An overview of ECO$_2$Clouds: Experimental Awareness of CO_2 In Federated Cloud Sourcing

White Paper

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Executive Summary

The ECO_2Clouds project[1] develops techniques and mechanisms for CO_2 aware deployment and management of workloads on federated Clouds. The project adopts an iterative development approach involving three key phases namely Measure, Create and Test-on-FIRE. The first phase focuses on quantification of energy consumption and environmental impact of Cloud computing, the second phase develops techniques and software artefacts to help realise awareness of the environmental impact of Cloud computing and improvements in the reduction of energy consumption and CO_2 emissions, and the third phase tests the outcome of previous two phases on an existing FIRE[2] facility known as BonFIRE. The ECO_2Clouds solution promises multidimensional benefits for Cloud users, researchers, commercial enterprises as well as environment and society.

Keywords: energy efficiency, cloud computing

About ECO_2Clouds: ECO_2Clouds is a EU project in the 7th Framework Objective ICT-2011-1.6 c) : FIRE Experimentation.
Grant agreement for: Small or medium scale focused research project (STREP) Grant agreement no.318048. The Project started October 2012 with a duration of 24 months.
Partners: ATOS, Spain. University of Manchester, UK. HLRS, Germany. EPCC, UK. Politecnico di Milano, Italy. Inria, France.

[1] http://eco2Clouds.eu/
[2] http://www.ict-fire.eu/home.html

Introduction to ECO$_2$Clouds

Ecological implications of Cloud computing represents an important gap in the current state-of-the-art in research and practice. Since energy consumption of ICT infrastructures (i.e. large scale data centres and Cloud infrastructures) in the EU is expected to exceed 10% of total in near future[3], addressing this gap is vital for sustainability of Cloud computing as its uptake increases. In this background, the EU funded ECO$_2$Clouds project investigates strategies and develops mechanisms for environmentally aware Cloud sourcing with the aim to reduce energy consumption and CO_2 emissions of Cloud applications as well as of the underlying infrastructure.

The ECO$_2$Clouds solution is built on top of *BonFIRE federated Cloud Infrastructure*[4] to cater for applications spanning over multiple Clouds. In a multi-cloud environment, individual Cloud providers may operate under different regulatory frameworks and cost structures in relation to environmental policies and energy value-chains. In addition, optimizing the way key assets, such as application logic and databases, are deployed is constrained by non-functional requirements such as quality, privacy and cross-platform service-level agreements. At present little effort if any is spent on how to incorporate carbon emissions and energy consumption in application development/deployment models. However, in future environmental implications of vast energy consumption may result in CO_2 constraints being imposed by regulators and environmental agencies on Cloud providers. Moreover, environmental awareness and pressure by regulatory authorities can influence consumers' selection criteria for Cloud sourcing

In this respect, ECO$_2$Clouds endeavours to radicalize the way applications are designed and deployed on the Cloud by incorporating energy efficiency and CO_2 footprint as key design parameters for Cloud applications, infrastructure and application deployment strategies.

ECO$_2$Clouds provides a challenging and innovative approach to eco-aware Cloud sourcing that encompasses:

- Quantification of energy consumption and CO_2 footprint for Cloud applications and different levels of underlying infrastructure
- Energy efficient and CO_2 aware deployment and management of workloads on multiple Clouds
- Application models to realise application level support for energy efficiency
- Monitoring of environmental factors at the level of applications and Cloud infrastructure
- Extension of Cloud APIs to expose information about energy consumption & CO_2 emissions as well as support for scheduling and runtime management of applications.

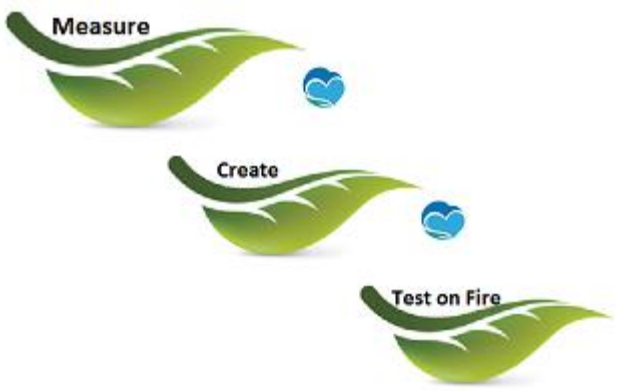
[3] Communication from the Commission: http://ec.europa.eu/information_society/activities/sustainable_growth/docs/com_2009_111/com2009-111-en.pdf

[4] www.bonfire-project.eu/

ECO_2Clouds: Energy Efficient Workload Management for Federated Clouds

ECO_2Clouds adopts an iterative approach towards developing techniques and mechanisms for CO_2 aware application deployment on Cloud.

The ECO_2Clouds approach encompasses the following phases:



Measure: Quantifying the environmental impact (i.e. energy consumption and CO_2 footprint) of Cloud computing.

Create: Development of techniques and mechanisms that consider environmental factors while deploying and managing workloads on Cloud.

Test on FIRE: Using existing FIRE facilities (i.e. BonFIRE) to test and validate the ECO_2Clouds solutions.

The overall ECO_2Clouds work programme spans over following aspects:

Scientific Aspects: The *scientific objectives* of ECO_2Clouds are based on the development of green metrics to express energy consumption and CO_2 footprint of federated Cloud facilities and applications. The gathered data about energy consumption and CO_2 footprint is fed into *an optimization and deployment model* to generate application deployment configurations that can contribute towards reducing the environmental impact when the workload is mapped to the infrastructure and VM levels. During the execution lifecycle of cloud applications, innovative adaptation mechanisms can change the deployment configuration of running applications based on energy consumption and CO_2 parameters. The overall approach is validated through experimental case studies.

Technical Aspects: The *technical objectives* of ECO_2Clouds aim to extend the Cloud application programming interfaces and mechanisms to expose green or eco-metrics at three levels: applications, VM and infrastructure. To realize this, specific types of power consumption probes (PDUs) are installed at BonFIRE sites used by the ECO_2Clouds project. Consequently, the monitoring mechanism of BonFIRE is extended to gather data about the eco-metrics. Furthermore, ECO_2Clouds develops software to implement the energy and CO_2 aware deployment optimization and runtime adaptation models that extend the scheduling capabilities of current cloud management toolkits e.g. OpenNebula[5] while ensuring adequate support for application specific requirements and constraints.

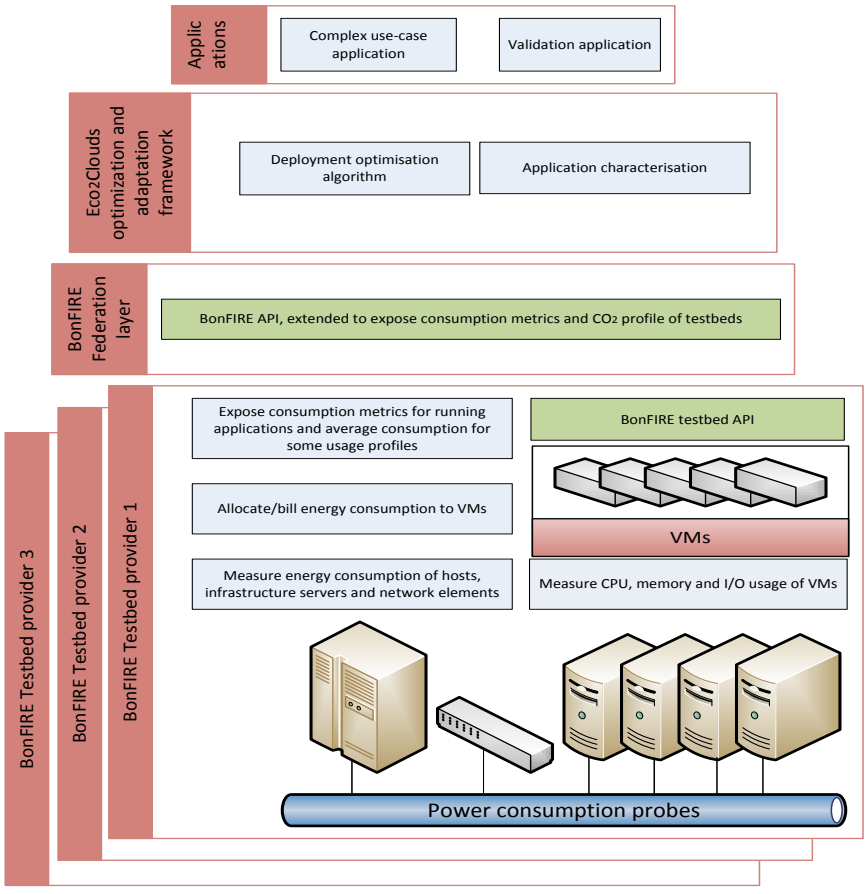
5 http://opennebula.org/start

Evaluation Aspects: The evaluation of ECO_2Clouds solution is carried out by means of experimental validation. In this respect, ECO_2Clouds solution relies on the use the BonFIRE (Building Service Testbeds on Future Internet Research and Experimentation) infrastructure, thus extending the capabilities of those facilities by enabling them to quantify the energy consumption and CO_2 footprint at different levels of the infrastructure. A number of case study applications have been selected to test during the evaluation phase. The case studies will test and evaluate the impact of energy and CO_2 aware application deployment and adaptation mechanism on different types of Cloud applications.

Exploitation Aspects: The conclusions about the validity of the scientific contributions are the primary results to be exploited, both academically and through consultancy. Some scientific publications about initial results are already available through the project website: http://eco2clouds.eu/documents/scientific-publications/. The verified technical innovations and extensions to the BonFIRE infrastructure will also be exploitable as a key project legacy.

ECO_2Clouds Relationship with FIRE

FIRE (Future Internet Research and Experimentation) offers a discipline, a platform and tools for trying out and experimentally validating highly innovative and revolutionary ideas for new service paradigms. Within the available FIRE facilities BonFIRE was selected as suitable platform that provides necessary infrastructure and conditions for developing and testing the ECO_2Clouds solution. BonFIRE matches the infrastructure requirements of ECO_2Clouds, such as the heterogeneous nature of the three infrastructures, namely the BonFIRE sites at UEDIN (UK), INRIA (F) and USTUTT (D). Besides building on top of existing BonFIRE offerings, ECO_2Clouds compliments core BonFIRE infrastructure by enabling it to provide real time information about energy consumption of different applications and Cloud resources.



Other metrics required for the ECO_2Clouds solution (such as resource utilization) are already provided through existing BonFIRE monitoring mechanism. Figure 1 shows the BonFIRE-ECO_2Clouds interactions, with ECO_2Clouds solution running on the BonFIRE API at the BonFIRE federation layer, and ECO_2Clouds eco metrics added to BonFIRE test beds.

Expected Results and Impact

ECO_2Clouds is currently starting its second iteration. However, based on the outcome of first iteration and the scientific and technical objectives ECO_2Clouds anticipates to provide results along following dimensions:

Environment and society: Cloud computing is increasingly seen as an effective solution to computational problems involving intensive data processing and storage. As a result, enterprises and even governments are keen to make a transition toward Cloud sourcing in order to achieve efficiency and save costs. However, the proliferation of Cloud facilities raise environmental concerns due to the heavy energy consumption and CO2 emissions of Cloud facilities. In this respect, the CO2-aware Cloud sourcing strategy will benefit the environment and overall society.

Cloud users and research community specialising in this area: energy consumption in Cloud and CO_2-aware applications on the Cloud is a key research topic in the area of Internet of Services (IoS). In this respect, the benefits will be in terms of feedback and recommendations regarding the federated Cloud infrastructure, the performance of the deployment optimization and adaptation mechanisms, and the development of deployment strategies including CO2 awareness.

Commercial and research interests on Cloud sourcing and computationally heavy modelling: The commercial or industrial enterprises and wider research community working on Cloud sourcing and computationally heavy modelling will benefit from innovative ideas concerning design of Cloud sourcing strategies, energy aware application design and general guidelines regarding the distribution of computationally intensive models onto federated Cloud infrastructure.

Summary

ECO_2Clouds is an EU funded project focusing on energy efficient and CO_2 friendly Cloud sourcing. The project adopts experimentally driven research methodology and adds an eco-aware service model on top of an existing FIRE facility. By considering ecological implications of running application on Cloud, the project promises to radicalise the way applications are deployed and managed on the Cloud infrastructure.

The following table summarises the expected benefits for ECO_2Clouds target groups. The table also suggests actions that may need to be implemented in order to achieve those benefits and the message for specific target groups.

ECO_2Clouds Targeted Group	Benefit in adopting ECO_2Clouds	Actions & Message
Data Centres	To reduce carbon emissions in a measurable and certified way and to improve efficiency of use of resources	*Actions*: delivering methodologies and toolsets for design and management of eco services for Clouds. *Message*: explain how to obtain a trade-off among Quality of Service, performance, virtual and physical resource allocation and overall energy efficiency over federated clouds.
Cloud Providers	To be able to evaluate the cloud environmental impact and to declare emission values for user applications, thus realising the goal of providing green Cloud applications.	*Actions:* Endowing the ECO_2Clouds toolset with energy and eco-related KPIs and advanced algorithms to closely align applications' demands for energy with resource availability and the measurement of carbon emissions. *Message:* show how to combine the KPIs and algorithms with cloud-typical measure and technologies.
Application Engineers/Cloud consumers	To enable application deployment on clouds with certified low environmental impact.	*Actions*: coupling design tools and methodology in a run-time environment for integrated detection, monitoring and control of emissions, so as to be able to assess (in quasi-real time) to what extent the taken measures will lower carbon emissions. *Message*: give guidelines on how to define low impact applications and technologies on the Clouds and how to specify Green Certificates for cloud-based processing environments.
BonFIRE providers	To be able to validate the platform on use cases.	*Actions*: The disseminated project outcomes can be adapted to the BonFIRE particular target groups and their standard to compare their knowledge of the platform with the outcomes of the project *Message*: the message has to be specific for the BonFIRE providers in that they need to understand the work done by the consortium and test the KPIs to check the benefits from their point of view.
Energy and Power Providers	To have real time information available about energy/power consumption and carbon emissions in order to gain	*Actions*: suggest a set of actions based on the results of ECO_2Clouds project which lead to increased efficiency and lower emissions. Further, to raise awareness of ECO_2Cloud

	improved energy matching techniques for effective Demand/Answer Energy marketplace.	services as part of any existing framework of "green" programs and initiatives. *Message*: to prepare a favourable technical and organizational ground that can facilitate the adoption of the project main outcomes.
ICT Technology/Service Providers (software)	To enter the growing market of green IT	*Actions*: disseminate project outcomes and raise awareness of ecological factors in ICT to unleash huge market for green ICT services as well as supporting ICT companies in providing low-emission platforms *Message*: show increased opportunity for producing greener applications with low emission on cloud platforms.
Hardware Producers	Increased opportunity for producing greener hardware for clouds connected with evaluation methods about the environmental impact of hardware platforms	*Actions:* Disseminate and use the ecological KPIs for an opportunity to develop integrated multi-level platforms including energy mix and carbon emission monitoring layers. *Message:* Show the synthetic indicators on which to assess the impact of various ECO_2Cloud techniques and methodologies.
Environmental, Energy and Health Agencies	Achieve easy inclusion of metrics and cloud services within their plans in the framework of green programs and initiatives	*Actions*: promote the adoption of the eco metrics, KPIs monitoring, design, and run time methods developed in the project and encourage green initiatives of research communities/groups and cloud platforms. *Message*: support and foster adoption of low-emission centres by promoting educational plans to increase cloud eco-efficiency.

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