Subject review

Best Practices of Biomass Energy Life Cycle Assessment and Possible Applications in Serbia

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Abstract

This paper aims to highlight the advantages of using »Life Cycle Assessment« (or LCA) tool in energy sector for rational energy consumption, selection of »green« technologies and process optimization. Besides the definition and description of basic principles of this method and its historical development, previous examples of worldwide applications are analyzed. Review of these examples is made on the basis of a critical analysis of the available literature regarding the application of LCA for sustainable production of electricity and heat. Trend of using this tool since its inception until now is rising, together with a greater interest of general public to reduce negative impacts on the environment during production, use and disposal of various products. Compared to other countries (EU and beyond), in Serbia the LCA tool is insufficiently studied and practically unused. With this regard, special emphasis is placed on the possibility of practicing LCA in terms of proving the environmental suitability of biomass as an energy source, considering its huge potential in the Republic of Serbia. Wider utilization of LCA approach would also enable investigation and assessment of possibilities for heat production by different renewable energy sources in order to identify optimized environmental solutions for Serbian energy sector and to decrease dependence on energy imports through increased reliance on domestic energy resources.

Keywords: life cycle assessment, renewable energy sources, biomass, electricity, heat generation

1. Introduction

Neglecting environmental problems is forcing a modern society to pay for a damage that has already been done. This usually occurs through rehabilitation of existing environmental problems or through a rapid development of environmental-friendly technologies. The development of environmentally friendly technologies, which are essentially based on utilization of renewable resources, is still happening at a slow pace, which makes them not-so-cheap replacements to the current fossil fuel technologies and processes and delays the achievement of sustainable development. Nevertheless, it is becoming more apparent that dependence on fossil fuels cannot be sustained anywhere in the world. Thus far, in Europe and around the world, a lot of work has been done in order to shift the focus from the application of traditional energy resources to renewable ones. This not-so-easy task was also imposed on Serbia to solve. For achieving a very ambitious goal adopted in Directive 2009/28/EC, Serbia has to invest in the development of renewable energy sector and to increase the application of green technologies. When establishing green technology, the very first step in project planning considers inclusion of the system design with the maximum protection of the environment (Jelić et al. 2014a, Jelić et al. 2014b). For these purposes, the inclusion of tools and indicators that are used for estimation of environmental impacts from different processes has almost become an obligation. The most distinguished environmental assessment tools that have been developed and applied so far are: Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA), Environmental Risk Assessment (ERA), Ecological Footprint and Life Cycle Assessment (LCA) which will be studied in more detail in this paper (Finnveden et al. 2009).

Nowadays, the Life Cycle Assessment is one of the leading and most used tools for environmental management. This tool provides a systematic, holistic and multidisciplinary approach in quantification of environmental burdens and their potential impacts over the whole life cycle of a product, process or activity. Although it has been used in some industrial sectors for about 20 years, only since the beginning of the 1990s, when its relevance as an environmental management aid in both private and public decision making became more evident, LCA has received methodological development (Pieragostini et al. 2012).

Learning how to incorporate environmental performance based on the life cycle concept into decision-making processes can be beneficial for academia, public facilities, companies and industry organizations (Anon. 2006). The LCA methodology is still developing and expanding its use to more different subjects, i.e. products and processes. The focus of this paper is on application of LCA in energy sector, especially for the assessment of the environmental justification of using biomass for energy. The main reason for placing the focus of the research on biomass is due to its abundance in the Republic of Serbia. Combustion of biomass provides energy production without increasing the CO_2 emission at the same time. Energy produced in this way is usually between 4 and 8 times less expensive than the energy produced by burning the fossil fuels. Fuel obtained from biomass is considered to be practically unlimited, it is being renewed every year and its quantity can be increased (Jovanović et al. 2013).

2. LCA: History in brief

Life Cycle Assessment technique was created at the beginning of 1960s. At that time, it was not exactly the same LCA as it is known today. Forerunner of LCA technique was firstly introduced into the field of risk analysis, thanks to Chauncey Starr, who was the first that pointed out that risk analysis could include more factors that are today called externalities[1]. One of the initiator of the development of life-cycle assessment was also Rachel Carson's book »Silent Spring« (1962), in which the author accused the chemical industry for spreading disinformation about the threats from persistent use of pesticides on living organisms, especially on birds. This was the opposite approach from the former one in which »externality« problems were kept away from general attention (Sørensen 2011).

At the beginning of 1970s, in the USA the environmental life cycle studies were called »Resource and Environmental Profile Analysis« (REPA), and in Europe, Ecobalance (Anon. 2006). In general, LCA approach was developed simultaneously in Europe and in the USA. Between 1970 and 1975, 15 REPA studies were performed due to public concerns caused by early 1970's oil crisis and increased demand for the accuracy of the information from industry sector to the public interest groups. The first REPA (LCA) study was conceived in 1969 for the Coca-Cola Company, by the Midwest Research Institute from Kansas City, Missouri. During that time, the Coca-Cola Company considered the possibility of producing their own beverage cans and was interested in a number of issues linked to the manufacture of packages. This REPA study quantified the resource requirements, emission loadings, waste flows of different beverage containers, and took into consideration the use of plastic as packaging material, which was a radical idea at that time. For the first time, it was proved that plastic can be used as a packaging material instead of glass, and a »green light« has been given for using plastic bottles instead of glass ones (Hunt and Franklin 1996). Unfortunately, this study was confidential and was only used within the company for their internal business decisions. Another REPA study also showed that plastic is a »greener« material, in particular, that polystyrene foam meat tray is more favourable or »greener« than the pulp tray.

During the 1980s, LCA studies were mainly focused on energy requirements. Total energy analysis in these studies included the energy spent in raw materials, manufacture of energy conversion equipment, the operational energy use and the energy used for recycling or final disposal of decommissioned equipment. This constituted a complete life cycle (»cradle-to-grave«), but only for energy use, not for environmental damage. In this period, the interest for LCA studies was decreasing and was slowly shifted to the waste management sector. Approximately, two LCA studies were conducted per year. This trend continued until 1988, when solid waste became a worldwide issue. This implied a re-use of LCA techniques and speeded-up its development (Anon. 2006, Sørensen 2011).

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[1] Externalities are factors whose benefit and costs are not incorporated in market prices of goods and services. Externalities are a loss or gain in the welfare of one party resulting from an activity of another party, without there being any compensation for the losing party. Externalities are an important consideration in cost-benefit analysis.

(Business dictionary)

Guineé (Guineé et al. 2011) divided the development of the LCA into three periods/decades:

⇒ Decades of Conception

⇒ Decade of Standardization

⇒ Decade of Elaboration

The first period (1970–1990) represented the very beginning of LCA development where due to application of widely diverging methodologies, approaches and terminologies, great differences among study results occurred. The Second decade of LCA development (1990–2000) was characterized by production of a number of guides and handbooks for practicing LCA, together with the production of two international standards used as guidelines for LCA practitioners: ISO 14040 (2006E): »Environmental management – Life cycle assessment – Principles and framework« and ISO 14044 (2006E): »Environmental management – Life cycle assessment – Requirements and guidelines«. The third period (2000–2010) was the period where LCA finally gained more attention – The International Life Cycle Partnership, Life Cycle Initiative was formed in order to promote Life Cycle thinking and the variety of LCA promoting networks has been established all around the world.

Future development of LCA predicts its wider use in the next decade, together with the development of regionalized databases and design of new impact assessment methods. In other words, the second decade of this century is predicted to be the decade of life cycle sustainability analysis (Guinée et al. 2011).

3. LCA technique in brief

Life cycle assessment is a cradle-to-grave analytical tool that effectively creates a mass balance over an industrial system by analyzing all of the inputs and outputs of a product system over its entire life cycle. In other words, the product is »followed« from its »cradle«, where raw materials are extracted from natural resources, through its production and use, to its »grave« – disposal (Fig. 1).

Beside this approach, there are other variants of LCA, which do not consider the whole life cycle of a product or process but rather some phases. »Cradle-to-gate« approach considers an assessment of a partial product life cycle from resource extraction (cradle) to the factory gate, i.e., before it is transported to the consumer. In this case, the use phase and disposal phase of the product are omitted (González-García et al. 2014, Mattila et al. 2014, Adams et al. 2015). The other variant of LCA is a »cradle-to-cradle« approach, which represents a specific kind of cradle-to-grave assessment, where the end-of-life disposal step is actually a recycling process, where new or practically the same product emerges from the used product (Braungart et al. 2007, Hsieh and Meegoda 2009, Llorach-Massana et al. 2015). Well-to-wheel is the specific LCA used for transportation fuels and vehicles (Heracleous 2011, Møller et al. 2014) and Economic input-output LCA (EIOLCA) investigates how much environmental impact can be attributed to each sector of the economy and how much each sector purchases from other sectors (Egilmez et al. 2013, Hendrickson et al. 2005, Tonini and Astrup 2012, Chang et al. 2010).

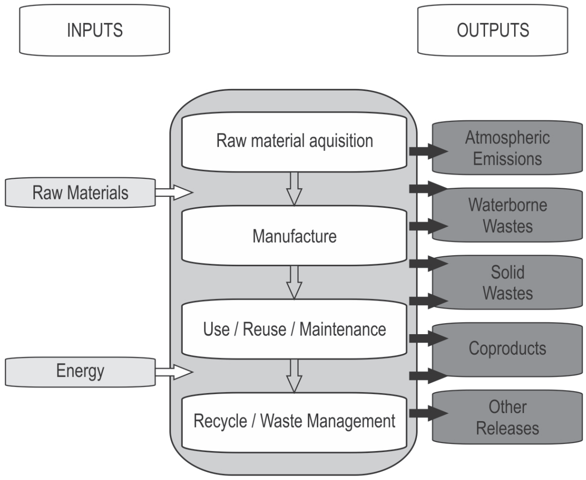

Fig. 1 Life cycle stages

Many organizations and bodies have created their own definitions of LCA in an attempt to provide a simple, but readily understandable, explanation of the tool and methodology. ISO 14040:2006 describes LCA technique as »compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle«. »LCA is an assessment process about limited numbers of the quality functions, cycles and lives« (Sinclair 2011). LCA is widely used as a decision-making tool in process of selection, design, and optimization in order to identify clean technologies (Binaghi et al. 2005). In ILCD Handbook for LCA made by European Commission, it is stated that »Life Cycle Assessment (LCA) is a structured, comprehensive and internationally standardised method, which quantifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with any goods or services (products)« (Anon. 2010a). An LCA can help decision-makers to select the product or process that has the least impact on the environment in combination with other factors such as cost and performance data. LCA is also a useful tool that avoids unwanted »shifting of burdens« in which the reduction of environmental burden at one point of life cycle leads to its increase at another. Shifting of burdens consider, for example increase of emissions in one country while reducing them in another, reduced greenhouse gasses, but increase in land use and formation of acid rain improvement of technology while causing waste problems, etc. This ability to track and document shifts in environmental impacts can help LCA practitioners to completely identify all environmental trade-offs associated with product or process alternatives. Life Cycle Assessment is, therefore, a vital and powerful decision support tool, complementing other methods, which are equally necessary to help effectively and efficiently make consumption and production more sustainable (European Commission 2010).

As mentioned above, there are two standards for providing the framework for LCA: ISO 14040 (ISO 14040:2006) and ISO 14044 (ISO 14044:2006). ISO 14040 considers the principles and framework for an LCA, while ISO 14044 specifies the requirements and guidelines for carrying out an LCA study. Although the ISO standards provide an indispensable framework for LCA, they are defined in a rather obscure way, which makes it difficult to assess whether an LCA has been made according to the standard or not.

Several software solutions for practicing LCA are available for LCA practitioners: SimaPro (developed by PRé Consultants), Umberto (developed by IFU Hamburg and IFEU Heidelberg), TEAM (developed by Ecobalance), GaBi (developed by Department of Life Cycle Engineering of the Chair of Building Physics at the University of Stuttgart and PE International GmbH), POLCAGE (developed by De La Salle University, Philippines, and University of Portsmouth, UK) and GEMIS (developed by Öko-Institut), mostly based on general databases, such as the ECOINVENT (developed by Swiss Centre for Life Cycle Inventories). Probably the most used software for conducting LCA studies is SimaPro (Pieragostini et al. 2012).

LCA technique is mostly used to identify environmental »hot spots« in a product's life cycle, for guiding the corporate product or process development (e.g., inform green design decisions), in benchmark against similar products, for comparison of different products or services, for support product eco-label certification and for support public policy decisions. For different application of LCA, different requirements are needed. For example, if the intended application of a study is to identify major environmental »hot spots« of some products, which will be used by internal staff to decide on which hot spots to make further study, LCA can probably be done by using literature data and a fairly simple analysis. However, if the intended application is to support public policy decisions, a study with high data quality, rigorous uncertainty analysis, extensive documentation, and external peer review is necessary.

According to the Society of Environmental Toxicology and Chemistry's (SETAC), there are four methodological components or four phases within LCA: Goal and Scope Definition, Life Cycle Inventory Analysis (LCI), Life Cycle Impact Assessment (LCIA), and Interpretation (Rebitzer et al. 2004). The first phase, Goal and Scope Definition, includes the reasons for carrying out the study, the intended application, and the intended audience (ISO 14040:2006, ISO 14044:2006). It is also the place where the system boundaries of the study are described and the functional unit is defined. The functional unit represents a quantitative measure of the functions that goods (or service) provide (for example 1 MJ of produced heat, 1 m^3 of wood logs, etc.).

A Life Cycle Inventory analysis or LCI is a process of quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes, and other releases from the entire life cycle of a product, process, or activity in relation to the functional unit (Anon. 2006). This phase requires a lot of data – setting up inventory data can be one of the most labour and time-intensive stages of LCA. This is often challenging due to the lack of appropriate data for the product system under study. Many public national, regional, industrial and consultants' databases have been developed in the last few decades in order to simplify the LCI. The most distinguished and the most commonly used national i.e. international database used in LCA studies is the aforementioned Swiss »Ecoinvent« database (Finnveden et al. 2009, European Commission 2010, De Bruijn et al. 2002).

In the third – Impact Assessment (LCIA) phase, assessment of the potential human and ecological effects of energy, water, and material use is done and the environmental releases are identified in the inventory analysis. The LCIA is aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of the studied system (ISO 14040:2006, ISO 14044:2006). When performing LCIA, there are three elements that are obligatory to conduct, according to ISO standards. Firstly, it is necessary to select and define Impact categories (global warming, acidification, terrestrial toxicity, etc.) that are relevant for the LCA study. In the next step, Classification, LCI results are assigned to the appropriate impact categories – in case of an impact category »global warming«, it is necessary to classify all carbon dioxide emissions. Modelling LCI impact within impact categories by using science-based conversion factors is taking place through Characterization phase (modelling the potential impact of carbon dioxide and methane on global warming impact category) (Anon. 2006, Pennington et al. 2004). Impact categories can be divided into problem-oriented midpoint and damage-oriented endpoint categories. Problem-oriented approaches focus on environmental problems that lie in the middle of the environmental cause and effect chain, while damage-oriented approaches focus on the end of the chain, i.e., the actual damage (De Bruijn et al. 2002). For example, when considering ozone depletion as a product of CFC-11 emission, the midpoint categories would consider ozone depletion itself, since it is a common stressor caused by the CFC-11 emission, whilst endpoint categories consider the ultimate consequence of the emission potential, such as skin cancer and eye damage in exposed humans, crop damage on exposed land, and degradation of plastics. Using of the endpoint approach is more complex since it takes more knowledge and data to model a larger part of the ecosystem and to calculate synergy and cumulative effects (Rebitzer et al. 2004, De Bruijn et al. 2002, Pennington et al. 2004). Many different Impact assessment methods (ReCiPe, Eco-indicator 99, IMPACT 2002+, TRACI, IPCC 2001 (climate change), Ecosystem damage potential – EDP, CML 2001, EDIP'97 and 2003 – Environmental Design of Industrial Products, etc.), which could facilitate and speed up the impact assessment process, are available in software for LCA (Frischknecht et al. 2007, Goedkoop et al. 2013). In the Interpretation phase, the results from the previous phases are evaluated in relation to the goal and scope of the study, conclusions and recommendations are given together with a clear understanding of the uncertainty and the assumptions used to generate the results (Finnveden et al. 2009, European Commission 2010, ISO 14040:2006, ISO 14044:2006, Pennington et al. 2004, Muench and Guenther 2013). Nevertheless, conducting an LCA study is almost always an iterative process. Once the goal and scope of the study are defined, requirements for the subsequent work are set. However, due to more information available after the LCI, LCIA and Interpretation phases, the initial scope settings usually need to be refined and revised (Fig. 2).

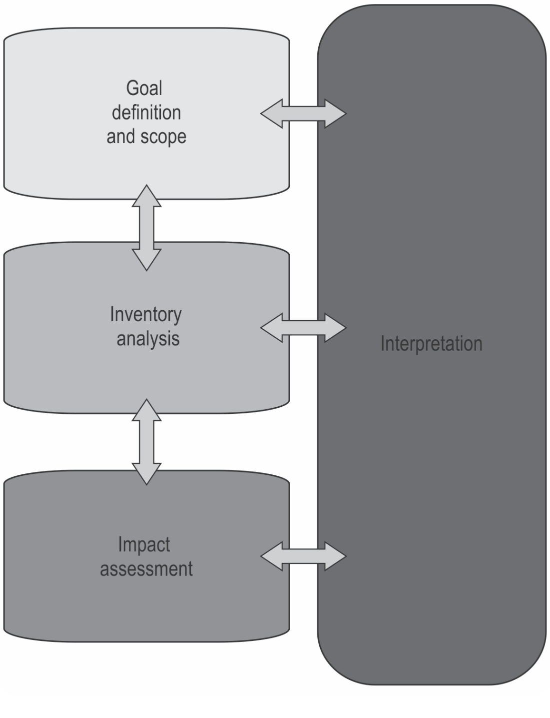

Fig. 2 Phases and iterative nature of LCA

4. LCA studies for use of biomass as an energy source

In the last few years, a certain number of scientific and review papers dealing with LCA in energy sector have been published (Finnveden et al. 2009, Pieragostini et al. 2012, Muench and Guenther 2013, Rebitzer et al. 2004, Bare 2009, Frischknecht et al. 2007, Goedkoop et al. 2013, Varun et al. 2009, Evans et al. 2010, Cherubini and Strømman 2011, Sherwani and Usmani 2010, Peng et al. 2013). In accordance with the topic of this paper, papers that deal with biomass as an energy resource have been considered with more attention.

Varun et al. (2009) reviewed the existing energy and CO_2 life cycle analyses of electricity generation systems based on renewable sources. Wind energy system, solar photovoltaic system, solar thermal system, biomass system and hydropower system were analyzed and compared with conventional systems such as coal fired, oil fired, gas fired and nuclear-based power systems. It has been concluded that the life cycle emissions are comparatively much higher in conventional sources than in renewable sources, except for the nuclear-based power electricity generation, where there is less emissions to the environment but much more damage due to radioactive waste disposal. For an optimum selection of the electricity sources, the use of mixed technologies is suggested.

Evans et al. (2010) concluded that electricity prices, efficiencies, greenhouse gas emissions, availability and limitations for biomass-produced electricity are currently favourable when compared with other energy generation options. In order to achieve sustainability, they suggested, significant attention had to be given to the reduction of the land and water use and to the social impacts of biomass power generation.

Cherubini and Strømman (2011) reviewed 94 different LCA bio energy studies, where the most (74) were papers published in scientific journals and the remaining (20) were grey literature. They pointed out that numerous published papers and studies worldwide evaluated the environmental performance of biomass final use, mostly as a transportation biofuel, i.e. bioethanol and biodiesel production, while only around 27% of published material considered the environmental performance of using biomass for the generation of heat and combined heat and power (CHP). Considering impact categories applied, about 90% of the studies included GHG emissions in their evaluation, a certain number of studies (20%) estimated other airborne emissions like NO_x, PM10, SO_x, and others. Other impacts, such as acidification, eutrophication, etc., were analysed in 20–40% studies. Lignocellulosic biomass is recognized as most used biomass feedstock due to its abundance worldwide.

Pieragostini et al. (2012) revealed that the most used concept for system boundaries definition in practice is »cradle-to-gate«, instead of the »cradle-to-grave« approach. Among the LCIA methods, the eco-indicator 99 is the most used LCIA method and SimaPro is the most used software for LCA applications.

Muench and Guenther (2013) singled out fifty eight LCA studies that consider LCAs on biomass electricity and heat generation. They took into account different biomass feedstock used, different conversion technologies applied, regional contexts, and different LCIA methods used in these studies. They showed that lignocellulosic biomass has been most commonly used biomass feedstock, and direct combustion of biomass the most commonly analyzed conversion technologies, from which, 37/47 studies assessed monocombustion and 21/47 assessed co-firing. The majority of investigated LCA studies have been prepared in the European context, while the remaining regions contribute in a smaller portion. All of the bioenergy LCAs in an Asian context considered rice straw or husk as feedstock, probably due to the abundance of this material and the absence of competing uses in this region. Midpoint categories were applied in most of the bioenergy LCAs (50/58), whereas endpoint approaches were used in only 12/58 studies. A total of 25 studies provided suitable information for the quantitative analysis from which most frequently used impact categories are: global warming potential (GWP, 25/25), acidification potential (AP, 13/25), eutrophication potential (EP, 12/25), and photo-oxidant creation potential (POCP, 9/25).

Environmental impacts of processing the biomass and its products at the forest field have also been studied by many authors. Schwaiger and Zimmer (Karjalainen et al. 2001) investigated the fuel consumption and related GHG emissions for main forest operations (harvesting, hauling and transport) for twelve different European countries (Austria, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Norway, Slovenia, Sweden and Switzerland) and concluded that due to the differences between the level of mechanization in harvesting operations, different levels of fuel consumption and subsequently, different level of GHG emissions occured in different countries. In Western and Northern EU countries, harvesting operations are more mechanized so higher level of fuel inputs are required and, also higher levels of GHG emissions occur, whilst other EU countries, which have less mechanised harvesting operations, have lower fuel inputs and less GHG emissions from harvesting operations, but higher impact on the environment from the hauling processes. From all biomass operations in the field, transportation of forest products from the forests to the industry has been proved to have the highest impact on the environment due to high levels of fuels consumption. Karjalainen and Asikainen (1996) took into consideration the impact on the environment form the building of forest road network and proved that it consumed a large amount of fuels and emitted high levels of GHG. Heinimann and Maeda-inaba (2003) concluded that on moderate slopes (up to 40%), construction of one meter of forest road consumes about 350 MJ of energy, while emitting about 20 kg of greenhouse gases, where this energy consumption is equivalent to the heating value of about 10 l of diesel fuel per meter of road length, and about 10 kg of wood mass that has to be grown to sequestrate the amount of emitted greenhouse gas. In the report about LCA of road construction in Finland, carried out by Mroueh et al. (2000), beside fuel and energy consumption, other environmental loadings, such as consumption of natural materials, effluents to soil and water (leaching of metals – As, Cd, Cr, Cu, Mo, Ni, Se, Pb, Zn; leaching or migration of organic compounds from materials), emissions to air (CO_2, NO_x, SO_2, VOC, CO, Particles), inert waste, use of water and noise are factors that were also considered.

Heinimann (2012) highlighted the importance of considering the environmental burden occurring from forest machinery construction, which is not negligible but usually neglected in LCA studies. Bosner and Poršinsky (2008) indicated the possibility of using data

Table 1 Structure of recent energy consumption in Serbia

Year	2010		2011		2012		2013*		2014**	
Gross final energy consumption, Mtoe	15.531		16.192		14.526		15.366		15.594	
	Mtoe	%	Mtoe	%	Mtoe	%	Mtoe	%	Mtoe	%
Coal	7.751	49.91	8.741	53.98	7.623	52.48	8.086	52.62	7.767	49.81
Oil	3.901	25.12	3.783	23.36	3.362	23.14	3.558	23.16	3.521	22.58
Natural gas	1.853	11.93	1.902	11.75	1.678	11.55	2.016	13.12	2.582	16.56
Electrical power	–0.026	0.00	–0.024	0.00	0.033	0.23	–0.189	0.00	–0.076	0.00
Hydro power	1.022	6.58	0.745	4.60	0.798	5.5	0.858	5.58	0.761	4.88
Geothermal power	0.005	0.03	0.006	0.04	0.006	0.04	0.006	0.04	0.006	0.04
Biomass	1.026	6.61	1.038	6.41	1.026	7.06	1.028	6.69	1.031	6.61
Biogas	0	0	0	0	0.001	≈ 0	0.002	≈ 0	0.002	≈ 0
Solar energy	0	0	0	0	0	0	0.000	0	0	0
Wind energy	0	0	0	0	0	0	0.000	0	0	0
Total of RES	2.053	13.22	1.789	11.05	1.831	12.60	1.894	12.31	1.8	11.53

* – Estimated
** – Planned

about life cycle of forest machinery from the manufacturer on the example of harvester Timberjack 770 and forwarder Timberjack 1410.

5. RES potential in Serbia

Considering energy consumptions of different energy sources (both non-RES and RES) in energy system of Serbia for the last five years (from 2010 to 2014), it is evident that RES are still having a small role in Serbian energy network with a share of 12.41% of the total energy consumption (Table 1).

Biomass is the most widely used type of RES for energy purposes, with the highest share from all other RES (approx. 6.68%) followed by hydropower (approx. 5.4%). The use of other RES such as biogas, solar, geothermal and wind energy is practically negligible – there are several small power plants that use biogas, solar and wind energy for electricity generation (Anon. 2012a, Anon. 2013a, Anon. 2013b, Anon. 2014). According to the estimations from the year 2013, the planned production of geothermal energy in 2014 in Serbia was 0.006 Mtoe. This amount of geothermal energy is only used for heating. Unfortunately, application of heat pumps in geothermal heating systems has not been included in these estimations. Despite this, several studies dealing with the application of heating pumps in geothermal energy based heating systems were completed. Criteria for use of groundwater as renewable energy source in geothermal heat pump systems for building heating and cooling purposes have been investigated (Milenić et al. 2010) together with the selection of optimal low-temperature ground water heat pump vapour compression cycle (Antonijević et al. 2012).

Two-stage, cascade, hydro-geothermal heat pump is anticipated as minimal pollution replacement for fossil fuel powered hot-water-heating systems. Besides high-grade energy efficiency of a system, it has been shown that positive environmental effects can be increased if old low efficiency and highly polluting central heating systems are completely substituted, together with the total omission of local fossil fuel energy sources (Antonijević and Komatina 2011). Research of the possibilities for the conjunction of biomass and geothermal energy into a hybrid power plant has begun just recently, therefore merely a modest number of investigated case-studies are available. One of the examples is the hypothetical hybrid power plant in Rotokawa I geothermal plant in New Zealand (Thain and DiPippo 2015). In Serbia, application of this kind of hybrid-power plants is in the initial phase and represents a good solution for the sustainable heating options in the future.

Table 2 Biomass potential (used, unused and total)

BIOMASS TYPE	Available technical potential in use, TJ/year	Available technical potential unused, TJ/year	Total available technical potential TJ/year
Agricultural biomass	1381.64	68,537.92	69,919.56
Residues from agricultural crops	1381.64	41,449.32	42,830.96
Residues in fruit growing viticulture and fruit processing	–	25,330.14	25,330.14
Liquid manure	–	1758.46	1758.46
Wood (forest) biomass	42,747.228	21,310.81	64,058.04
Energy crops	–	–	unavailable
Biodegradable municipal waste	–	8582.94	8582.94
TOTAL	45,510.516	168,476.832	212,480.10

5.1 Forest biomass potential in Serbia

According to some studies, total available technical potential of biomass in Serbia is 212.5 PJ/year (Table 2) (Anon. 2013c), where the biggest share comes from agriculture biomass, around 70 PJ/year (residues in crop, livestock, orchards, vineyards and primary processing of fruits), while the potential of wood biomass is slightly less, around 64 PJ/year. From this potential, only about 30% is used, while the rest of about 70% is unused and represents a good basis for an increased use of biomass for providing energy in the Republic of Serbia.

Considering biomass potential from Serbian forests, it is estimated that the roundwod presents around 28% and fuelwood around 72% from the total annual volume production potential of wood assortments (Oka et al. 1997, Ilić et al. 2003). The annual volume potential of logging operations in Serbian forests is estimated to be more than 5 million cubic meters of wood, where both roundwood and fuelwood account for 58% and residues from logging operations together with unused parts of branches and stumps that stay in forests account for 42%. This would mean that, if the whole forest potential in Serbia is used, additional 3 million cubic meters of wood would be available (Table 3), where only large-sized forest residues would be available in the volume of 140,000 m^3. Given the quality and other characteristics, this amount of wood volume can be used in chemical industry, for board manufacturing and finally as an energy source – in its original form or transformed. According to data from another study, the maximum amount of forest residues that can be collected in Serbian forests is around 1.1 m^3, where large-sized residues are available in the amount of 750,000 m^3 per year (Anon. 2008). This indicates that the data about the actual amount of available forest biomass are inconsistent among various researches in Serbia. There is no consensus among researches regarding biomass potential in Serbia.

Table 3 Structure of potential forest residues in Serbian state forests

Forest residues	Quality		Share		Remark
	Humidity,%	Size	%	m^3	
Leafage and needles	30–60	–	–	144,000	Ignored
Stumps and roots	40–60	Large	47.3	1,255,000	Remains in woods
Small branches	40–60	Large	25.7	750,000	Partly used
Offcuts Sawdust	40–60	Large Small	27.0	900,000	Partly used
TOTAL			100.0	3,049,000	

Table 4 Distribution of estimated energy potential of fuelwood and forest residues in the Republic of Serbia (data from state forests)

Area	Energy potential, TJ/year				
	Fuelwood	Forest residues			
		Stumps and roots	Small branches, twigs	Offcuts and sawdust	Total
South-east	1168	2759	1649	1979	6387
East	1074	2536	1516	1819	5871
Central	706	1667	996	1195	3858
West	903	2132	1274	1529	4935
Belgrade's	1075	1991	1190	1428	4609
North	483	806	482	578	1866
TOTAL	5409	11,891	7107	8528	27,526

Potential use of forest residues as an energy resource is determined by different technical-technological and economic factors. In what amount this residue can be used for energy depends on the terrain, stamps and other conditions of the place of origin of these residues. In intensive lowland forest plantations, it is technically possible to use almost 100% of wood from wood waste categories. However, in natural forests in mountainous regions, categories and quantities of wood residues must be significantly reduced, due to difficulties in their transportation, their role in erosion control and in fertilization of forest soil (Ilić et al. 2003). According to the estimated mass of wet wood and bark and corresponding lower heating values, provisional data of the available amount of energy of forest residues in the Republic of Serbia are calculated (Table 4). It can be assumed that the average moisture content of all types of wood residues is 60%, and the most dominant type of trees in the North and Belgrade areas are broadleaves (100% and 60%, respectively) (Ilić et al. 2003). Calculated Energy potential of the fuelwood is around 5410 TJ/year, where 2/3 of the available fuel wood is used for heating, and the rest is used for chemical processing. Estimated energy potential for forest residues is much higher and is estimated to be around 27,530 TJ/year (Ilić et al. 2003). Still, this type of biomass is insufficiently used in Serbia. Reasons for this lie in inappropriate forest management method applied, unsatisfied level of competency and low technical and technological capacities.

Considering residues from wood processing industries in Serbia, the potential volume (Table 5) of wood residues and bark is estimated to be 234,163 m^3 and 91,876 m^3, respectively, i.e. 326,039 m^3 in total (Ilić et al. 2003). This calculation is made according to the balance of expenditures for certain technologies and tree species. The calculation results are only given for three basic technologies of wood processing in Serbia (sawmilling, veneer and panel production and chemical processing), since the production of particleboards in the Republic of Serbia is practically stopped, and the final processing of wood furniture production is based on imported raw materials.

Due to the fact that the approximate volume of imported panels is around 50,000 m^3, another 5000 m^3 of wood waste from processing of these boards are available for further use. The available energy of wood waste and bark is calculated in the same way as for the forest residues – from the mass of wet wood and corresponding lower heating values. In total, energy potential of wood waste from wood-processing industry is 2718.12 TJ/year (Table 6). Part of this potential has already been used for heating of wood-processing plants. These data are obtained from processing of logs felled in state forests, which were purchased through public company »Srbija šume«. Accurate data for the processing of logs in private forests are not available, and can only be speculated (Ilić et al. 2003).

Exploration of biomass potential from energy plantation in Serbia is still in the initial phase of research. There are good possibilities for the establishment of short rotation plantations of fast-growing species of broadleaves on the area of about 20,000 hectares along flooded areas of Serbian main rivers (Danube, Sava, Morava and Drina), where the potential annual production of air dry biomass could reach up to 46 tons/ha (Dražić et al. 2006). The establishment of energy plantations at the disposal sites of the barren soil (deposoils) of the open-pit coal mines have also been

Table 5 Potential volume of wood residue and bark durring wood processing in the Republic of Serbia

Area	Type of wood processing	Wood waste, m^3					Bark, m^3
		Beech	Oak	Conifers	Poplar	TOTAL	
Belgrade	Sawmill	4175	7726	287	11,193	23,381	9615
	Veneer and panel production	607	2973	0	26,851	30,431	10,474
	Chemical	0	0	0	0	0	4941
	Total					53,812	25,030
Central Serbia	Sawmill	24,940	891	4440	1214	31,485	11,237
	Veneer and panel production	0	0	0	0	0	0
	Chemical	0	0	0	0	0	0
	Total					31,485	11,237
East Serbia	Sawmill	12,208	735	0	0	12,943	4214
	Veneer and panel production	1907	0	0	0	1907	445
	Chemical	0	0	0	0	0	0
	Total					14,850	4659
Southeast Serbia	Sawmill	31,513	120	322	374	32,330	10,647
	Veneer and panel production	2014	0	0	0	2014	470
	Chemical	0	0	0	0	0	0
	Total					34,343	11,117
North Serbia	Sawmill	4290	3200	0	19,637	27,127	12,257
	Veneer and panel production	0	0	0	36,678	36,678	13,166
	Chemical	0	0	0	0	0	0
	Total					63,805	25,424
West Serbia	Sawmill	19,122	188	11,454	4516	35,280	14,272
	Veneer and panel production	587	0	0	0	587	137
	Chemical	0	0	0	0	0	0
	Total					35,868	14,409
Total wood waste and bark from wood processing in the Republic of Serbia 326 039 m^3						234,163	91,876

studied on the example of Kolubara basin, where the potential for production of air dry biomass is estimated to be around 200,000 tonnes per year, or 1,200,000 tonnes in six year rotation period with highest volume increment and mass of the seedlings registered in poplar species (Dražić et al. 2011). Unfortunately, there is no record of energy generation from forest plantations nor systematic approach for the utilization of this type of energy source in Serbia (Table 2).

From all the above, it can be concluded that the total potential amount of energy obtained from forest biomass collected in Serbian state forests and from wood processing plants during one year is around 35,658 TJ, where the biggest share comes from forest residues (27,530 TJ), then from fuelwood (5410 TJ) and, at the end, waste wood from wood-processing technologies (2718 TJ). This calculation represents the optimal case of biomass utilization based mostly on the

Table 6 Calculated available energy potential of wood waste and bark from wood processing for different regions in the Republic of Serbia

Area	Type of processing	Potential energy value, TJ/year		
		Wood	Bark	Total
Belgrade	Sawmilling	194.58	69.23	263.80
	Veneer and panel production	222.87	75.41	298.28
	Chemical	0.00	35.58	35.58
	Total	417.45	180.22	597.66
Central Serbia	Sawmilling	324.07	80.91	404.98
	Veneer and panel production	0.00	0.00	0.00
	Chemical	0.00	0.00	0.00
	Total	324.07	80.91	404.98
East Serbia	Sawmilling	142.18	3.34	172.52
	Veneer and panel production	21.30	3.20	24.51
	Chemical	0.00	0.00	0.00
	Total	163.48	33.55	197.03
South East Serbia	Sawmilling	353.42	76.66	430.07
	Veneer and panel production	22.50	3.38	25.88
	Chemical	0.00	0.00	0.00
	Total	375.91	80.04	455.95
North Serbia	Sawmilling	198.13	88.25	286.38
	Veneer and panel production	247.02	94.80	341.82
	Chemical	0.00	0.00	0.00
	Total	445.15	183.05	628.20
West Serbia	Sawmilling	324.00	102.76	426.76
	Veneer and panel production	6.56	0.99	7.54
	Chemical	0.00	0.00	0.00
	Total	330.56	103.75	434.30
TOTAL		2056.62	661.5	2718.12

approximate values but it still provides a clear picture of huge energy potential of this renewable energy source that can be used in Serbian power grid. This amount of available energy potential of forest biomass could be even higher if the data from privately owned forests were available and included in the calculation.

One of the ways to increase the share of RES in Serbian energy network lies in the increased support from the government. Without the initial support from the state, the use of forest residues (as a source of energy) could not withstand the competition with other fuels (Ilić et al. 2003). Fortunately, during the last few years, some efforts have been made towards more inclusion of RES in Serbia's energy sector. In the year 2012, Serbia adopted the EU Directive 2009/28/EC, which obliges the increase of RES share in its gross final energy consumption to 27% by the year 2020 (European Commission 2009).

6. LCA application on biomass and other RES in Serbia

A certain number of studies about potentials and possible implementations of biomass in the energy system of Serbia have been done (Anon. 2013c, Jovanović and Parović 2009, Ilić et al. 2003, Anon. 2010b, Anon. 2012b, Anon. 2008, Anon 2012c) mostly focusing on the current situation in the energy sector, potentials of wood biomass and other RES for energy provision, and on identification of the best practice for their increased use in the future (Martinov et al. 2005, Golusin et al. 2010, Dodić et al. 2012, Danon et al. 2012, Lalić et al. 2011). Significant efforts have been made to include agricultural biomass in energy systems in Serbia, especially in case of heating of greenhouses inside the Agricultural Corporation PKB – Belgrade with soybean straw bales (Erić et al. 2011, Erić et al. 2010, Mladenović et al. 2000). In general, all of these studies are basically focusing on techno-economic analyses, not much on identification of consequences on environment and human health that can occur during the life cycle of biomass products. Since the main reason for increased use of RES is to lower GHG emissions and to mitigate global warming effect that occur from fossil fuel combustion, this environmental impact is the mostly studied environmental impact both worldwide and in Serbia (Đerčan et al. 2012, Cvetinović et al. 2013, Brkić et al. 2005). Other environmental impacts that can occur during the whole biomass life cycle, (such as stratospheric ozone depletion, acidification, eutrophication, photochemical smog formation, terrestrial toxicity, aquatic toxicity, human health, resource depletion, land use and water use), which can have serious consequences on the environment and human health, are practically neglected.

Considering the application and practice of LCA technique in Serbia, there is no evidence about any significant LCA study conceived so far. There is a limited number of publications regarding the application of LCA technique in Serbia available, mostly for waste management and eco-design of products (Vujković et al. 2002, Popović and Filipović 2010, Čarapina et al. 2010). Only recently, LCA has been included in the assessment of efficiency and environmental impacts of solid biomass fuels, with the focus solely on the assessment of energy inputs and GHG emission. The study published last year by Furtula (2014) analyses consumption and energy structure together with emission of GHG in all life cycles stages for three types of solid biomass fuels: firewood, wood chips and wood pellets. It was concluded that firewood has the lowest energy consumption and CO_2 emission, but a high raw material consumption per unit of produced thermal energy. Pellets have the highest energy consumption and CO_2 emission, with a possibility of its reduction by previously natural drying of raw material and by using the process of cogeneration (CHP) during pellet production. At the end, authors gave suggestions for a more efficient use of solid wood fuels in Serbia, such as higher application of natural drying of raw materials, lower transport distance to the end user, increased production of woodchips and pellets, increased use of wood chips in industry and in electricity generation through cogeneration, deploying of cogeneration in pellet production process, etc. Beside this study, there are no other records about LCA studies in the energy sector in Serbia.

7. Conclusions

It is evident that biomass, especially lignocellulosic biomass, has a high priority in energy sector worldwide, especially in Europe. The greatest attention has been paid to the effects on global warming from biomass use, while some other impact categories, i.e. other effects on the environment, such as land use, particulate matter formation, etc., are practically neglected and/or need to be improved and considered with more attention in future researches. When studying environmental impacts of products and services it is vital to study them in a life cycle perspective, and to avoid problem shifting from one part of the life-cycle to another, from one geographical area to another. So far, Life Cycle Assessment tool has proven to be a very useful and practical tool for these purposes. Unfortunately, not much attention has been paid to the application of LCA for the assessment of environmental sustainability of different energy resources in Serbia. Scientists, public and business sector in Serbia should broaden their knowledge about the possibilities, benefits and importance of practicing this technique in Serbian case studies. By using the LCA tool, it could be possible to measure, not only environmental impacts from the use phase of biomass products, but also all other environmental impacts that occur through the whole biomass product life cycle (from planting, maintenance, harvesting, logging, hauling, processing, transporting, disposal, recycling, etc.). Also, by using this tool, identification of the most promising solutions for heating and electricity production from biomass (and other RES) in Serbian energy sector will be possible. In this way, more specific data about environmental benefits from using RES could be defined and thus available to decision-makers and other relevant bodies responsible for the selection of most promising and most beneficial projects, technologies, or products (Sørensen 2011). Together with the most cost-effective solutions, the application of LCA technique in energy sector of Serbia could lead to the increased use of domestic renewable energy sources which, beside less negative environmental impact, could provide greater dependence on domestic energy resources and less reliance on energy imports. In other words, the application of LCA could also contribute to the achievement of bigger energy supply security of the Republic of Serbia.

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Appendix

Table 7 Abbreviations

AP	Acidification potential
CO_2	Carbon dioxide
CO_2e	Equivalent emission of carbon dioxide
CHP	Combined heat and power
CFC-11	Trichlorofluoromethane
EIA	Environmental Impact Assessment
EIOLCA	Economic input–output LCA
EP	Eutrophication potential
ERA	Environmental Risk Assessment
EU	European Union
GHG	Green-House Gasses
GWP	Global warming potential
ISO	The International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MJ	Megajoule (unit of energy)
Mtoe	Miliontones of oil equivalent (unit of energy)
NOx	Nitrogen oxides
PM10	Particulate matter, particles ≤ 10 micrometers
REPA	Resource and Environmental Profile Analysis
RES	Renewable energy sources
SEA	Strategic Environmental Assessment
SETAC	The Society of Environmental Toxicology and Chemistry's
SOx	Sulfur oxides
POCP	Photo-oxidant creation potential

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