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Production of Solid Sustainable Energy Carriers from Biomass by Means of Torrefaction

Deliverable No. D9.8

Executive summary of WP 9 results

Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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O	Other	

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Authors:	Stefan Majer, Eva Nebel, Marek Gawor (DBFZ) Fabian Schipfer, Lukas Kranzl (TU Wien) Markus Meyer, Jörg Priess, Tanzila Chand (UFZ)
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1 Main findings from Sector WP 9

This Deliverable summarises the main findings and results from the environmental assessment (WP 9) in Sector. For this assessment, a huge number of (torrefied)-biomass-to-end-use-chains considering various feedstocks, locations and technological configurations as well as end uses have been assessed with regards to their economic and environmental implications. The results of this assessment have been discussed and compared to both fossil energy carriers and white pellets as references.

- The techno-economic assessment in WP 9 showed that optimisation of pelletisation through torrefaction can lead – depending on the proper adjustment of the key process parameters – to considerable cost savings in comparison to white pellets in scenarios where higher amounts of solid bioenergy carriers are deployed. Production cost differences for torrefaction are mainly outweighed in these scenarios by better unit scaling effects and thus higher optimal plant sizes as well as through the positive effect of higher heating values of the final product for longer transport distances and import from third countries. Torrefaction can lead to considerable cost savings especially for large scale torrefaction plants due to higher scaling effects for a more expensive technology but especially for lower quality woody feedstock.

- Economic profitability of torrefaction is highly sensitive on the different key parameters of the entire biomass-to-end-use chain. This can be explained by the example that the average supply distance depends on a combination of feedstock yield, availabilities and accessibilities and (also) size dependent E&M balance of the plant which should be optimised. Furthermore not only competitiveness to white pellets but also general economic viability has to be ensured. Therefore, if the final product price is still in an affordable range for the end user, increased transport distances can be favourable for torrefaction.

- According to our analyses the argument regarding a diversification of the biomass for energy portfolio through torrefaction can be supported only to a certain extent at this stage of the research. Production costs of torrefied pellets depend on the density of the used feedstock. Here the utilisation for higher cost woody biomass can be beneficial if costs stay in an affordable range. For recycled wood cost savings can be expected but for herbaceous biomass no clear advantage for torrefaction can be outlined yet. Cost reduction for herbaceous biomass can be reached through pre-pelletisation.

- The assessment of GHG-emissions has shown advantages for torrefied pellet supply chains compared to conventional pellet production in those cases where the heat supply of the torrefaction and densification process was supplied from biomass. As expected the results also showed that, due to the higher energy density, the transportation of the torrefied pellets leads to lower GHG-emissions compared to the transportation of conventional pellets. Another important factor was the use of electricity for the process of torrefaction/densification. Depending on the location specific mixture of energy carriers for electricity supply, the emission factor for electricity differs between the four considered locations. Together with the different distribution scenarios this explains the main differences between the results of the various locations.

- CO_2 emissions of torrefied pellets are in most of the investigated pathways lower than for white pellets. It has to be considered that advantages for torrefied to white pellet mitigation costs for co-firing cannot be determined in all cases in the investigated scenarios. Increasing coal and energy prices (also for production and transportation of pellets) but also increasing average mitigation costs between the two commodities in most cases result in lower mitigation costs for torrefied pellets.

- For the sustainability of (torrefied) pellet production, supply and use, the aspect of biomass production is one of the most crucial aspects. Key objectives of sustainable biomass production include low to no direct and indirect land-use change (dLUC and iLUC), diminishing greenhouse gas emissions and/or increasing carbon stocks and minimal competition with food production (since the agricultural and forest residues were assumed to be used). Currently, mostly residues from forestry or forest industry (e.g. saw mill residues) are used as feedstocks for pellet production. Also in Sector special focus was on the use of residues and waste materials for the production of torrefied energy carriers. The iLUC risk associated with these feedstock is considerably lower compared to the use of energy crops or stemwood.
  Sustainability criteria and certification might be one approach to ensure the preconditions for a sustainable feedstock production. Within our assessment we found that the current certification schemes often have limitations in their representation of the environmental systems affected by feedstock production. Existing bioenergy certification schemes hardly go beyond demonstrating compliance with underlying legislation, such as the EU Renewable Energy Directive (EU RED), which does not always enable them to provide a comprehensive environmental sustainability assessment. To enhance existing certification schemes, we propose combining the strengths of several certification schemes with research-based indicators in order to increase the reliability of environmental assessments.

- An assessment of ecosystem service supply (i.e. the various benefits which these systems provide) in the three SECTOR case studies, (i.e. Rufiji basin in Tanzania, Satilla watershed in the Southeast U.S.A., Mulde watershed in Central Germany) has been conducted. Expectedly, carbon storage is higher on forest plantations than on croplands in the Satilla watershed and the Rufiji basin. For sediment and phosphorous retention and biodiversity, the trade-offs are less clear, most likely, due to varying management intensities. Therefore, a final conclusion on sustainability in the context of ecosystem services is difficult to make and further investigations would be necessary.

2 Introduction to the structure and goal of WP9

Both socio-economic and environmental aspects are important factors for the assessment of torrefaction technologies and processes in the SECTOR project. The objective of SECTOR WP9 is the assessment of different torrefaction-based biomass-to-end-use chains according to their social, economic and environmental impacts. The assessment work in WP9 has been based on different torrefaction-based biomass-to-end-use chains defined in Task 9.1. The approach for the definition of these pathways and the collection of the corresponding data for the different process steps was described in the Deliverable 9.1 of WP9. Main purpose of the assessment was:

i) the discussion of economic and environmental optimisation potentials for the analysed pathways and processes, as well as

ii) the discussion of possible advantages of torrefaction-based biomass-to-end-use-chains compared to the conventional use of biomass and fossil reference pathways for the production of energy and finally

iii) the derivation of recommendations for a sustainable production and use of feedstock for torrefaction.

The work in WP9 has been structured into two main parts. Socio-economic parameters have been analysed in Task 9.2. The environmental assessment has been conducted in Tasks 9.3 and 9.4.

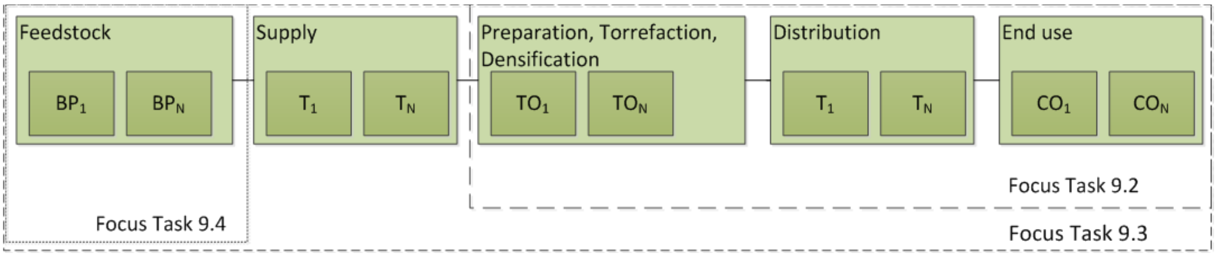

Figure 1: Focus of the different tasks in WP9

3 Summary of results from the techno-economic assessment (Tasks 9.1 & 9.2)

The techno-economic evaluation of a realistic market diffusion of torrefaction for the pellet market in the upcoming decades is linked to considerable uncertainties and corresponding methodological challenges. This is due to the fact that the simulation of the market penetration and price formation of biomass for bioenergy in general asks for a sound understanding and computation of interdependencies with **1)** competitive energy commodities on the demand side and **2)** the different utilisation paths for land and biomass on the supply side. Pelletisation as a preparation step for biomass to obtain uniform, better tradable and standardised products is a rather new way of commoditisation compared to other energy and bioenergy products taking off mainly in Sweden and Germany only six years ago[1]. The early stage of the development of this bioenergy carrier makes it difficult to simulate prices and quantities. This applies especially for differences induced through further optimisation by torrefaction where differences between white and torrefied commodities should be outlined.

However it is useful to estimate cost differences between traditional pellets and torrefied pellets for varying key parameters including feedstocks already used for white pellet production as well as key parameters (feedstock, countries, production plant sizes, distribution distances and modes) that could potentially have a realistic connotation in the future for white and torrefied pelletisation. This was done successfully using the model **BioChainS** and technical and economic information produced within the SECTOR-project. It is important to stress that some not (yet) quantifiable parameters are left aside in the simulation even though they could play a crucial role for the deployment of torrefied pellets. Selected examples are grindability and capacity effect costs for co-firing (see D 9.5) and advantageous and disadvantageous performance differences for torrefied pellets for handling (see D 9.5).

However first conclusions and recommendations for policy makers and stakeholders can be drawn mainly based on the impact of the differences in production costs and heating content of the final products white and torrefied pellets.

For **EU policy makers** following main findings have to be stressed:

Optimisation of pelletisation through torrefaction can lead to considerable cost savings in scenarios where higher amounts of solid bioenergy carriers are deployed. Production cost differences for torrefaction are mainly outweighed in these scenarios by better unit scaling effects and thus higher optimal plant sizes as well as through the positive effect of higher heating values of the final product for longer transport distances and import from third countries. This is illustrated in the following figure.

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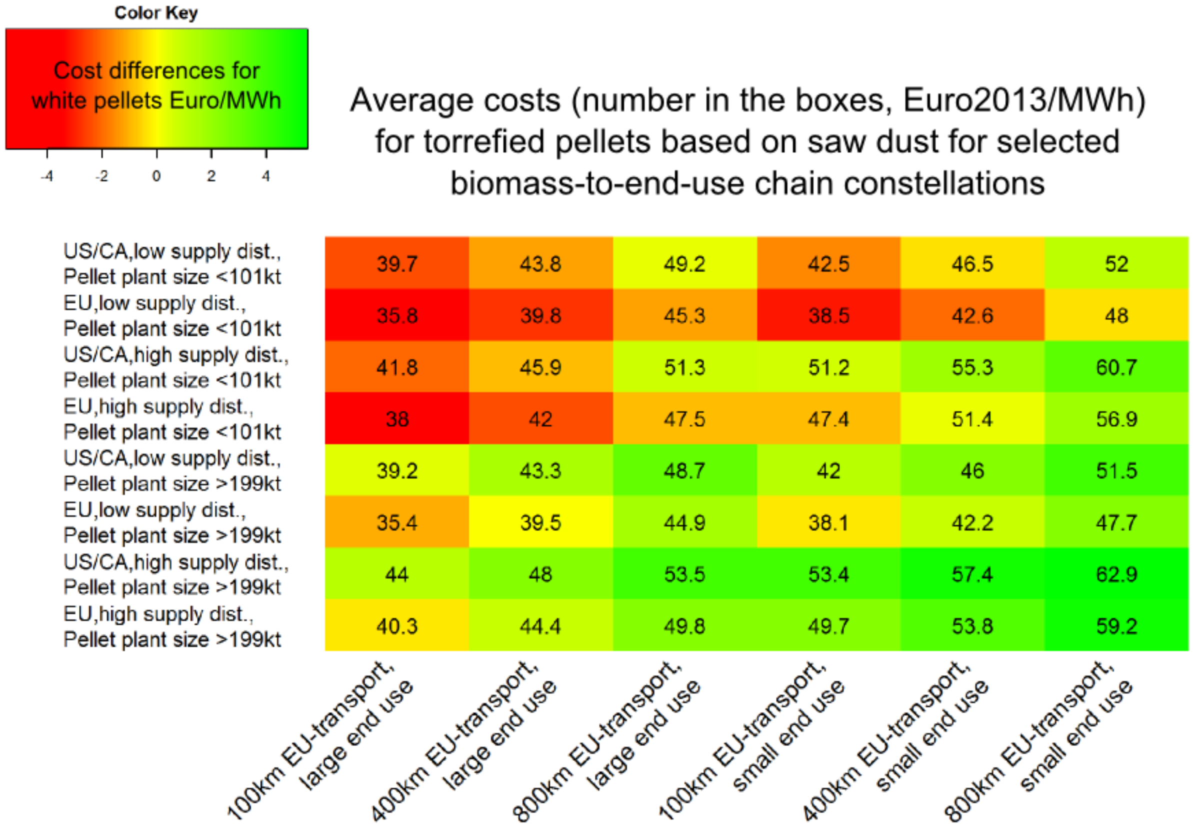
[1] compare Forestry statistics: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Forestry_statistics_overview# (accessed 11.17.14).



	100km EU-transport, large end use	400km EU-transport, large end use	800km EU-transport, large end use	100km EU-transport, small end use	400km EU-transport, small end use	800km EU-transport, small end use
US/CA,low supply dist., Pellet plant size <101kt	39.7	43.8	49.2	42.5	46.5	52
EU,low supply dist., Pellet plant size <101kt	35.8	39.8	45.3	38.5	42.6	48
US/CA,high supply dist., Pellet plant size <101kt	41.8	45.9	51.3	51.2	55.3	60.7
EU,high supply dist., Pellet plant size <101kt	38	42	47.5	47.4	51.4	56.9
US/CA,low supply dist., Pellet plant size >199kt	39.2	43.3	48.7	42	46	51.5
EU,low supply dist., Pellet plant size >199kt	35.4	39.5	44.9	38.1	42.2	47.7
US/CA,high supply dist., Pellet plant size >199kt	44	48	53.5	53.4	57.4	62.9
EU,high supply dist., Pellet plant size >199kt	40.3	44.4	49.8	49.7	53.8	59.2

Figure 2: Average simulated costs for torrefied pellets based on saw dust for selected biomass-to-end-use chain constellations (see x- and y-axis). The difference for same constellations but without torrefaction step (white pellets) are indicated with colours from dark red (cheaper white pellets) to dark green (torrefied pellets are cheaper).

In order to highlight biomass-to-end-use chains for which advantages for torrefaction can be expected, the cost differences of the biomass-to-end-use chain pairs have been compared for a huge number of chains: In Figure 3 the deployment costs for identical biomass-to-end-use chains which only differentiate in the preparation type are averaged and plotted against the deviations from these averages. The negative deviation indicate cheaper white pellet deployment costs while for torrefied pellets the same deviation has to be added to the plotted average. Interestingly it is possible to observe a linear correlation for increasing average total deployment costs already presumed in the previous paragraph, which drives the deviations towards and beyond the breakeven line (in black). Above this breakeven line the torrefied counterparts become cost competitive with white pellets. The dots in the figure are coloured with regards to the yearly biomass preparation plant output size reaching from 40kt/a to 1Mt/a for white or torrefied pellets, respectively. The explanation for the vertical shift towards economic advantages for torrefied chains with increasing pellet plant sizes can be found in the same scaling factors used for scaling capital costs for white and torrefied pellet plants which results in stronger effects on the production costs for more expensive technologies than for cheaper ones. Therefore production cost differences decrease for biomass-to-end-use chain pairs with increasing production plant sizes indicated by the vertical colour shift.

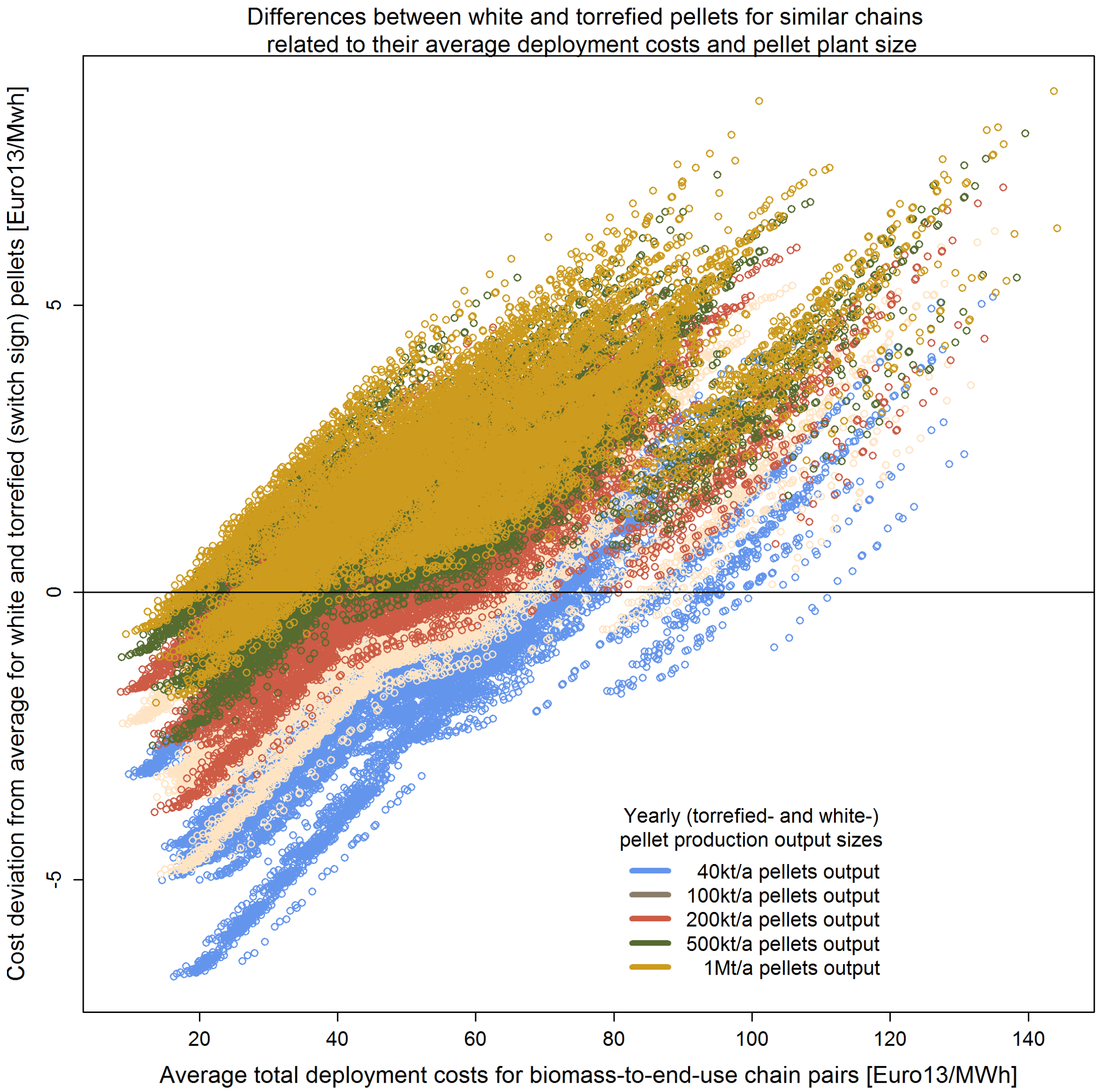


Figure 3: On the X-axis simulated deployment costs are indicated averaged for every biomass-to-end-use chain pairs individually. The Y-axis shows the deviation to be added to obtain the respective white pellet deployment costs or subtracted to obtain the respective torrefied pellet cost (therefore cost deviation times two equal cost differences between white and torrefied pellets). Furthermore the yearly pellet plant output sizes which are similar for the calculated biomass-to-end-use chain pairs are indicated using different dot colours.

According to our analyses the argument regarding a diversification of the biomass for energy portfolio through torrefaction can be supported only to a certain extent at this stage of the research. Production costs of torrefied pellets depend on the density of the used feedstock. Here the utilisation for higher cost woody biomass can be beneficial if costs stay in an affordable range. For recycled wood cost savings can be expected but for herbaceous biomass no clear advantage for torrefaction can be outlined yet. Improvement for herbaceous biomass can be reached through pre-pelletisation.

CO_2 emissions of torrefied pellets are in general lower than for white pellets. Still advantages for torrefied to white pellet mitigation costs for co-firing cannot be found for all cases. Increasing coal and energy prices (also for production and transportation of pellets) but also increasing average mitigation costs between the two commodities in most cases result in lower mitigation costs for torrefied pellets (compare D 9.5 Chapter 3.2). Figure 4 shows average GHG-mitigation costs for various feedstock and pellet types analysed in Sector WP9.

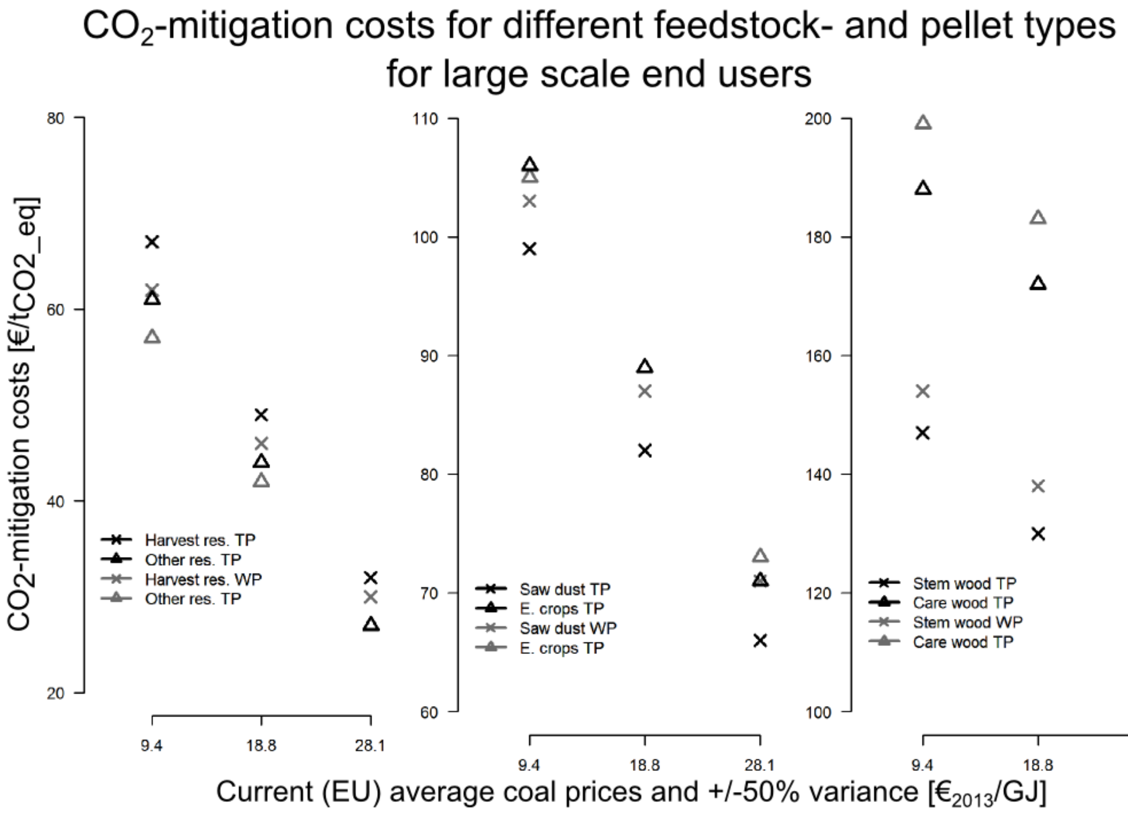


Figure 4: Average CO_2-mitigation costs for the different feedstock and pellet types (for large scale end users) and a 50% variance to the averaged European coal price in 2013 (IEA, 2014).

The employment effects for white and torrefied pelletisation is very similar if measured as pellet mass specific labour requirement. Thus, energy content specific staff hours used for their production is between 30% and 40% lower for torrefied pellets. No conclusions can be derived at this stage of the research on how much this effect would be offset by higher pellet production through the deployment of torrefaction and about the effects on the employment of competitive energy and bioenergy deployment.

For the interested **industry** it should be highlighted that **1)** economic profitability of torrefaction is highly sensitive on the different key parameters of the entire biomass-to-end-use chain. This can be explained by the example that the average supply distance depends on a combination of feedstock yield, availabilities and accessibilities and (also) size dependent E&M balance of the plant which should be optimised individually.

2) Furthermore not only competitiveness to white pellets but also general economic viability has to be ensured. Therefore the example of increased transport distances can be favourable for torrefaction if, and only if the product stays in an affordable range for the end user. **3)** In general the production cost difference and the relation between the lower heating values is sufficient to roughly estimate the breakeven costs between torrefied and white pellets. **4)** Torrefaction can lead to considerable cost savings especially for large scale torrefaction plants due to higher scaling effects for the more expensive technology and for high quality but especially also for lower quality woody feedstock.

A **final remark** outlines considerations about general risks and advantages of additional bioenergy preparation and commodity optimisation steps using an example for torrefaction: The torrefaction technology is applicable where a high demand makes larger scale pellet plants for more expensive feedstock economic viable. Thus torrefied pellets are considered to mainly cover the upper part of the pellets merit order in this example. On the one hand this placement induces risks for the torrefied pellet suppliers for varying cost-demand curves. On the other hand the diversification of the solid bioenergy portfolio would lead to a flattening of the pellet merit-order in general and thus to more stable pellet costs for the end users, especially for small scale consumption since torrefaction is more applicable for higher biomass-to-end-use chain costs. If this effect is desired risks should not only be kept in mind but also addressed and mitigation strategies investigated on policy and on investor sides.

4 Summary from the environmental impact assessment – Part 1: GHG-emissions

The purpose of SECTOR Task 9.3 was to investigate the potential environmental impacts (focussing on GHG-emissions) from various pathways for the production and application of torrefied and non-torrefied biomass. This assessment has being based on the life cycle assessment (LCA) methodology and is conducted according to the ISO 14040 & 14044 standards.

The basics of the LCA methodology and the general approach have been described in detail in SECTOR deliverables D 9.2 and D 9.4. The main assumptions regarding the energy and mass balances for the investigated (torrefied)-biomass-to-end-use-chains have been taken from SECTOR WP 2, WP 3 and WP 4 Deliverables. Based on this information a number of value chains considering different biomass feedstock as well as locations for the torrefaction and densification process (USA, Tanzania, Canada and Spain) and the end use (always transport to Europe – the Netherlands) have been defined and analysed. As expected the results showed that, due to the higher energy density, the transportation of the torrefied pellets leads to lower GHG-emissions compared to the transportation of conventional pellets.

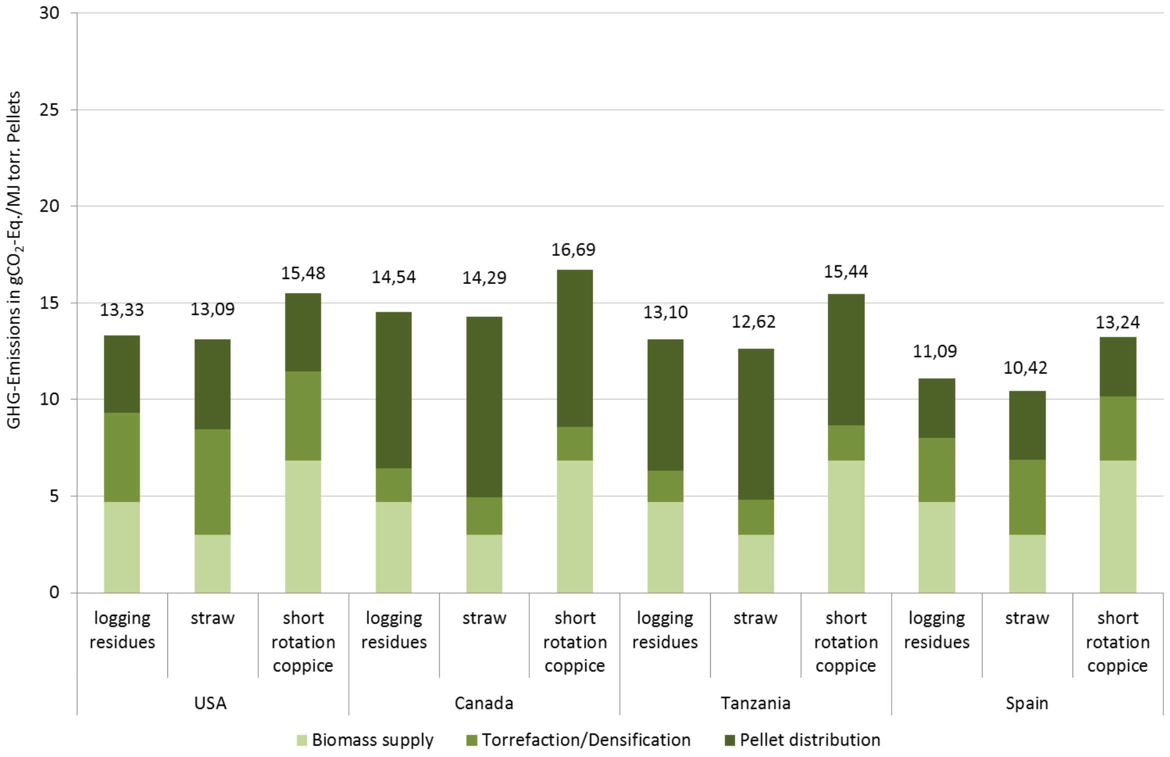


Figure 5: GHG-emissions from the supply of torrefied pellets from different feedstock types and locations (per 1 MJ of pellets supplied).

Another major impact factor that has been identified during the assessment is the type of energy carrier used during the processes of torrefaction/densification. In case biomass (or another renewable energy carrier) is used to provide process energy (e.g. for drying purposes) the GHG-emissions for the supply of the torrefied pellets are significantly lower compared to conventional pellet production (e.g. compared to the datasets included in the BioGrace calculator). Another important factor was the use of electricity for the process of torrefaction/densification. Depending on the location specific mixture of energy carriers for electricity supply, the emission factor for electricity differs between the four considered locations. Together with the different distribution scenarios this explains the main differences between the results of the various locations. In general, the production and use of pellets from residues resulted in lower emissions compared to the use of plantation wood. In addition to the potential GHG-emissions from the supply of (torrefied) pellets from different origins, the GHG-emissions and potential GHG-mitigations from the use of the provided pellets for co-firing in a hard coal power plant as well as for the production of heat in a small scale boiler and the production of biomethanol have been investigated.

The results for the investigated end-use-scenarios to produce electricity, heat and MeOH indicate a significant GHG-reduction potential for all considered supply chains of torrefied and conventional pellets (compared to the fossil reference pathways).

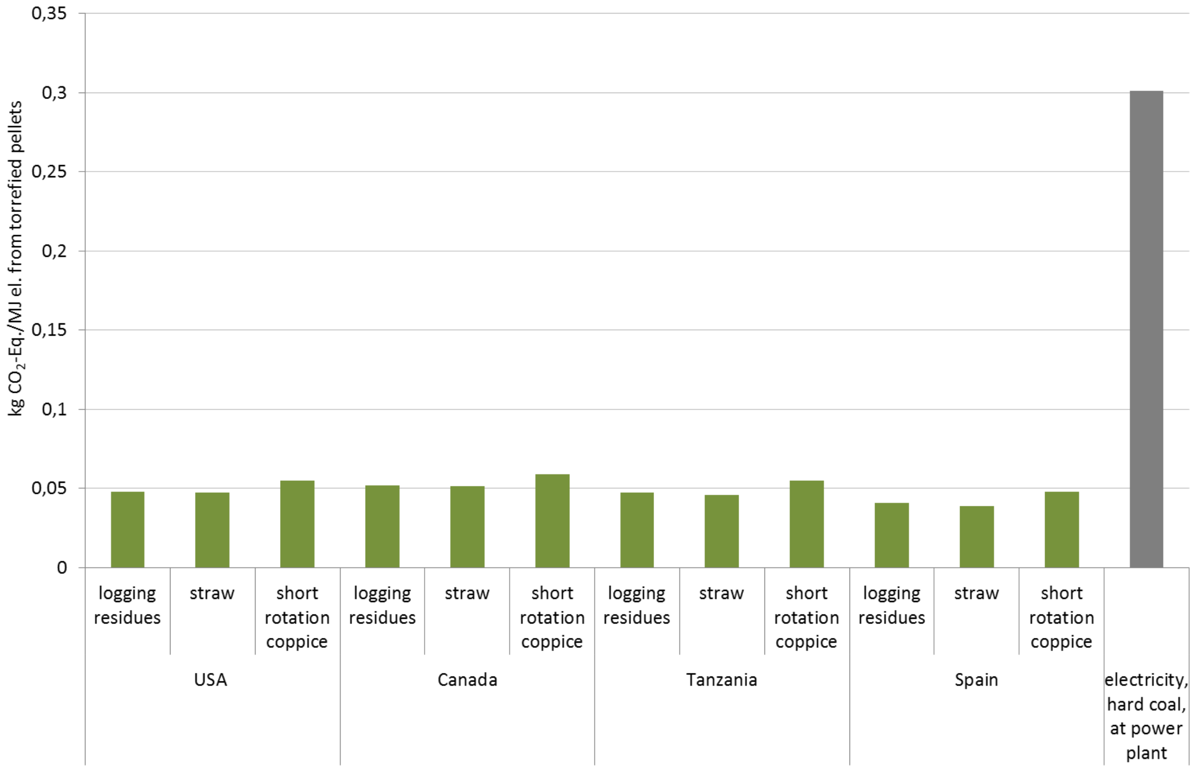


Figure 6: GHG-Emissions from the use of torrefied pellets in power plants compared to the production of electricity from hard coal

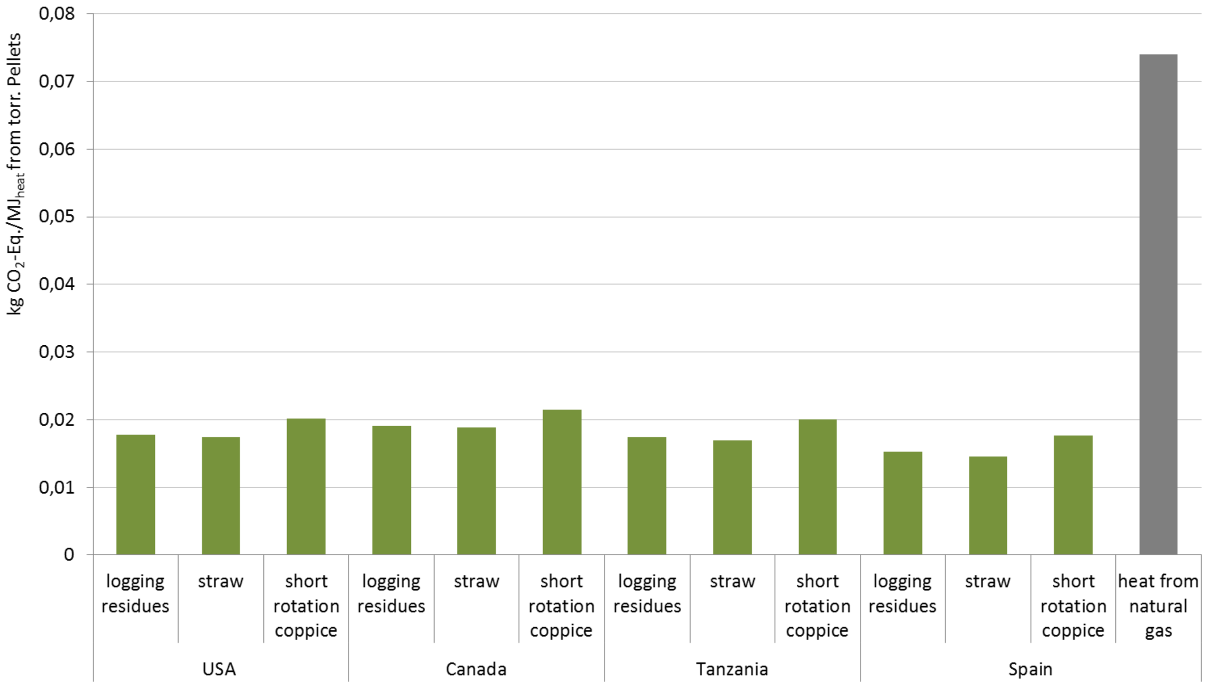


Figure 7: Emissions from the heat production from torrefied pellets in a 15 kW small scale boiler compared to heat production from natural gas

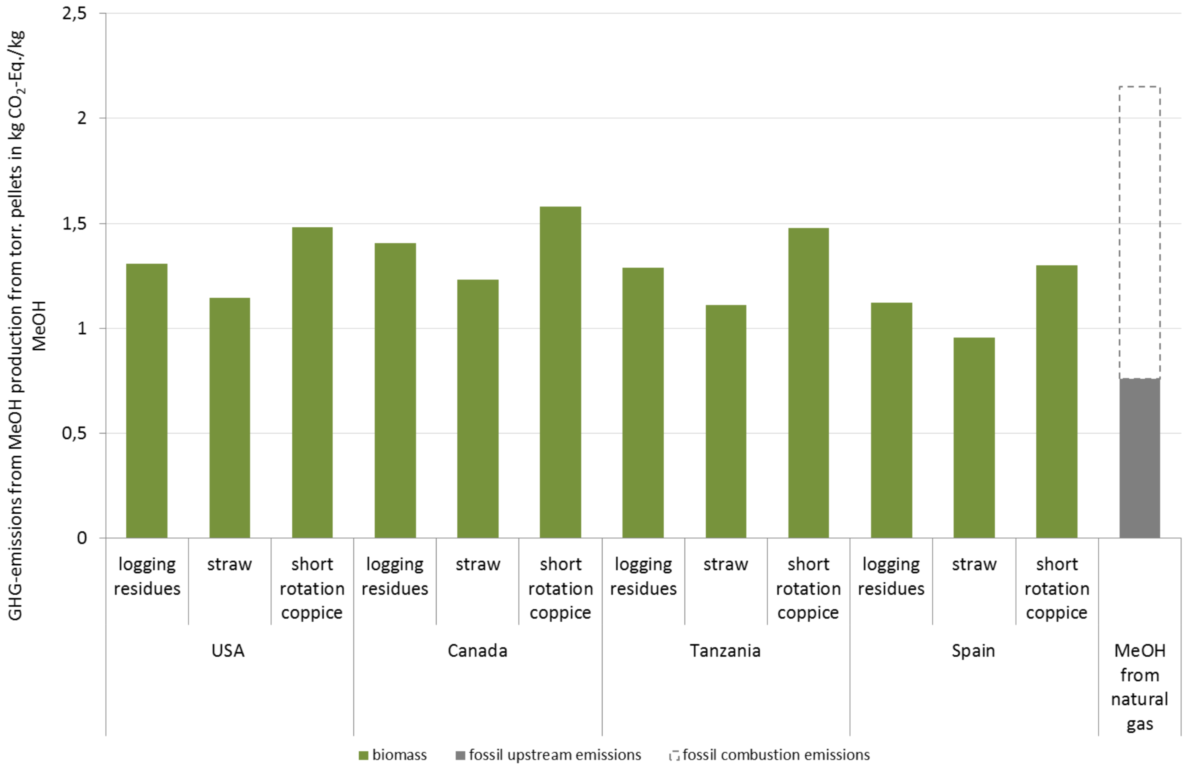


Figure 8: GHG-emissions from the production of methanol from torrefied pellets compared to MeOH production from natural gas per 1 kg of methanol (the upper/dashed part of the bar for MeOH from natural gas indicate the use and end of life[2] GHG emissions from the fossil MeOH)

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[2] In this specific case, end of life means a disposal scenario after the use phase

5 Summary from the environmental impact assessment – Part 2: local/regional environmental impacts[3]

Bioenergy is receiving increasing attention because it may reduce GHG emissions, secure and diversify energy supplies and stimulate rural development. The environmental sustainability of bioenergy production systems is often determined through non-spatial life-cycle assessments that focus on global environmental effects, such as the emission of greenhouse gases or air pollutants. Local/regional environmental impacts, e.g., the impacts on soils or on biodiversity, require site-specific and flexible options for the assessment of environmental sustainability, such as the criteria and indicators (C&Is) used in bioenergy certification schemes.

Key objectives of sustainable biomass production include low to no direct and indirect land-use change (dLUC and iLUC), diminishing greenhouse gas emissions and/or increasing carbon stocks and minimal competition with food production[4]. To accomplish these goals, a set of sustainability C&Is are required to ensure that bioenergy is actually helping to reduce climate change[5]. A critical review of the approaches adopted by certification schemes and policymakers can help to achieve these objectives. For example as reviewed by Scarlat and Dallemand[6], 2011, the Renewable Energy Directive 2009/28/EC of the European Union (EU-RED) should include reporting of methodologies for the assessment of carbon stock changes due to iLUC, while biofuels from nonfood and lignocellulosic residues being double credited for GHG emission reduction. The Roundtable on Sustainable Biofuels (RSB) and the reporting of the Netherlands already included methodologies for iLUC assessment. Currently, the Global Bioenergy Partnership (GBEP) is working on the harmonization of sustainability criteria for bioenergy feedstock production.

In Sector D9.7 certification schemes have been compared and assessed according to their indicator quality via environmental impact categories, using standardized rating scales to evaluate the indicators. Current certification schemes have limitations in their representation of the environmental systems affected by feedstock production. For example, these schemes predominantly use feasible causal indicators, instead of more reliable but less feasible effect

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[3] This section is largely based on the following three publications:
Meyer MA, Priess JA. Indicators of bioenergy-related certification schemes - An analysis of the quality and comprehensiveness for assessing local/regional environmental impacts. Biomass Bioenerg 2014;65:169 - 151.
Meyer MA, Chand T, Priess JA. Comparing bioenergy production sites in the southeastern US regarding ecosystem service supply and demand. PLoS ONE 2015;10(3): e0116336.
Meyer MA, Seppelt R, Witing F, Priess JA. How can we compare environmental and ecosystem service assessments for biomass production systems in different parts of the world? Environmental Research Letters; *under review*.

[4] Van Stappen F, Brose I, Schenkel Y. Direct and indirect land use changes issues in European sustainability initiatives: State-of-the-art, open issues and future developments. Biomass Bioenerg 2011;35(12):4824-34.

[5] Overmars KP, Stehfest E, Ros JPM, Prins AG. Indirect land use change emissions related to EU biofuel consumption: an analysis based on historical data. Environmental Science & Policy 2011;14(3):248-57.

[6] Scarlat N, Dallemand JF. Recent developments of biofuels/bioenergy sustainability certification: A global overview. Energ Policy 2011;39(3):1630–46.

indicators. Furthermore, the comprehensiveness of the certification schemes concerning the evaluation of environmental systems and the causal links between human land use activities and biophysical processes in these systems have been assessed. Bioenergy certification schemes hardly go beyond demonstrating compliance with underlying legislation, such as the EU Renewable Energy Directive (EU RED), which does not necessarily enable them to provide a comprehensive and reliable environmental sustainability assessment. Beyond, current certification schemes often lack a methodology to determine sustainable biomass use, e.g., based on environmental or socio-economic thresholds.

Within Task 9.4 of Sector WP 9 an assessment of the ecosystem service supply in three case studies, i.e., a tropical (Rufiji basin in Tanzania), a subtropical (Satilla watershed and Big Sunflower watershed in the Southeast US), and a temperate site (Mulde watershed in Central Germany), which contain (i) forest plantations and/or (ii) agricultural commodities as bioenergy feedstocks has been conducted. We have shown ecosystem service (ESS) tradeoffs and synergies of plantation forestry, i.e., pine/eucalyptus poles, and agricultural production, with the counterfactual natural or semi-natural forest in the tropical and subtropical watersheds. Expectedly, carbon storage is higher on forest plantations than on croplands in the Satilla watershed and the Rufiji basin. For sediment and phosphorous retention and biodiversity, the trade-offs are less clear, most likely, due to varying management intensities.

Lacking thresholds, imprecise causal links and incomplete indicator sets may hamper comparisons of the environmental performances of different feedstocks. In the Southeast US, using indicators of landscape composition and configuration, we could show that landscape planning can affect the overall ESS supply and can partly determine if locally set environmental thresholds are being met. Indicators on landscape composition, configuration and naturalness explained more than 30 % of the variation in ESS supply. Landscape elements such as largely connected forest patches or more complex agricultural patches, e.g., mosaics with shrub and grassland patches, may enhance ESS supply in both of the bioenergy production systems. If tradeoffs between biomass production and other ESS are not addressed by landscape planning, it may be reasonable to include rules in certification schemes that require, e.g., the connectivity of natural or semi-natural forest patches in plantation forestry or (semi-)natural landscape elements in agricultural production systems. Integrating indicators on landscape configuration and composition into certification schemes is particularly relevant considering that certification schemes are governance tools used to ensure comparable sustainability standards for biomass produced in countries with variable or absent legal frameworks for landscape planning. To enhance existing certification schemes, we propose combining the strengths of several certification schemes with research-based indicators, to increase the reliability of environmental assessments.