

Advancing Ecological Awareness in the Cloud. The world needs new and more ambitious approaches to help organizations adopt IT solutions that embrace Greener Strategies



New Approaches for a Greener World. Society has increased pressure during the last years over all economy sectors to implement immediate action plans to alleviate climate change effects. In this context, IT Industry has still areas of improvement. One key aspect is the increasing proliferation of large Cloud data centers raise environmental concerns due to the heavy energy consumption and CO₂ emissions of Cloud facilities. Use and energy consumption will only continue to go up due to the increasing number of mobile users and people accessing online services. Therefore, society, and in our case, the IT industry, must take “Green Actions” to reduce its increasing impact. The IT industry should pay even higher attention to this issue, and CO₂-aware Cloud holistic strategies will benefit the environment and overall society.

The ECO₂Clouds team has been working during the last two years to research and validate a different approach that goes beyond traditional approaches that focus on optimizing energy for reducing carbon footprint in data centers equipment. We explore the use of two different new approaches: the possibilities offered by multi-site clouds to reduce environmental impact by taking into account deployment, workloads and energy sources of different sites; and by enabling ECO-aware decision making at application level. By seizing these opportunities ECO₂Clouds endeavors to radicalize the way applications are designed and deployed on the cloud in an energy efficient and CO₂ friendly manner.

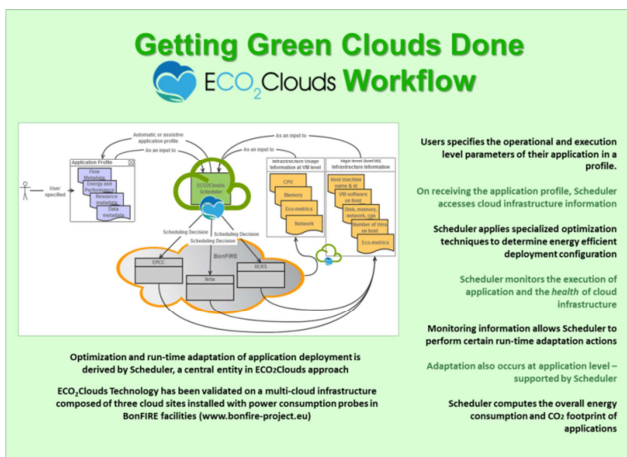
The ECO₂Clouds Approach. Traditional approaches that face the issue of reducing carbon footprint in

data centers in general focus on reducing, or optimizing, energy consumption of IT equipment and other electronic and networking devices present in data centers. Some approaches also seek to increase the energy efficiency of non-IT components, such as cooling systems. Other approaches include heat recovery; transformation of heat into energy; dynamic mechanisms for better allocating workload to reduce energy wasted in cooling such systems; and lately, the emergence of mechanisms to optimize workloads with virtualization environments. All these attempts focus on reducing the carbon footprint by reducing the environmental impact of physical IT infrastructures and energy consumption.

The ECO₂Clouds emphasis on CO₂ footprint and environmental impact is what uniquely distinguishes our approach from other energy and resource optimization approaches. The ECO₂Clouds solution includes components for monitoring energy consumption and for adapting the infrastructure, virtualization and application levels to achieve energy efficiency and reduce the CO₂ footprint.

However, the ECO₂Clouds team decided to investigate a different and more innovative approach. Our objective is to take a broader approach by also considering not only CO₂ emissions produced by data center infrastructures but also, the running applications and their deployment configurations in a multi-cloud scenario and the possible reductions that could be gained by considering the impact of using different energy sources and workloads. Therefore, the ECO₂Clouds objective is achieved by considering the ecological

parameters and the resource usage of both the infrastructure on which VMs are running and the applications that are executed on those VMs, managing workloads on clouds through federated cloud infrastructures, where applications may span several cloud sites.

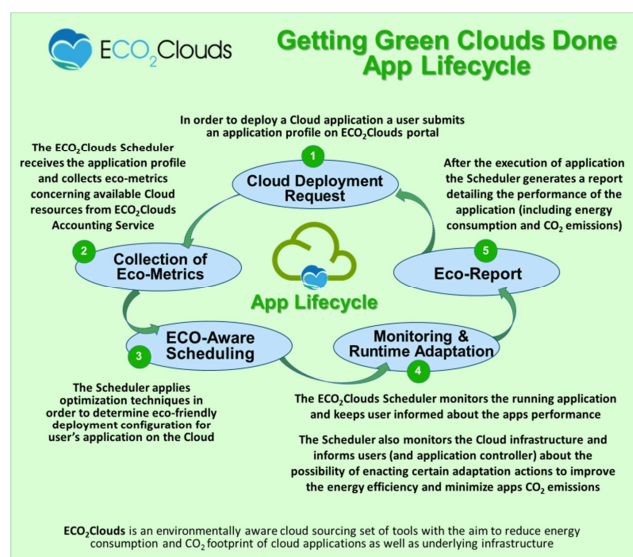


The ECO2Clouds Technology. The ECO2Clouds solution is built with the intention to provide the underlying technology to enable greener cloud deployments in a three step approach: Measurement; Monitoring and Analysis; and Acting Green.

Measurement: The first step is to put in place the means for quantifying the environmental impact of cloud computing by using a set of metrics that measure the greenness of running applications and infrastructures from a number of sites. This set of metrics reflects the energy efficiency of IT systems from a holistic perspective and allows the derivation of the interrelation between different components of IT cloud infrastructure. For this reason, we adopted a layered metric approach that extends the set of metrics proposed in The Green Grid consortium for the measurement of Data Center energy impact¹. More specifically, ECO2Clouds considers: a) **Infrastructure layer metrics** includes the host layer and the site layer; b) **metrics at the virtualization layer** characterize the virtual machines on which the applications are running; and c) **application layer**

metrics capture the behavior, in terms of energy consumption and CO₂ emission, of the applications running on the VMs deployed in the infrastructure. Several of the metrics used by the platform have been proposed by ECO2Clouds and include infrastructure metrics for measuring site and storage use and Green Efficiency Coefficient (GEC). Our team advocates that these are really important and provide advance for reducing CO₂. For applications, the metrics measure task execution time, response time, throughput, A-PUE (application PUE), application energy productivity (AeP) and Application Green Efficiency Coefficient (A-GEC). At virtual level, ECO2Clouds uses standard metrics for virtual machine monitoring (e.g. CPU, Storage, I/O, and memory use).

Monitoring and Analysis: Once we have implemented the required set of ECO2Clouds metrics and properly instrumented the Cloud infrastructure with a monitoring system, the ECO2Clouds environment is able to collect and track energy and carbon footprint data from sites, physical and virtual infrastructure, and from applications. The gathered data are fed into an optimization and deployment model and are constantly analyzed using data mining techniques to generate application deployment configurations that can contribute towards reducing the environmental impact when the workload is mapped to the infrastructure and VM levels.



¹ D. Azevedo, J. Cooley, M. Patterson, and M. Blackburn, "Data Center Efficiency Metrics: mPUE, Partial PUE, ERE, DCcE," GreenGrid, Tech. Rep., 2011.

Acting Green: ECO₂Clouds provides different means of enabling greener utilization of modern IT. More concretely, the ECO₂Clouds technology allows acting Green in Cloud infrastructures and software development, by employing techniques and mechanisms that consider environmental factors while deploying and managing workloads on multi-cloud scenarios in a greener way.

The result of the ECO₂Clouds analysis constitutes the basis for the initial deployment of applications on the Cloud infrastructure and the further enactment of

adaptation actions that our technology makes available for running applications. During the execution lifecycle of cloud applications, innovative adaptation mechanisms can be taken by developers to change the deployment configuration of running applications based on energy consumption and CO₂ awareness provided by ECO₂Clouds technology. At the end of the execution the user is informed about the energy consumption, CO₂ footprint and other resource utilization parameters.

ECO₂Clouds innovations make Clouds Greener. The most innovative contributions of our project include:

- Quantification of energy consumption and CO₂ footprint for Cloud applications and different levels of underlying infrastructure by means of key metrics at infrastructure, virtualization and application level.
- Energy efficient and CO₂ aware deployment and adaptation of workloads on multiple Clouds
- Application models to realize 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 and CO₂ emissions as well as support for scheduling and runtime management of applications.

ECO₂Clouds benefits the most important stakeholder: The Environment. Even though our project is modest in scope and budget, we proudly believe that small steps can make an impact on the industry. We are not satisfied only by helping IT operations use less energy, more efficiently, and therefore, optimizing and saving significant business operational costs. We have built ECO₂Clouds technologies with the objective to build an approach that helps the world be greener.

We help organizations implement solutions to help businesses become more sustainable and embrace the “*We Are Going Green*”, marketing or social corporate responsibility driven trend, by aligning IT operations with sustainability goals according to the increasing demand to provide transparency and build positive corporate social responsibility credentials. Our technology also enables a new research area to allow accountability of cloud

services of energy usage and type; and also how green cloud applications behave. ECO₂Clouds provides to organizations the foundation to monitor performance of cloud infrastructures and applications facilitating greener strategies.

ECO₂Clouds enables **ECO-Control** at application level, so cloud applications can be aware and evaluate their execution performance against ECO conditions and implement actions to take control and to

decide their best execution venue. The framework also provides **ECO-Agility** by adopting ECO-Metrics into the decision making process for deployment and runtime adaptation, in conjunction with new methods and models proposed by our technology that optimize execution and deployment. These altogether offer greener scenarios in Multi-Clouds environments, which provides yet a more powerful tool for organizations and cloud datacenters, **ECO-**



Getting Green Clouds Done

Portability among different sites if using different locations managed by Multi-Cloud software to take advantage different workload and energy mixes.

BonFIRE. The technology and the rationale of our innovative approach, along with the analysis and validation tests, are now being field-tested and validated through three different experimental case studies on top of the BonFIRE Foundation facilities (bonfire-project.eu), BonFIRE is a federated multi-site Cloud Infrastructure used for testing and experimentation. BonFIRE provides three cloud sites installed with power consumption probes along with infrastructures using Open Nebula Cloud Stack Management Software.

We also love Open Source. The ECO₂Clouds technology has been designed to be general enough and open so that can be used in other multi-cloud scenarios outside the BonFIRE domain. The ECO₂Clouds technical team is working to release an open source version of different components, the ECO-aware metrics and a guide to adapt other sites to use ECO₂Clouds technology and start acting green by deploying greener federated Cloud computing models and by allowing application decision making.

Summary. In summary, ECO₂Clouds proposes useful techniques and technologies that we call the “**Getting Green Clouds Done**” Workflow. This will help the IT industry consider utilizing advanced ECO-aware optimizations at infrastructure, cloud site and

cloud application level. Based on our **ECO-Metrics** and technologies, we advocate acting green with the use of adaptation actions at cloud infrastructure level involving the use of the **ECO₂Clouds ECO-Aware Cloud Scheduler** to better deploy applications, which implies the possibility to migrate VMs among physical hosts and among different sites considering a multi-criteria decision approach. The **ECO₂Clouds ECO-Aware Cloud Application Controller** also provides application level adaptation actions. This component is in charge of controlling the execution of the application and to enact adaptation actions like switching on/off VMs, assuming that the application is properly designed to perform and support runtime adaptation, and provides an API in conjunction with the scheduler, that informs applications to take its own ECO-aware decisions to adapt its deployment configuration. As a result, ECO₂Clouds approach provides answers to important questions such as quantification of environmental impact of cloud computing, enacting deployment and runtime adaptation actions that can decrease the energy consumption and CO₂ footprint of Cloud computing and considering environmental implications in the design and subsequent execution of Cloud applications.

Learn more about how to use our technology and join our “Getting Green Clouds Done” movement at eco2clouds.com.