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GREEN DESKTOP-GRIDS: SCIENTIFIC IMPACT, CARBON FOOTPRINT, POWER USAGE EFFICIENCY

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Abstract. Desktop Grids take their place in the e-Science distributed computing infrastructure - scaling into the millions of PCs. Desktop-Grids collect CPU cycles from PCs contributed by donors, by volunteers who are willing to support science and research. The Green key advantage of Desktop-Grids over service Grids and data centers based on clusters of servers is the minimal heat density. Compute Clusters without energy intensive aircondition would run into thermal disaster within minutes. PCs participating in Desktop-Grids usually do not make use of any aircondition. In return and with raising energy prices, data centers have implemented lower costs air-conditioning means like e.g. free cooling, improving their thermodynamic-efficiency and PUE rating. This paper, based on [24], investigates whether Desktop-Grids still have a Green advantage over Service-Grids and describe several distinct Green Methodologies to optimize compute unit specific energy consumption. Green-IT metrics as Carbon Footprint and PUE are analyzed for their relevance and applied to Desktop-Grids. Pragmatic implementation steps to Green-Desktop-Grids are described.

1. Desktop-Grid: Scientific Impact of large scale DCIs. During the past years, volunteer Desktop Grids have become a regular part of the computational infrastructure for e-Science. Although they already form an impressive computational power, the EDGeS infrastructure for instance connects about 150.000 computers in Desktop Grids to the European Grid Infrastructure (EGI), this is only the beginning, as there are hundreds of millions of computers, alone in Europe that could be connected. Desktop Grids take their place in the e-Science distributed computing infrastructure - scaling into the millions of PCs [23].

Compute time harvested from resource owners, typically individuals at home but also institutions and companies, does not request large upfront investment by the scientist; it is a low cost approach towards significant scientific output. Typically implemented using BOINC [17], sometimes XtremWeb [19], OUR-Grid [49], or other packages, Desktop-Grids are found among the largest Distributed Compute Infrastructures (DCI) [1]. Also known as Volunteer-Computing, Desktop-Grids have been around since the very early days of Grid computing [18]. An outstanding illustration of Desktop-Grid scientific impact was delivered these days by Einstein@Home. The new binary radio pulsar J1952+2630 was detected in data recorded at the Arecibo telescope back in 2005 [35].

The aggregations of so many machines result in significant performance well beyond Petaflop/s for selected applications. For example: BOINC network averages about 5.1 Petaflop/s as of April 21, 2010 [2]. Key difference to service Grids like EGEE (now EGI) is the voluntary character of the resources citizens contribute their PCs compute time to the Desktop-Grid projects in order to support scientific challenges of their choice. The FP7 project DEGISCO [20] supports Desktop-Grid deployments in and beyond Europe, especially countries that strongly collaborate with the European Union. DEGISCO recently published a first version of the Desktop Grids for eScience Road Map [21, 22], a guide to prepare and implement successful Desktop-Grid roll-outs, second release scheduled for June 2011. DEGISCO is accompanied by the EDGI project that continues to maintain and further develop the 3G-Bridge [3], a gateway transparently connecting gLite, Unicore, and KnowArc based infrastructures (Service-Grids) to Desktop-Grids by automated translation of the job-languages.

Sustained development and success of this combination of Desktop-Grids and Service-Grids has been proven at the EGI User Forum 2011 in Vilnius, Lithuania, by command-line submission of 10,000 jobs to a Desktop Grid from and through gLite, one of the main EGI Grid stacks [26].

Fascinating progress in material science using Desktop-Grids was reported by O. Gatsenko et al at the CGW2010 [27, 28, 29, 30], proving even complex problems to be solvable on a distributed Desktop-Grid platform.

2. The need for Green Desktop-Grids. One core topic of DEGISCO is the energy efficient handling of Desktop-Grid workload and management of resources, provided as configuration advice to Desktop-Grid operators. The need for Green-Desktop-Grids derives from sheer size: Desktop-Grids can aggregate hundred-thousands of machines per project. Power consumption of such large amounts of devices should be considered when making use of them. Indeed, when used for computation, energy consumption of PCs (like of any other computer) goes up [5,31]. The contributor, the volunteer, who allows and enables the use of her or his machine,

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not only provides compute time for free but also pays for the additional electrical energy to cover the computation induced power consumption during a potentially increased uptime.

Key advantage of Desktop-Grids is the minimal power density compared to conventional data centres. Typically, PCs participating in Desktop-Grids in Europe are not hosted in air-conditioned environments. Without the energy burden of air-conditions, Desktop-Grid are intrinsically greener than data centre based clusters and thereof built Service-Grids. Data centers have been improving their power efficiency in the recent years, so we want to investigate how Green they are compared to Green-Desktop-Grids.

3. PUE a Green IT metric. PUE Power Usage Efficiency has been broadly accepted as metric to determine how green data centers are [32]. PUE is defined as "Total Facility Energy divided by the IT Equipment Energy". The best possible value is 1,0 = all energy provided is used in the IT equipment. PUE values are to be measured over a full year timespan to have winter temperatures with lower cooling efforts balance summer heat. PUE typically ranges between 1.5–2.5.

The Code of Conduct on Datacenters [4] quotes that most (older) European data centres are actually worse: they consume more than 200% of the IT related energy (PUE 3) for cooling, UPS and power distribution losses.

Recently the Facebook Open Compute Project [33] published PUE 1.07 which was criticized to be a snapshot value, calculated over a limited period during perfect conditions [34]. In order to try a comparison between Desktop-Grid and Service-Grid Green level, we transfer the PUE concept[32] from data center boundary to a system boundary including Desktop-Grid servers and Desktop-Grid-Clients. To clarify this fact, we call it the System-PUE. In our example we take 150000 PCs with partial-PUE (PPUE) of 1.0 + 15 BOINC servers with a PPUE of 1.8 deliver a System-PUE of 1.00020 (Fig. 3.1).

Desktop-Grid nodes			IT-Energy		System-Energy
	# nodes	[W]/node	Sums [kW]	PPUE	Total [kW]
Clients	150.000	150	22.500	1,0	22.500
Servers	15	380	6	1,8	10
		Sum	22.506	Sum	22.510
				PUE	**1,00020**

Fig. 3.1: Calculating a Desktop-Grid "System"-PUE

Transferring the PUE metric from data center to Desktop-Grid seems adequate for the similarities in thermodynamic definitions of systems. PUE for data centers is defined with regards to the data center boundaries. Still this is not a thermodynamic ensemble, not a closed system. The key advances in data center efficiency are based on introducing free-cooling [36] and direct-air-cooling, both implying open system thermodynamics as cold water or air is opportunistically fed into the data center - which is quite similar to the fundamental air-condition method of Desktop-Grid-Clients: "open the window". Intel has exercised the open window approach successfully in a production data center even to the point where servers became dust covered, exposed to varying humidity. The whitepaper [37] reports results like saving 2,8 million USD in power consumption annually with only minimal increase in server failure rate. Another example [38] keeps the air quality to ETSI standards but cools directly with air also.

3.1. Limited applicability of PUE. The resulting amazing PUE values derived from open window and similar approaches are questionable. IT equipment is stressed to the full extend of safe operations temperature range. Pointed out in the chapter Difficulties of temperature measurements below, built in fans are temperature controlled now running at maximum speed, causing raised energy consumption. By definitions of PUE, this additional cooling consumption does not worsen but improves the PUE value a clear mistake.

3.2. More Green Desktop-Grids needed. The need for compute power, the progress of Computer Aided Science (CAS), is massive and unstoppable. Researchers from all sectors are urgently looking for more compute power. By June 2010 and well ahead of operations start, PRACE resources were already oversubscribed by a factor of 5 [6]. Although Desktop-Grid suitable workload is not HPC and only the lean-data-fraction of all HTC, significant scientific output has been, is, and will be produced with their help [7]. With the growing importance of Desktop-Grids in the scientific process and the significantly growing deployments, the need to optimize the use of energy is obvious both for general environmental considerations as well as for the attraction of contributors. Citizens providing their machines are interested in finding their contribution used in the most optimal way, producing more science and less waste-energy.

4. Questioning the Aims of Green IT: CO2 Footprint and the Energy mix. The original aim and claim of Green IT was formulated as "Reduction of IT activities CO2 footprint". As extended scope reduction of energy consumption in general and especially thermal emissions in metropolitan areas, both impacting a) global climate b) local (micro) climate and c) human quality of life. Production of CO2 and accordingly the reduction of CO2 footprint are difficult to measure from the perspective of a concrete IT activity like computation.

Even if energy consumption as such is accounted for, it depends on the local energy mix how much CO2 this is equivalent to.

Zero CO_2 electricity sources by 2007					
Energy Mix	Total	**Nuclear**		**Renewable**	
Electricity	[TWh]	[TWh]	%	[TWh]	%
Germany	607,0	167,1	**27,50%**	58,2	9,60%
France	572,2	448,2	**78,30%**	66,0	11,50%
Denmark	40,5	0	0,00%	10,2	25,20%

Fig. 4.1: EC Data sheet: Zero CO2 electricity sources by 2007

The electrical energy mix, the combination of electrical energy sources, depends on national specifics. The electrical energy mix (Fig. 4.1) in Germany [9] includes a nuclear energy portion of 27.5%, scheduled to be phased out, while the French [10] one (78.3%) is stable on a higher level. Denmark [11] produces 25% of its electricity consumption from wind sometimes up to 150% (when strong winds produce more electricity that the Denmark needs) causing negative energy prices at the spot market [12].

In Desktop-Grids, main energy consumption takes place at the client, compare Fig. 3.1. Accordingly the individual PC owner is in control which energy source, which energy tariff is primarily used. The Desktop-Grid server operator respectively the BOINC project manager can target to recruit donors from specific regions with their specific regional energy mix.

Typical for concurrent Green-IT discussion, it avoids mentioning nuclear power. For example the whitepaper on data center metric "Carbon Usage Effectiveness" (CUE, TheGreenGrid) [42]) states: "...the electricity may have been generated from varying CO2-intensive plants. Coal or gas generate more CO2 than hydro or wind. " but skips nuclear.

As pointed out in the following chapter on Green Desktop-Grid Methodologies it is possible to direct workload towards a region by recruiting volunteers from those specific geographies. In order to reduce Carbon Footprint, the Desktop-Grid-Project could recruit donors from France for example, automatically assuring 90% CO2 free computing (=80% nuclear + 10% renewables.), a CO2 value much lower than for example for Denmark not owning any nuclear power plant.

With a more general approach towards environmental protection - latest under the impression of Fukushima - it is difficult to prefer nuclear power plants with their intrinsic security threads and unresolved radioactive waste issues over natural gas powered electricity generation, although emitting carbon dioxide. Nevertheless it is beyond the scope of this paper to discuss alternative energy production strategies as we are focusing on alternative energy uses.

Desktop-Grid operators and donors together can implement environmental friendly policies:

- Energy tariff choice. Green energy tariffs excluding nuclear power are generally available for private households, companies, and institutions and meanwhile price-wise acceptable as examples from UK and Germany indicate [39, 40, 41];
- Reduce energy consumption in general.

As CO2 footprint alone fails to reflect energy production reality, it seems adequate rephrasing the core aim of Green IT from "Reduce CO2 footprint" to "Save energy".

4.1. €- metrics for Green IT success. In order to measure the effectiveness of energy saving policies and methods, we need to introduce a metric that can be "metered". The obvious advantage of "kWh" as the base metric for Green IT is the simplicity of measurement: electricity is metered everywhere. Different from data centres and conventional Service-Grids, policies and methods are applied and executed in Desktop-Grids mainly by the volunteer effort of the resource contributor. As success metric for Green IT, the translation into cost, into money, is helpful to connect to business considerations and propel motivation. With €(for kWh) as metric, contributors can relate their choice of workload and policy-compliance to the personal electricity bill. Green Desktop-Grids help the planet and your budget may express this motivation appropriately.

5. DEGISCO Green Desktop-Grid Methodologies. DEGISCO investigates conceptually different methodologies, based on technology means like Desktop-Grid-Client based ambient metrics, exploitation of natural ambient conditions, and more. Some of those methodologies are technological, some are purely organizational. DEGISCO promotes innovative Desktop-Grid deployments through the International Desktop-Grid-Federation [8] especially by the Desktop Grids for eScience Road Map. The Desktop-Grid-Federation will offer consulting and advice based on Green methodologies, continuing the roadmap process to reflect and integrate future findings and developments. One focus topic in the roadmap process is the application of Green Methodologies to achieve reduction in energy consumption of research infrastructures.

5.1. Seven Green Desktop-Grid Methodologies. DEGISCO has started with a shortlist of 7 methodologies which are a collection of best practices, techniques and policies:

- Ambient metrics based Green optimization;
- Cool strategy: avoid air-condition use;
- Energy profiling of applications;
- CPU speed steps;
- Exploitation of natural ambient conditions;
- Time-of-day dependent energy tariffs;
- Management of unused resources in a local Desktop-Grid.

In the course of the roadmap process [21, 22] these methodologies are challenged, refined or replaced, according to feedback and feasibility tests supported by contributors.

5.1.1. Ambient metrics based Green optimization. In order to tune DEGISCO connected Desktop-Grids towards saving of energy suitable configurations and parameters are to be identified enabling the Desktop-Grid client to intelligently select adequate workload. A regular PC [13] almost doubles its power consumption from idle 160W to 300W under full CPU load. BOINC general preferences [45] allow to specify that computation consumes a certain portion of the machine, e.g. 50% of CPU time, by this reduces heat dissipation.

Ambient temperature measurement or at least estimation could be used to control and potentially prevent download of workload items if the PC and its environment are too hot for comfortable or safe operations. The measurement and observance of ambient conditions, mainly temperature, is essential for several advanced Green Methodologies, too.

5.1.2. Cool strategy: avoid air-condition use. Desktop-Grids are the real Green Grids: lower energy density than clusters results in less energy wasted for cooling. However, this may not longer be true if air-conditions are used to assure proper operation of Desktops. According to the principles of thermodynamics, the energy consumption by air-conditions for cooling range from 30% to >200% (PUE: 1.3..>3) of the energy dissipated by the IT device. The wide range is a direct result of the cool-reservoir temperature the heat pump can utilize to get rid of the heat. The prime advice to configure Green-Desktop-Grids: avoid air-condition use.

Selection criteria for the "maximum temperature" as described above could be that temperature which would just not yet trigger the start of the local air-condition. In case the use of air-condition is unavoidable, the recommendation to participate in Desktop-Grids depends:

- if the additional workload by Desktop-Grids would cause proportional air-condition power consumption, a change of strategy should be considered. Maybe by restricting the acceptance of workload to night times would help, configurable in the BOINC client settings [44] and preferences [45];
- if the air-condition is in full power use anyway – like in tropical ambient – the additional heat dissipation during compute load processing may not impact the total energy balance too much. Still the additional heat dissipation can be controlled as described above [45].

Example: light building structures with poor thermal insulation and continuously running air-conditions are de-facto standard in sub-tropical and tropical regions globally. If we assume a 3.5kW air-condition (2-3 room flat, small house) to run non-stop in order to keep the ambient temperature 15°C below the 40°C outside, additional heat dissipation of a standard office PC (60W idle, 120Watts fully loaded) would raise the ambient temperature by ≈1°C (assumed 50% efficiency of the air-con). The 120 Watts compare to the 100W approximate basal metabolic rate [47] + 20-40W brain activity of the human body so the user of the PC will raise the ambient temperature for another 1°C while awake and thinking. The raise in room- or ambient-temperature is minimal since the thermal balance in this example is dominated by the heat flow through the building structure. Massively higher impact on the room-temperature is caused by cooking activities (in the multi-kW range).

5.1.3. Energy profiling of applications. Different applications and codes consume more or less CPU at any given time, resulting in different energy consumption per time interval, specific energy profiles. They behave differently in raising machine and ambient temperature. According to our findings within the DEGISCO available pool of applications (see Desktop Grid Application Super-Repository: [14]), these are could be classified accordingly with a heat index as +, ++ and +++ for example. We refrain from using "green", "orange", and "red" at this point: The +++ index marks an application that makes maximum use of a given machine, is raising its temperature, but finishes the computation quickly. This behaviour may total in less energy consumed/computation than the application which creates less heat/time but runs longer. Still heat/time is an important parameter from a green operations point of view. As PC owners can select the project and by this the application they want to contribute to, they can take into account their specific knowledge of local operations conditions, primarily how much additional heat they can accept. If energy profiling of applications does not supply sufficient control range, the BOINC native method of setting general preferences [45] to specify CPU% utilization may be used.

5.1.4. CPU Speed Steps. A similar effect could be achieved by exploiting processor speed steps, avoiding additional preparation work on the application side. Current processors provide multiple steps (8-16) for CPU speed, thus controlling energy consumption. Gruber and Keller discuss the use of "SpeedStep" among other methods in order to use the minimal CPU frequency to run an application at full memory bandwidth [15]. Different from the application, the OS and tools installed at the PC are under control of the Desktop-Grid contributor, placing the management of methods like "SpeedStep" into the volunteers hand.

5.1.5. Exploitation of natural ambient conditions. DEGISCO investigates another completely independent green strategy: exploitation of natural ambient conditions. A specific project advantage facilitates the aggregation of partners from various different geographies, a fact that allows benefiting from differences in regional weather situations in order to save energy. Workload indexed as "+++" may systematically be offered to contributors located in low temperature areas while those in sunny summer weather will be offered to contribute for "+" workload. Different locations yield different climates:

- Kazakhstan, Amaty: `http://worldweather.wmo.int/070/c00152.htm`
- Russia, Moscow: `http://worldweather.wmo.int/107/c00206.htm`
- Hungary, Budapest: `http://worldweather.wmo.int/017/c00060.htm`
- Denmark, Copenhagen: `http://worldweather.wmo.int/173/c00190.htm`
- Spain, Zaragoza: `http://worldweather.wmo.int/083/c01240.htm`

Recruiting regions with opposite weather conditions allows to counteract actual weather conditions. E.g. if there is only "+++"-workload-type available today, Copenhagen may be preferred over Zaragossa. DEGISCO partners from Kazakhstan, Russia, and Spain confirmed the weather conditions reported on "worldweather" as already averaged – the peak temperatures exceed both into heights and lows significantly.

5.1.6. Time-of-day or weather dependent energy tariffs. The value and price of electrical energy is changing according to the conditions of generation as well as by changing consumption. Accordingly, the tariffs for electricity are changing over time of day and year. While in Germany electricity prices are high during lunch time, in Kazakhstan the energy prices go up in the evening – in both cases dependent on consumption.

Energy prices at the Spot markets vary depending on excess production capacity. Since wind energy can deliver significant amounts of energy, these spot market prices can even turn negative [12].

To improve the energy cost situation and to take advantage of excess Green electricity, advice could be given to contributors how to configure their Desktop-Grid-Clients to prefer workload during low tariff times [45, 46].

5.1.7. Management of unused resources in a local Desktop-Grid. A seventh Green strategy can be reported from the OUR-Grid project, presented e.g. at OGF30, Brussels: Lesandro Ponciano and Francisco Brasileiro have focussed on sleeping- and wake-up-strategies for Desktop-Grid-Clients from various modes like off, suspend, or hibernate, and the according impact on responsiveness of a campus Desktop-Grid [49]. Wake-up-strategies like WOL (Wake on LAN) are usually not applicable for Internet scale deployments but work well in local networks.

6. Desktop-Grid the loosely coupled virtual data centre. A major difference between a data centre situation and volunteer based Desktop-Grids is the almost complete lack of central control over the compute resources. Further, Desktop-Grid applications are executed as user with limited permissions (no root rights). Accordingly, installation of support tools, in our case for temperature and energy consumption measurement, is not possible without active voluntary contribution by the resource owner, installing tools with administrator (aka "root") rights. This cannot be done as regular Grid job: different from service Grids, Desktop-Grids implement highest security standards also on the execution side. Applications that are downloaded and executed on the contributed Desktop-Grid client are security validated and, dependent on the Desktop-Grid technology used, even rewritten to execute exactly that computation as described and nothing more. Any activity beyond the sandbox, e.g. accessing local HW devices like sensors, is off limits for Desktop-Grid jobs. When DEGISCO is looking to gather detailed temperature and energy consumption data we are asking for volunteers to download and install tools and allow the upload of resulting metric data.

6.1. Difficulties of temperature measurements. In order to apply the Green Methodologies described, it is very helpful to adequately understand the ambient conditions of the PC, especially the ambient temperature. It seems obvious to utilize the PC's built in temperature sensors – but there are difficulties to overcome. The temperature sensors included in PCs and laptops are optimized to support energy management of the PC and its components – not to provide ambient conditions, the kind of information we need. Mainly the position of the sensor determines what is measured. On-die temperature sensors may reflect the CPU internal temperature quite precisely while "system" temperature sensors are placed "somewhere" on the mainboard – delivering temperature measurements that cannot be interpreted meaningful without precise and detailed knowledge of the individual board. Although this seems doable in a lab situation, it is completely beyond scope for real world deployed Desktop-Grids. The situation is not very much better in regular data centres: depending on the placement of the temperature sensor in the rack, a hot spot will be detected or not. A detailed temperature measurement at several positions in the rack is still not commonly found. For safety reasons, the single temperature sensor is placed to detect the (known or anticipated) hot spot, caused by poor local airflow – delivering information misleading with regards to average, typical, or total (i.e. = full rack) energy consumption. Further complication is deriving from the application of temperature aware fan speed controls embedded in the systems. Originally developed for Desktops in order to keep their operations noise level convenient for living room conditions, meanwhile regular servers are controlling their fan speeds to provide exactly that amount of cooling needed to keep board temperature within the targeted operations range while enhancing the lifetime of the fans. The "Code of Conduct on Datacenters" [4] explicitly requests control of fan speeds also on the data centre level. The result for our aim to understand the ambient conditions of a machine by reading its temperature sensors gets complicated by these features.

Still the information retrieved may well be sufficient for our aims:

1. Understand values delivered by PC internal temperature sensors as non-linear non-calibrated relative information on machine cooling effectiveness;
2. For ambient temperature use meteorological data by independent sources;
3. To calibrate and QA the methods, call for participation by contributors in a temperature measurement campaign.

Even qualitative temperature information is suitable to distinguish condition “too hot for workload” from “cool and ready to work”. To verify our understanding on ambient conditions, we started working Fraunhofer Institute ITWM, Kaiserslautern to reuse a simple and low cost temperature sensor [16] that can be connected to the desktop or laptop (USB) and delivers proper ambient metrics. This temperature sensor may be offered to Desktop-Grid volunteers by mail-order, requesting the commitment to provide temperature measurement data for automated upload.

Desktop-Grids have been used for sensor applications frequently, like the project “Quake”: Quake-Catcher Network Seismic Monitoring [48]. The Quake project tried to use the built-in sensors primarily, but offers external sensors too.

7. Conclusion and outlook on International-Desktop-Grid-Federation. We need to progress on wise usage of donated compute time and the accompanied energy, otherwise future willingness of donors is questionable. Desktop-Grids are positioned well as the comparison with data centers show – but improvements are possible and looked for like improved energy aware scheduling interconnected with user friendly project specific energy aware client preferences. This will need to be implemented on the Desktop-Grid technology (client, server) in an easy to manage, easy to operate way, something that could be targeted by an upcoming research project. For immediate use and implementation, DEGISCO provides the roadmap document to assure Green-Desktop-Grid success.

In order to improve Desktop-Grid services for e-science and to sustain Desktop-Grids as regular DCI (Distributed Compute Infrastructure) the International-Desktop-Grid-Federation (IDGF, [14]) takes over from DEGISCO and EDGI. The IDGF is becoming the crystallization point for new projects and advances in Desktop-Grids and especially Green-Desktop-Grids.

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