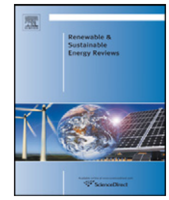
Renewable and Sustainable Energy Reviews 16 (2012) 2966–2972

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Impact of nanotechnology advances in ICT on sustainability and energy efficiency ☆

Dragan S. Markovic [a,*], Dejan Zivkovic [b], Dragan Cvetkovic [a], Ranko Popovic [b]

[a] *Faculty of Management, Singidunum University, Belgrade, Serbia*
[b] *Faculty of Informatics and Computing, Singidunum University, Belgrade, Serbia*

ARTICLE INFO

Article history:
Received 2 February 2012
Accepted 4 February 2012
Available online 22 March 2012

Keywords:
Information and communication technology
Sustainability
Energy efficiency
Renewable energy
Nanotechnology
Thermoelectricity
Photonics

ABSTRACT

Urbanization, sustainability, energy efficiency, information and communication technology (ICT) and nanotechnology are emerging at the beginning of the 21st century. They are seeking to improve environmental effectiveness in the context of connected communities, global competitiveness, economic development, climate change, and demographic shifts. Virtually all proposed solutions to energy consumption and climate change acknowledge the role ICT plays as a key enabler of environmental effectiveness. One of the major challenges that the ICT sector faces today is that hardware is being pushed to its physical limits. The traditional means to reduce product size, increase functionality and enhance computing capabilities are becoming difficult and expensive every passing day. On the other hand, the industry is benefiting from nanotechnology advances with numerous applications including those in smarter sensors, logic elements, computer chips, memory storage devices, optoelectronics, quantum computing, etc. This paper presents an overview of the ICT benefiting from development in nanotechnology with respect to sustainability and energy efficiency.

Contents

1. Introduction

Environmental sustainability is a very hot topic at the moment. Topics such as climate change and global warming have generated a lot of discussion and even some international regulations aimed at reducing the human environmental load [1]. This is the urban century—more people worldwide are living in urban areas than rural for the first time in recorded history. The urbanization trend picked up pace in the 20th century and has accelerated since. Whereas in 1950 only about 30 percent of the world's population lived in cities, today it is more than 50 percent. Urbanization manifests itself in two ways: expansion of existing cities and creation of new ones [2].

Cities are already the source of close to 80 percent of global CO_2 emissions and will account for an ever-higher percentage in the coming years, as more and more people reside in and move

☆ This work has been supported by the Serbian Ministry of Education and Science (project III44006).

* Corresponding author.
E-mail address: dsamarkovic@singidunum.ac.rs (D.S. Markovic).

1364-0321/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2012.02.018

to cities in search of prosperity. If we continue with the same solutions that have been used to address urban development needs in the past, the resulting urban ecological footprint will not be sustainable—humanity will need the equivalent of two planets to maintain those lifestyles by the 2030s. At the heart of the matter, we face a challenge of meeting demands of urbanization in an economically viable, socially inclusive, and environmentally sustainable fashion [2,19].

Urbanization is an inevitable progression. It can go well, it can happen badly, but progress it will. To make urbanization a positive and productive transformation that will deliver long-term gains to citizens, three goals need to be achieved—social equitability, economic viability, and environmental sustainability. Social equitability is based on the principle of inclusion; there is no discrimination in access to benefits across population segments. Economically viable solutions are those that are financially self-sustaining. Environmental sustainability ensures the preservation of the environment for future generations [2].

According [3], most of the attention in sustainable urban development has been directed to three sectors: buildings, energy, and mobility. Today, however, it is becoming evident that a fourth, equally important element must be addressed: ICT. When it comes to urban sustainability, ICT is part of the problem (based on its contribution to overall energy consumption), but an even bigger element of the solution. ICT is a significant contributor to energy efficiency: for every extra kilowatt-hour of electricity demanded by ICT, the U.S. economy increases its overall energy savings by a factor of ten [4].

World is facing an increasing scarcity of raw material supply in various fields. In order to reduce the energy and carbon burden linked to building materials and components, Knowledge Society will see an increasing pressure on their sustainable performance, i.e. longer service life, multi-functionality as a primary step to create added-value of material use, more efficient use of primary raw materials, an increase in recycling as well as an increasing use of renewables. In addition, the application of lightweight materials and systems will be inevitable to reduce the environmental impact of the construction process. Particularly with respect to the last two issues, the scarcity of resources will be a restraining factor. As energy demand for the operational phase of the building life cycle is decreasing and/or for a larger part covered by renewable energy, the embodied energy of building materials and components will become an increasingly important aspect to take into account. The present ratio between embodied energy and energy during the use phase of a building is about 20/80. Because of the way the building industry is organized, decision-makers/investors in e.g. energy saving or sustainable energy are not the ones who benefit from the gains that these can provide. As a result of this imbalance, market forces do not provide any strong incentives towards Life-Cycle-Costing for buildings, and breakthroughs are only likely if regulations are also set in place. Because cost optimization is to a large extent linked with optimization of the required amount of man-power, more and more use will be made of prefabrication and ICT (e.g. Building Information Models) in the building process [5].

Materials have to be manufactured on demand today, meeting the complex set of the specific requirements. Embodied energy (emergy) in materials represent a relatively high percentage of energy throughout the life cycle of buildings, especially when increasing the level of energy performance in operation. New approaches combining novel processes, sensors and material science are needed to minimize the embodied energy of main construction materials such as cement, concrete, glass, steel, ceramics, etc. Development of new multifunctional materials is needed, having a low embedded energy and also higher thermal and acoustic properties (embodied energy is often proportional to mass), overcoming scarcity of renewable materials. It is becoming more apparent that the next technological frontiers will be opened not through a better understanding and application of a particular material, but rather by understanding and optimizing material combinations and their synergistic function, hence blurring the distinction between a material and a functional device comprised of distinct materials. Future research will be strongly focused on the final performance properties and less on the individual material performance. New technology routes to integrate waste in the production cycle (recycling) of materials are needed [5,20].

The remainder of this paper is organized as follows. Section 2 explains role of ICT in sustainability and energy efficiency in urban communities and Section 3 presents a quick overview of materials and properties. Section 4 details developmental trends in nanotechnology and applications in the ICT sector. Finally, Section 5 summarizes future trends of the ICT in the context of sustainability and energy efficiency.

2. Role of ICT in sustainability and energy efficiency

A new dimension has been added to the world of information and communication technologies: from *anytime, any place* connectivity for *anyone*, we will now have connectivity for *anything*. Billions connections create an entirely new dynamic network of networks – an Internet of Things (IoT).The Internet of Things is a technological revolution that represents the future of computing and communications, and its development depends on dynamic technical innovation in a number of important fields, from wireless sensors to nanotechnology [15]. Leading technology companies in the world, such as Cisco, Microsoft, and IBM, have recognized the value of the global information infrastructure and they are offering their solutions. Virtually all proposed solutions to energy consumption and climate change acknowledge the role ICT plays as a key enabler of environmental effectiveness in large metropolitan areas (Stern, 2006; IPCC, 2001, 2007). The SMART 2020 report (The Climate Group, 2008) addresses exactly *how* urban ICT and broadband connectivity can help, and what the carbon-reduction impact of innovative urban ICT policy for energy efficiency can be. Any discussion of sustainable urban development must acknowledge that ICT is part of the problem facing cities today, based on its ever-increasing levels of energy consumption. This downside, however, is more than mitigated by its valuable contributions to energy efficiency, its ability to reduce energy demand in other activities (e.g., using teleworking to reduce trips to the office), and the existence of ICT applications that increase the efficiency of energy used in these activities (e.g., car routing that cuts traffic congestion) [3,21].

The ICT infrastructure (servers, storage, networks, and the IT team) supporting the city domains is not operating in an integrated and coordinated manner. Having these silos of ICT infrastructure often leads to increased cost of operation, underused and overused hardware, and redundant software. These ICT infrastructure issues might be less obvious, but they are an important aspect of cutting costs, providing more openness, and streamlining operations [6,16].

It should be no surprise that, as the society moves into the digital realm and uses more instrumentation, there will be a lot of data. You might find the following common challenges, among others, when handling data:

- A need for data from various sources to get an accurate view of an event or potential situation. The data must be collected, stored, transformed, and analysed to provide actionable information.
- Data security, including proper governance, such as audit trails and controlled access.
- Management of the data life cycle such that data is collected, stored, transformed, and archived properly [6].