Eco-balancing of Forestry and Field Plant Production Technologies in Environmental Life-Cycle Thinking

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Abstract

One of the aim of the agricultural ecosystem's researches is to detect the relationships between the current land uses, cultivation technologies and the changed environmental features caused by climate change.

During the project "Agricultural Climate 2." (VKSZ_12-1-2013-0034) we educe a suitable method in the technological aspect to the environmental assessment of land use changes caused by climate changes.

We make an eco-balance (environmental inventory of input-output material and energy data) to the environmental effects classification in life-cycle approach in connection with the typical agricultural / forestry technologies. The results of the balance evaluated with the use of environmental impact categories are connected to different environmental problems. The use of balances and environmental classification are possible to compare land-use technologies and their environmental effects per common functional unit.

The environmental assessment of technological aspects of land use represent an important addition to the climate researches.

Keywords: *life-cycle assessment / life-cycle impact assessment / carbon footprint / life-cycle thinking*

Background and aim

It is a fact, that only 11-13% of the surface of the Earth is cultivated, and on the major part of these areas the cultivation is not intensive. Hungary is in the special situation, namely the 50% of its territorí is cultivated intensively, and 20% of Hungary is covered by forest treated by a nearly intensive way (Neményi - Milics 2010).

About three quarters of Hungary's surface is occupied by primarily climate-related, which is non-irrigated, area: arable land, meadow, forest.

Rumpf (2011) cites according to Mátyás (2006), recognizing the importance of the atmospheric carbon sequestration puts forestry in a favorable position. Forest management is the only economic activity, which, in addition to being carbon neutral, allows the sustained removal of a significant amount of carbon from the atmosphere.

According to generally accepted projections, forest zones of Europe will shift polewards during this century. The expected changes of climate will cause an expansion in the North but a retreat in the South. Mainly due to its effects on biodiversity and landscapes, the shift is receiving wide public attention (Mátyás 2010).

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In land uses, in addition to the growing conditions changed by the cultivation techniques and the effects of land cover, the specific environmental aspects of each technology must be taken into account. The main objective of the work of our research group was the development of an environmental analysis method for changes in land-use caused by the projected climate change, in technological aspect.

Material and methods

In Hungary, our studies in forestry were focused on the sample area of Zala County, while in the case of arable crop cultivation technologies we used the data available in Győr-Moson-Sopron County.

In the areas we identified the processes of primary wood production, harvesting, tree utilization and wood processing. Experts established (Rumpf - Szakálosné Mátyás - Horváth 2014) that forest and tree utilization activity have the most significant environmental impact so we focused on the final harvest. In characterized forest stands of the studied area (beech, oak, spruce), we have identified the shortwood system with upper landing.

In the case of arable crop production, according to expert proposal (Gergely 2014), we examined the production technological process steps in the cultivation of maize (previous cropping: winter wheat), winter wheat 1. (previous cropping: colza) and winter wheat 2. (previous cropping: maize).

As the next step, we performed the life cycle assessment (LCA) of the selected technologies, in order to rank their impacts on the basis of carbon footprint (carbon footprint – CF, IPCC study, 2007).

The methodology applied for preparation of LCA corresponds to requirement of ISO 14040: 2006 and ISO 14044: 2006 standard.

Results

The steps of the LCA were the following:

1. Goal and scope definition:

We performed the comparative environmental analysis of technologies by the LCA method, which allows for ranking them. On the basis of this, environmental risk of them was identified, in the context of the climate scenario used. The system boundaries of the forestry and the arable crop production technologies have been determined by their process steps.

As a functional unit, we considered 1 ha cultivation area. As reference flow, we took into account the following: beech: 110 m^3, oak: 450 m^3 and spruce: 450 m3 harvesting; maize: 8 t/ha, winter wheat 1-2: 5,6 t/ha.

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Table 1. Total input and output environmental inventory data in the examined forestry technologies per 1 ha (Hungary, Zala County, Zalaerdő Ltd.) (Polgár – Baráth 2014)

Flow	**Unit**	**Forest Stand**		
		Beech	**Oak**	**Spruce**
Reference period	year	2013-2014, winter	2013-2014, winter	2013-2014, winter
Reference flow: standing wood before cutting	m^3	110	450	450
Input				
Fuel mixture	kg	38,05	155,66	0
Disel	kg	333,47	1420,89	1951,15
Lubricating oil	kg	39,42	170,71	147,05
Output				
Carbon-dioxide (fossil)	kg	1175,24	4986,38	6155,4
Carbon-dioxide (biotic)	kg	63190	268510	76170
Waste sump oil (recycled)	kg	23,74	106,56	106,95

The environmental parameters of machines and tools necessary in the technologies have not been included in the analysis.

2. Life cycle inventory analysis:

We established environmental inventory database (input- output, elementary flow) of examined technologies by using expert data and calculations (Gergely 2014) (Rumpf - Szakálosné Mátyás - Horváth 2014). According to Gockler (2014) we used average data, which can be determined error-laden many times, but their use is essential for the analysis.

The reference period for the data of forestry technologies was 2013/2014 winter. In terms of the geographical validity of the data, they originate in the territory of operation of Zalaerdő Ltd. The data source were our own data, expert estimation, published data.

The reference period for the data of arable crop production was 2012/2013. In terms of the geographical validity of the data, they come from the territory of educational farm of Institute of Plant Cultivation, Faculty of Agricultural and Food Sciences, University of West Hungary.

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Table 2. Total input and output environmental inventory data in the examined arable crop production technologies per 1 ha (Hungary, GYMS County) (Polgár – Wachter 2014)

Flow	**Unit**	**Cultivated plant**		
		Maize	**Winter wheat 1.**	**Winter wheat 2.**
Reference period	year	2012-2013	2012-2013	2012-2013
Reference flow (grain)	t	8	5,6	5,6
Input				
Disel	kg	134	128	128
Lubricating oil	kg	4,42	4,83	4,7
Compound fertilizer (MAP, mono-ammonium-phosphate)	kg	200	0	0
Urea fertilizer	kg	200	0	0
Complex fertilizer (NPK)	kg	0	300	300
Lime-ammon-saltpetre fertilzer	kg	0	450	450
Herbicide	l	200	200	200
Output				
Carbon-dioxide (fossil)	kg	423	404	402
Waste sump oil (recycled)	kg	4,42	4,83	4,7

Then we prepared the life cycle model of the examined technologies.

3. Life cycle impact assessment:

The steps of the evaluation methodology are described in the ISO 14044:2006 standard.

In case of the standard impact assessment, we assigned the results of the inventory to impact categories according to the aim and frames of the LCA study.

According to Simon (2012) we established that the characterization factor of CML 2001 method, belonging to the main emissions defining the value of GWP 100 years, fits well to the IPCC study 2007. The compliance is similar also in terms of the Eco-indicator 99 method. The methods are able to calculate carbon footprint (CF).

There is a wide range of effect evaluation methods. For the above reasons, the analysis was performed with:

- the CML2001 (Nov. 2010) impact-driven (midpoint) method and
- the Eco- indicator 99 (EI 99) injury-oriented (endpoint) method.

4. Interpretation

In the last phase of the LCA, the results of life cycle inventory and impact assessment was verified. We have done the comparative analysis and have drafted conclusions.

Among the results of LCA, the CML2001 (Nov. 2010) - Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.] – and EI 99 – Human health, Climate Change [DALY] – values of examined technologies were used in the followings. On the basis of the values we set up a technological ranking. So we have received some sort of environmental comparative impact classification of the technologies. The result of the effect of the GWP 100 years category indicator expressed in [kg CO_2-Eqiv.] value can be considered to be the carbon footprint of the technology which is in accordance with IPCC study 2007.

In the final step the impact of the technologies were qualified with a ranking of climate scenario (Gálos et al. 2014).

Forestry technologies

In CML2001 (Nov. 2010) environmental life cycle impact assessment of systems, the following results were based considered according toon during Polgár - Baráth (2014).

Table 3. Environmental impacts of examined forestry technologies based on CML2001 (Nov. 2010) evaluation method (extract) (Polgár – Baráth 2014)

Environmental quantities - CML2001 - Nov. 2010	**Unit**	**Stand**		
		Beech	**Oak**	**Spruce**
Abiotic Depletion (ADP fossil)	[MJ]	4740,982911	85385,9283	91980,74558
Global Warming Potential (GWP 100 years)	[kg CO_2-Equiv.]	13311,01956	198406,3937	82848,80109
Global Warming Potential, excl biogenic carbon (GWP 100 years)	[kg CO_2-Equiv.]	365,3942257	6558,138975	7089,884801
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	[kg DCB-Equiv.]	3181,803748	60440,93431	66103,06407

The work systems had the greatest impact on global warming (GWP 100 years) throughout their life cycle. This is explained by the amount of carbon dioxides releasing to the atmosphere resulting from the fuel usage of the technologies. In this impact category, life cycle share of the technologies was in the case of beech around 5%, in the case of spruce around 28%, in the case of oak around 67%. Significant impact category emerged as the abiotic depletion (ADP foss) and the marine aquatic ecotoxicity (MAETP). These impact categories could be explained by the share of input of fuel and lube.

The work systems raking gives the he increasing order of beech-spruce-oak in every case.

Arable crop production technologies

In CML2001 (Nov. 2010) environmental life cycle impact assessment of systems, the following results were based.

Table 4. Environmental impacts of examined systems based on CML2001 (Nov. 2010) evaluation method (extract) (Polgár – Wachter 2014)

Environmental impact categories - CML2001 - Nov. 2010	**Unit**	**Cultivated plant**		
		Maize	**Winter wheat 1.**	**Winter wheat 2.**
Abiotic Depletion (ADP fossil)	[MJ]	6546,086641	6280,774697	6251,105662
Global Warming Potential (GWP 100 years)	[kg CO_2-Equiv.]	461,1663339	440,8882628	439,1164061
Global Warming Potential, excl biogenic carbon (GWP 100 years)	[kg CO_2-Equiv.]	491,5926241	469,9362901	468,0552221
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	[kg DCB-Equiv.]	4763,867695	4578,725278	4555,56446

In the case of arable crop production technologies, the greatest impact occurred in the category of Abiotic Depletion (ADP fossil) and next in Marine Aquatic Ecotoxicity Pot. (MAETP inf.). Technologies had impact on global warming (GWP 100 years) after the previous ones. The life cycle share of the technologies can be considered to be almost equal.

That is about 34% in case of maize, 33% in case of winter wheat 1 and hardly 33% in case of winter wheat 2.

Even if with a small difference, the ranking of technologies gave the increasing order of *’winter wheat 2 – winter wheat 1 – maize’* in each case.

Total environmental impact

In the case if we want to show all of the environmental impacts in one figure, we have to use the means of normalization and weighting. This method is able to show the results of all impact categories in the same time.

Looking at the next figure, it can be stated that also in the case of the total environmental impact (normalized for Central Europe) of the technologies applied for the examined forestry work systems in forest stands and arable crops the increasing order of:

- ’ beech-spruce-oak’
- ’winter wheat 2 – winter wheat 1 – maize’

can be set up.

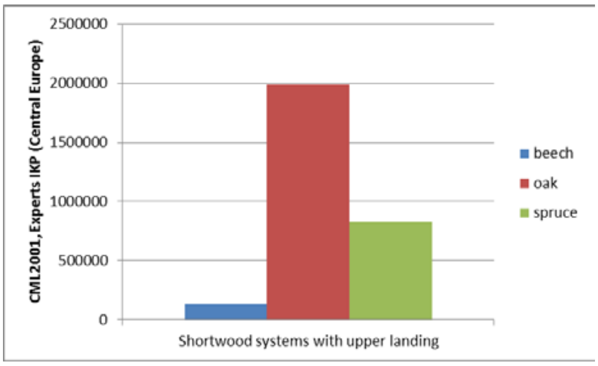

Figure 1. Environmental impacts of work system’s life cycle (normalized, weighted values) (Polgár – Baráth 2014)

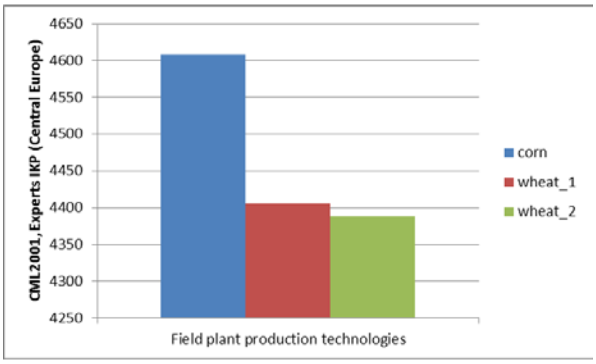

Figure 2. Environmental impacts of total life cycle of arable crop production technologies (normalized for Central Europe, weighted values) (Polgár – Wachter 2014)

We also valued the inventory data according to Eco-indicator 99 method in egalitarian, hierarchic and individualist approach.

Highlighting the EI 99, Human health, Climate Change [DALY] values, in the case of total environmental impacts of work systems, we got the increasing order of

- ’ beech-spruce-oak’
- ’winter wheat 2 – winter wheat 1 – maize’

in all three approaches.

By the applied methods of environmental impact assessment, we got the same affirmed result.

Summary

In our work we developed an environmental analysis model for changes in land-use caused by the projected climate changes, in technological aspect. In our opinion, the examination of technological aspect of land use represents an important addition to the existing climate research. Using life cycle analysis we performed the carbonfoot based ranking of environmental impacts of work systems. The classification could be a guideline for farmers and decision-makers in choice of technology.

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