, Computing and Communication Meet*, e-Energy '12, pages 4:1–4:10. ACM, 2012

- Dang Minh Quan, Robert Basmadjian, Hermann de Meer, Ricardo Lent, Toktam Mahmoodi, Domenico Sannelli, Federico Mezza, Luigi Telesca, and Corenten Dupont. Energy efficient resource allocation strategy for cloud data centres.
  In Erol Gelenbe, Ricardo Lent, and Georgia Sakellari, editors, *Computer and Information Sciences II*, pages 133–141. Springer London, 2012

- Dang Minh Quan, Andrey Somov, and Corentin Dupont. Energy usage and carbon emission optimization mechanism for federated data centers.
  In *Proceedings of the First International Conference on Energy Efficient Data Centers*, E2DC'12, pages 129–140, 2012

Submitted articles:

- Corentin Dupont, Mehdi Sheikhalishahi, and Michele Santuari. Improving renewable energy consumption in iaas/paas hybrid data centres.
  Submitted to Futur Generation Computer Systems, 2016

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