Green computing within the context of educational and research projects

Vyacheslav Kharchenko, Oleg Illiashenko, Chris Phillips, Jüri Vain

***Abstract*—** The paper summarizes concepts of green computing and is about the one of the most important challenges caused by a power crisis in context of information technologies application. Main definitions and taxonomy of green computing are provided. The article represents main objectives and specific tasks of TEMPUS GreenCo project and other projects, funded by European Commission – TEMPUS SEREIN, TEMPUS CABRIOLET and by FP7 Programme – KhAI-ERA. The deliverables of TEMPUS GreenCo project and connections with other TEMPUS projects are described.

***Keywords* —** green IT, green computing, taxonomy, TEMPUS GreenCo project.

I. INTRODUCTION

Green technologies are innovations (innovative technologies) based on the principles on sustainable development and reuse of resources. Their main goal lies in decreasing of negative influence on the environment, e.g. reduce the amount of waste, increase energy efficiency, improve the design to reduce the amount of resources consumed [1]. Green technology and *green energy* is complemented by the concept *green business*, which is characterized by the use of such technologies (and such energy) at different stages of production, corporate and social responsibility, which are directly related to the concept of *green culture* [2]-[3].

During literature review and analysis on green computing and green IT, it is needed to select [4-7]. Part of them addressed problem of resources saving in IT offices, and it was not just about energy, but also other resources, including consumables (paper, toner cartridges, etc.). Among the first books of it should be noted book on green IT for the "Dummies" [8]. Later on several books (joint monographs) were published [9]-10]. The first one should be noted specifically it more fully covers all the problems of green IT. It is interesting to note that the main sections of the book were in tune with the list of courses that have been included in the project TEMPUS GreenCo. The second book continues the series of publications on green data centers. The paper goal is to summarize concepts and taxonomy of green computing. The article represents objectives and specific tasks of TEMPUS GreenCo and other projects, funded by European Commission. The deliverables of TEMPUS GreenCo project and connections with projects TEMPUS SEREIN and CABRIOLET are described.

II. GREEN COMPUTING. BIG PICTURE

A. Green computing taxonomy

Information technologies can be described and viewed in the narrow and broad sense in the context of sustainable development. In a narrow sense – it is energy-saving and energy-efficient information technology and systems in broad one – they take into consideration environmental, security and sustainable development in general.

So, main entities in the field of sustainable development (sustainability) and green IT, as an "IT Sustainability Set (ITSS), could be described by the Cartesian product of two subsets:

- Sustainability Development Set (SDS) of: energy and resource (EnF), ecology (EcF), safety (SF) и social and economic (CF);
- Two-element set (Means-Object Set – MOS):

$$ITSS = \\ =SDS * MOS = \\ = (EnF, EcF, SF, CF) * (Means, Object) \quad (1)$$

Table 1 represents this multiplication. Each cell contains particular task in the field of green IT. String "Means" isn't parted to the components because when IT is used as a tool, the combinations of components is used as a rule. Moreover strictly speaking both net and infrastructure means (tools) include hardware and software. To the strings "Object" yet another is added, which brings together all the components. This matrix allows conducting preliminary analysis of green IT directions and corresponding facts. It generalizes the similar matrices proposed by the project participants TEMPUS GreenCo [11]-[12]. The analysis performed allows developing and analyzing taxonomic scheme of green information technologies. In this article, we confine our analysis to the taxonomy of green IT in the narrow sense: define the hierarchy, clarify the basic concepts and logical connections between them.

Green energy – energy derived from renewable sources without affecting or with acceptable damage from the point of view of sustainable development for environment human and technical facilities.

Green technology – is an innovative technology, understood as a set of methods, processes and materials used in any kind

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of business to create new tangible or intangible products, and based on the principles of sustainable development, obtaining and use of green energy.

SET, MOS		SETS OF FACTORS OF SUSTAINABLE DEVELOPMENT, SDS			
		EnF	EcF	SF	CF
MEANS		Means * EnF	Means * EcF	Means * SF	Means * CF
Object, IT-components	HW	EnF * HW	EcF * HW	SF * HW	CF * HW
	SW	EnF * SW	EcF * SW	SF * SW	CF * SW
	NW	EnF * NW	EcF * NW	SF * NW	CF * NW
	IS	EnF*x IS	EcF * IS	SF * IS	CF * IS
	IT	EnF * IT	EcF * IT	SF * IT	CF * IT

Tab. 1. Matrix of tasks of green IT in a context of sustainability concept

Green engineering – a special kind of engineering or, as is often said, engineering, based on green technologies. It could be represented in a form of services tended to improve energy efficiency, safety and environmental performance of industrial processes and products.

Green IT – is an adaptation of the practice of IT's development and application so as to use IT more effectively. It forms a vector of development.

Green computing – a special kind of computing. In order to clarify the concept of green computing, it is necessary to understand the nature and evolution of the paradigm of computing in general. We can say that today there is a concept of computing in a narrow, broad and global sense.

In a narrow sense computing – is a calculation (the set of transformations that are performed by applying a finite number of pre-defined rules) that runs on a computer or in a computer system.

In a broad sense computing – is a collection of scientific knowledge engineering methods and activities aimed at the development and application of computer technology, including hardware and software, in different areas for the purpose of information and automation.

In a global sense, computing or noocomputing – is part of the noosphere, a theory which has developed a great scientist V.I. Vernadsky [13]. In the processes of globalization noocomputing, which formation can be completed within this decade [14], should play a key role.

Definition of **green communications** in a similar manner is projected on computer networks and telecommunications, and can be considered as a component of green computing.

Green information technology (green IT) – a set of processes, methods and tools for data collection, storage, processing, supply, distribution of information and methods of their implementation, aimed at improving energy efficiency, safety and environmental technologies themselves and the systems in which they are applied, as well as dissemination of the relevant values in the society.

Green IT engineering – kind of engineering based on the development and application of green IT in different types of human activity. Therefore, it is possible to distinguish and properly interpret the green computer engineering and green software.

Based on the concepts discussed the following components can be determined:

- **green hardware** minimizes power consumption and the risk of dangerous failures when using systems important to safety. Accordingly, one can speak of green chips, microprocessors, modules, etc.;
- **green software** minimizes the information and energy systems, as well as based on the code, optimized on the energy metrics.

IT systems (infrastructures), based on green hardware and / or software may be called **green IT systems (infrastructures).**

Green cloud computing can be defined as technology that can provide potential benefits for the environment and energy savings in the provision of services via the Internet or other distributed computing technologies.

Greenware – is a combination of hardware and software, and services that allow the user to minimize the effect of using a computer or computer system on the environment and the cost of expenses for their use and maintenance.

IT greening (or ***greenwashing*** by [9]) and **green IT reengineering** are process terms and are particularly important when it comes to developing of energy efficient software, as well as modernization of existing IT systems of different nature in the interests of reducing power consumption, etc.

Green IT culture – these are the values and norms of behavior related and directed on preservation and enhancement of all components of the environment, resources, energy and safety by improving the development and implementation of green technologies and information systems, as well as methods of professional and social activities, IT specialists in forming, development, dissemination and adoption of these values and norms.

Green IT business aims at developing and implementation of IT and green technologies, which affirmed the value of green culture, implementing a business organization that minimizes the use of energy and other resources, and direct or indirect CO2 emissions in creating products and services.

Green IT policy – is a set of goals and activities regulating the achievement of rational results in the field of green IT, specific indicators on energy efficiency and resource conservation.

B. Green computing metrics

Energy saving and energy efficiency are the main characteristics; the first one is determined by the consumption of energy, and the second – how efficiently the energy is used. It is about power, being measured by capacity P_e.

Thus energy E_e is the complex indicator that can be calculated as the ratio of capacity to be achieved, precision, and other characteristics, or their growth ΔP using technology or IT systems per watt P_e or its changes

$$\Delta P_e : E_e = \Pi / P_e \quad (2)$$

or

$$E_e = \Delta П / \Delta P_e \quad (3)$$

Energy saving has a broader meaning and indicates not only the quantitative value of energy savings by using green IT, but also on a set of measures aimed at reducing consumption.

In order to estimate the share of energy P_e, which is consumed by equipment of such system with respect to the total energy Ps of technical complex, enterprise, or any object that is embedded in the software and hardware, they use simple index MEI (power IT-system metric):

$$PIM = P_e / P_s \quad (4)$$

When talking about data centers (data center computing clusters, cloud infrastructure) one should use used metric PUE (power usage effectiveness):

$$PUE = P_s / P_e \quad (5)$$

The following metrics are also used:

GEC (green energy co-efficient) – defines the part of the energy Per, which is derived from renewable sources: GEC = Peg / Pe.

ERF (energy reuse factor) determines the fraction of energy (heat primarily), released during the calculations work of and data centers as a whole, beneficial use in the future Per (e.g. for heating, greenhouses, etc.):

$$EPF = P_{er} / P_e \quad (6)$$

Carbon usage effectiveness takes into account the impact of data centers and similar systems on the environment, the measured CO_2 emissions, and is determined by the ratio of emissions CE caused by a common data center power Ps to the volume of energy consumed for processing information Pe [16]:

$$CUE = CE / P_e \quad (7)$$

For the IT system, its components and processes associated with the development and application the particular indicators, which are sometimes called green metrics [17] could be calculated. They are described more detailed in [18]-[19] and in broad sense are based on so called GAMES-approach (Green Active Management of Energy in IT Service Centres). Such metrics indicate:

- the proportion of processes aimed at reducing the use of resources, including reducing energy consumption and improving energy efficiency;
- assessment of the relative influence of each of these processes and project activities on resources, energy consumption and energy efficiency;
- degree of improvement in resource characteristics of the products obtained at different stages, etc.

III. TEMPUS AND FP7 PROJECTS ACTIVITIES

A. TEMPUS GREENCO tasks and structure

At the time of TEMPUS GreenCo project proposal there were no MSc programmes in Green IT Ukraine and other post-USSR countries. Hence it was needed to fill in the formed GAP in teaching of green IT in Academia. Concept, main activities, tasks and structure of TEMPUS GreenCo project (Green Computing and Communication), reference number 530270-TEMPUS-1-2012-1-UK-TEMPUS-JPCR, were developed at department of computer systems and networks (CSN) of National Aerospace University KhAI together with colleagues from Newcastle University. Detailed evolution of another joint TEMPUS projects is described in [20].

Specific *outcomes of TEMPUS GreenCo project are [20]:*

1. To introduce a green computing & communications programme for master students in universities in Ukraine and Russian Federation;
2. To introduce a green computing & communications programme for doctoral students in universities in Ukraine and Russian Federation;
3. To facilitate intensive capacity building measures for Ukrainian and Russian IT tutors;
4. To establish two PhD incubators in Ukraine and Russian Federation on green computing & communications.

Main activity of such TEMPUS-funded project is development of teaching courses, their dissemination for MSc, PhD and LLL (long-life learning) level. In frame of TEMPUS GreenCo project the following courses are to be developed:

1. **MSc courses:**
   - Foundations of green IT-engineering
   - Technologies of green computing
   - Technologies of green regulators and robotics
   - Technologies of green communication
2. **PhD courses**
   - Standardization of green computing and communication
   - Research and development (R&D) for green FPGA-based systems
   - R&D for green mobile applications
   - R&D for green wireless networks
   - R&D for green cloud computing
   - R&D of ITs for smart energy infrastructures
   - Green software
3. **LLL (long-life learning) courses**
   - Techniques and tools (T&T) for green computing
   - T&T for green control systems
   - T&T for green communication and management

MSc courses form a conceptual base of green ITs and provide review of existed technologies in the field of energy-saving computing, network decisions and decisions for automated process control system and robotic systems. They are intended for IT bachelor graduates to gain an understanding of the green computing methodologies and paradigms, energy efficient system level software such as compilers, hypervisors, monitoring and profiling tools, workload managers, and

programming environments, energy aware large scale distributed systems, such as Grids and Clouds. They are suitable for those aspiring to be software developers, software architecture designers, FPGA developers, experts on distributed infrastructures.

PhD courses include materials of research and development of "hot-topic" directions in green IT on the level of microcircuits, systems, networks and infrastructures. Moreover the normative regulation issues in the field of green IT and related fields are reviewed.

LLL (long-life learning) courses are aimed at practical aspects – engineering techniques and tools for development and management of green IT systems.

B. TEMPUS Greenco project deliverables

In frame of TEMPUS GreenCo two-volume multi-lecture edition covering different aspects of green IT concept was developed [21]-[22]. It presents lecture material including theoretical and practice issues of green IT-engineering for MSc-courses, PhD-Courses and training modules developed in frameworks of the project TEMPUS GreenCo.

Volume 1 [21] contains material based on the outcomes of analysis, research and development in the area of green (energy saving and energy effective) computer components and systems. The base concepts, principles and taxonomy of green computing and green IT-engineering are described. The methods and techniques of green hardware and software development and assessment for CPU- and FPGA-based embedded and mobile systems are proposed. The models and algorithms allowing save resource and power consumption at modeling, development and verification of FPGA design, high performance systems and lightweight cryptography systems are analyzed.

Volume 2 [22] contains material based on the outcomes of analysis, research and development in the area of green (energy saving) computer systems, networks, cloud IT-infrastructures and their application in industry and in context of green culture of society as a whole. The methods, technologies and cases related to the following directions are described: green Wi-Fi and mobile systems and networks (routing in networks, sensor networks, adaptation, hybrid systems); green databases and cloud computing (access and storage of data, data centers, architecting, management); green IT and industrial instrumentation and control (I&C) systems (smart grid, I&C for industry and universities); green IT for business and society (web for green, economic issues, IT-cooperation).

Figure 1 shows taxonomical scheme which describes the links between main concepts of green computing and green IT engineering and correspondent volumes of "Green IT engineering" book, published in frame of TEMPUS GreenCo project. In the left part of the scheme four groups of concepts related to the following issues are identified:

- Sustainability and its components (environmental, safety, and resource);
- Engineering, technology and systems;
- Culture, including green culture;
- Business, including green business.

On the right side, in addition to the above terms the logical connections between them are specified:

- Green computing, noocomputing;
- Green IT and Green IT engineering;
- Green IT software (components, processes, properties, characteristics and metrics) and green IT systems;
- Green IT culture and green IT business.

C. Other TEMPUS and FP7 projects

TEMPUS GreenCo project is closely connected with other projects performed at CSN department at KhAI:

SEREIN project [23] "Modernization of postgraduate studies on security and resilience for human and industry related domains". This project is performed in frame of TEMPUS programme. To reach the main objective the international MSc and PhD programme on cyber security and resilience for Ukrainian universities will be developed. Power consumption and its leakage allow conducting successful power analysis-based attacks. Security is often about balance of protection measures and cost, so students should be able to resources efficiently.

CABRIOLET proje**ct** [24] "Model-oriented approach and intelligent knowledge-based system for evolvable academia-industry cooperation in electronic and computer engineering".

The project is aimed on design and nation-wide sustainable introduction of model-oriented approach based on implementation of general life cycle model of Evolvable Academia-to-Business Cooperation (EA2BC) and 3 customized models serving different types of Academia-to-Business cooperation and introduction of intelligent knowledge-based system (IKBS) for analysis, processing and generating of assessment results and recommendations for involved academic departments and companies. In order to establish such sustainable system the results of GreenCo project are qualitatively and effectively used.

KhAI-ERA project [25] is a special support action funded by the European Commission within FP7 Capacities Specific Programme which aims to reinforce National Aerospace University "KhAI" research cooperation capacities in order to become more closely integrated into the European Research Area (ERA). CSN department at KhAI play key role in topic C "Dependable Embedded Systems" of KhAI-ERA project (covering the topics related to architecting, development, formal methods and verification of dependable FPGA- and software-based embedded systems). Energy-saving plays in important role in embedded systems of critical application, and so the experience obtained during GreenCo project allows to act more effectively in this case.

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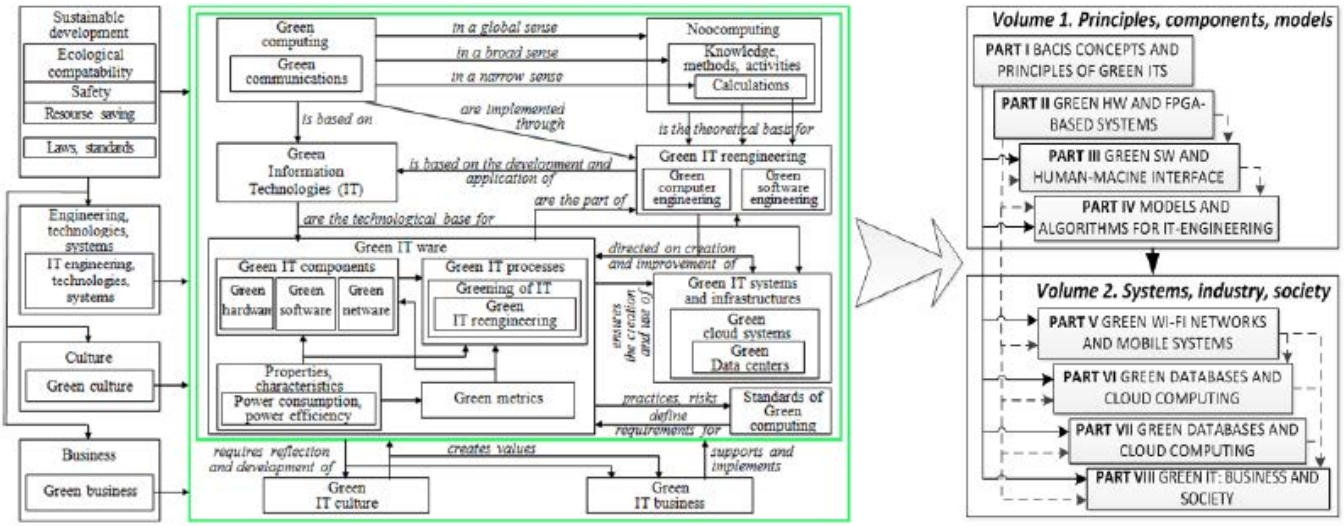

Fig. 1. Taxonomical scheme of green computing and structure of "Green IT engineering" book

KhAI's experts established permanent contacts with CEBE-TUT's [26] trainers and lecturers in order to organize training modules and deliver workshops in dependable embedded systems for experienced researchers and summer schools for young researchers. Training modules to be developed are intended for KhAI`s experienced, mid-level and young participants (as well as in GreenCo project for MSc, PhD and LLL levels, SEREIN project for MSc, PhD and In-service training) selected in competitive basis taking into account their teaching activity, experience, gender issues and language skills. The overall picture of reviewed projects is described in detail in [15].

D. National green related projects

Amongst international projects the department of computer systems and networks of National Aerospace University "KhAI" took part in the national project *"Theoretical foundations, methods and information technology of critical software and hardware development under resource limitations (2012-2014)"*. The following tasks were considered:

1. Development of scientifically grounded principles, models and methods for use of language-based approach for creating critical software systems
2. Development of principles of multiversion computing multiparameter adaptation and methods of dependability ensurance for I&Cs and infrastructures taking into account resource constraints

One more project that is currently performed at CSN department of KhAI is *"Scientific fundamentals, methods and tools of green computing and communications"* (2015-2017).

IV. Conclusion

Green computing plays an important role in formation of sustainable development of human civilization. The described concepts and taxonomical scheme of green computing are a base for defining connections with other IT-domains. The links between GreenCo, SEREIN, CABRIOLET and KhAI-ERA projects allow getting synergy effect for the teams of developers. Energy saving, green and safe ITs should be considered in computing more due to in tend to obtain sustainable society.

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