D4.2

Report on chances and challenges of LCMW biomass conversion pathways on different scale
About the greenGain project

The greenGain project is looking for solutions to increase the energy use of biomass feedstock coming from landscape conservation and maintenance works (LCMW) carried out in the public interest. The main target groups are regional and local players, who are responsible for maintenance and conservation work and for the biomass residue management in their regions. Moreover, the focus will be on service providers - including farmers and forest owners, their associations, NGOs and energy providers and consumers.

The three year project which started on January 2015 is supported by the Horizon 2020, European programme to foster research and innovative solutions in the EU. The project is gathering partners and researchers from Germany, Italy, Spain and Czech Republic. Researchers will map biomass potential coming from landscape conservation and maintenance work, various technological options to utilise it, identify possible obstacles and provide recommendations to a wide range of stakeholders in the EU 28.

Project coordinator

Project partners
This report corresponds to D4.2 Chances and challenges of LCMW on local, regional and European scale. It has been prepared by: SYNCOM Forschungs- und Entwicklungsberatung GmbH

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Executive summary

The use of landscape biomass for bioenergy production incorporates a variety of chances and challenges. Among them low density in the area, heterogeneity, seasonal occurrence and many more which limit its practical use. This report shows the issues faced when landscape conservation and maintenance work (LCMW) biomass will be exploited on different geographical scales among them local heat production, heat, power and biogas production and transportation fuel production. Today LCMW biomass is used for bioenergy production mainly on local level for producing heat less often on regional scale for heat and electricity either in combined heat and power plants (CHP) or in biogas plants. Biofuel production from lignocellulosic feedstock is known to have a strong economy of scale effect. Therefore, a fuel production pathway was chosen which produces an intermediate energy carrier on regional level followed by transportation of a high energy density intermediate to existing refineries for fuel production. For the investigation of this fuel value chain a cost optimization model was chosen developed in a previous European Project1. A thermo-chemical fuel production pathway was modelled in terms of production cost optimization. Several feedstock potentials among them forest residues, hedge- and tree row and fruit pruning have been used. The pruning wood potential on NUTS-3 level was supplied by CIRCE (Coordinator of the Europruning project) and was used to identify optimum plant locations and capacities for catalytic pyrolysis plants which produce a low oxygen content biooil transported by train to existing refineries with a 10 % spare hydrogen capacity to produce a drop-in biofuel. Seasonal variations were compensated by a storage capacity for one year at pyrolysis plant site. Because cost, demand/supply curves and logistic data for pruning feedstock were not easily available same parameters as for wood residues have been used. The comparison between both is especially interesting as it shows the behaviour of fuel production cost, plant locations and capacities for feedstock potentials which vary by more than one order of magnitude.

Information used has been prepared in greenGain but also in other national and European projects especially S2Biom2, Europruning3 and BioBoost. The results achieved complement the activities undertaken in other parts of the greenGain project especially in work package (WP 5), which followed a bottom up approach i.e. identifying the feedstock potential locally and investigate an optimum local use. The investigations show that for LCMW feedstock with suitable properties, the utilisation in locally existing conversion plants is favourable compared to long range applications. Utilisation of LCMW biomass in long range applications like transportation fuel production leads to high costs per unit fuel. Investment costs (CAPEX) for dedicated conversion plants for fuels are high and operational costs (OPEX) are

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1 www.BioBoost.eu
2 www.s2biom.eu
3 www.europruning.eu
high because of high logistic costs. The adding up of feedstock potentials – forest residues, fruit pruning and roadside maintenance show economic advantages compared to forest residues as a single feedstock.
D4.2 Chances and challenges of LCMW biomass conversion pathways on different scale

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1. Introduction

The overall intention of the greenGain project is to mobilize biomass resources from landscape management for bioenergy applications by disseminating good practice among the stakeholders and highlighting technical, economic and environmental properties on top of the present practice for a variety of value chains and different geographical scales.

This deliverable reports the work in task 4.2, which is targeted towards identifying the chances and challenges expected in exploitation of LCMW feedstock on different geographic scales.

The methodology chosen in greenGain implements:

- A bottom up approach from identifying the biomass in the model regions i.e. on local scale, characterizing it and testing its utilisation in pilot experiences later on in the project. This activity is concentrated in work package 5 (WP 5).
- A top down approach concentrated on a demand oriented investigation of certain applications (Figure 1). These applications include the biofuel demands on European and national scale but also the needs of electricity, gas and heat production. The supply and value chain down to the local level utilizing landscape and maintenance work (LCMW) biomass is investigated. This approach is the focus of WP 4.

![Diagram: Top down and bottom up approach]

**Figure 1: Top down and bottom up approach**

The different types of LCMW feedstock and their characteristics have been described in Deliverable 4.1 ([D4.1](#)). The development and the properties of the cost optimization model used in this task are only briefly described. Further details can be found at [www.bioboost.eu](http://www.bioboost.eu).
2. Objectives

The objectives of task 4.2 and thus D 4.2 within WP 4 are:

- Evaluation of available information on LCMW feedstock in Europe and comparison to other available data from literature or European projects (reported in D4.1).
- Investigate the characteristics and some suitable conversion technologies of LCMW.
- Presenting the potentials and challenges of the feedstock conversion into energy intermediates that can foster a sustainable use of bioenergy feedstocks on regional, inter-regional and cross member state level.
- Optimisation of LCMW biomass-based energy generation in regions, inter-regional and across member state borders with the BioBoost-tool.
- Draft European LCMW biomass business development cases on base of the results of the greenGain model regions (to be studied in D4.3).

Within D4.1 the status quo of LCMW biomass potentials and applications in Europe has been documented. Subsequently, task 4.2 compares these biomass potential data from literature and other European projects with the greenGain-data prepared in WP 5. The aim is to validate the literature data from national or European databases by taking certain assumptions with the bottom up biomass potential data investigated in the model regions of this project.

Evaluation of compatibility of LCMW as feedstock for bioenergy applications focuses on the physical and chemical properties of the LCMW feedstocks and their suitability for energy generation in electricity, heat, gas and drop-in transportation fuels.

The last part focuses on the exploitation of some LCMW biomass types on different geographical scales. The use of lignocellulosic feedstock is investigated towards:

- Generation of heat and/or electricity on local and regional scale.
- Application of LCMW biomass for drop in biofuel production via small scale, regional catalytic pyrolysis plants, which deliver an intermediate energy carrier to existing refineries in Germany.
- Use of fruit pruning and forestry residues via the same pathway as above, however on European scale.
3. Methodology

LCMW biomass as a feedstock can be grouped into three general categories:

- Pure lignocellulosic materials from roadside maintenance, hedge- and tree row cutting, fruit prunings or landscape management.
- Herbaceous material from garden and park management.
- Grass and other material with high moisture content from riverside cleaning.

Feedstock potential data are not easily available for LCMW biomass. Some data have been collected from literature (D4.1) on the level of EU-28 and other European projects. Available data from the BioBoost project on NUTS-3 level have been compared and validated with data from the greenGain-NUTS-3 model regions in chapter 4. The later data were generated by a bottom up approach described in D5.1.

Chapter 5 describes some characteristic properties of the LCMW biomass types and often-applied conversion technologies including combustion in CHPs for generation of electricity and heat or biogas fermentation.

Chapter 6 investigates the use of two typical LCMW feedstocks – woodchips from hedge rows and roadside to be used in regional CHPs and the use of herbaceous materials in local biogas plants.

Chapter 7 studies the use of lignocellulosic LCMW biomass for the production of drop-in biofuels in comparison to forest residues as a feedstock in Germany. Secondly, biomass potential data for the woody part of greenGain-LCMW biomass, forestry residues from the BioBoost project and prunings from the EuroPruning project were used to identify costs of drop-in biofuel production for EU28.

The wood chips based pathways for the production of synthetic drop-in biofuels have been intensively investigated in the past and a large amount of data is available. Overall there are two approaches – a large scale gasification for fuel synthesis with long distance biomass transport; or regional pre-treatment in several e.g. catalytic pyrolysis plants, and long distance transport of an intermediate energy carrier of high energy density to a central, existing oil refinery for upgrading to a transportation fuel. The latter two-stage approach has been chosen as it seems most appropriate for low density biomass availability.

Herbaceous material and materials with high moisture content are more suitable and likely to be used as a feedstock in biogas plants which either supply electricity or heat on a local scale or biogas into the available networks.

Grass and other herbaceous materials are usually composted which is a non-energy producing process and therefore it is not within the scope of this project.
4. Potential of LCMW biomass in the model regions and validation of the data

Introduction

The main aim of the greenGain project is to explore the energetic utilisation of biomass available from the landscape conservation and maintenance work (LCMW). The LCMW consists of a number of activities in public interest e.g. cleaning of tracks, abandoned land restoration, maintaining roadsides and parks in urban areas or hedges- and tree rows on banks. The type of biomass originating from LCMW is woody, herbaceous or a mix of both. This LCMW biomass mostly remains underutilised or left on site or disposed as waste. Within WP 5 of this project, pilot experiences in seven model regions in Czech Republic, Italy, Germany and Spain are planned to initiate and realise the strategies to utilize LCMW biomass. In D5.2 at greengain.eu, LCMW biomass in the model regions are categorised and annual amounts of LCMW biomass have been identified specifically for those biomasses that have relevance for the selected region. An overview on these results is given in Table 1. Each region has a large variety of LCMW biomass with different composition. The different types of biomass obtained from the model regions could be grouped in 3 categories:

- Woody material like wood chips from roadside maintenance, hedge- and tree row cutting, fruit prunings or landscape management like moors and cattle track cleaning.
- Herbaceous material e.g. grass with high moisture content and reeds.
- Mixed materials like leaves, twigs and shrubs.

Woody biomass is the largest available LCMW biomass particularly in the model regions of Germany and Spain, whereas herbaceous LCMW biomass is only abundant in model regions of Czech Republic. The LCMW biomass in Italian model regions is a mix of both herbaceous and woody vegetation. The biomass potentials have been defined in terms of tons of fresh matter per annum (Table 1). The highest density of woody biomass up to 16.6 t/km² is observed in Friesland, Germany, which is originated from the maintenance of Hedge- and tree rows on banks. The density of herbaceous biomass is highest in the model region Kněžice, Czech Republic, at 11.18 t/km² obtained from maintenance of grass in urban space e.g. parks and recreational areas (Table 1).
Table 1: Potential and properties of landscape conservation and maintenance work (LCMW) biomass in the greenGain model regions.

Biomass _SUST_ & Biomass _THEO_ = sustainable & theoretical biomass potentials, respectively; Mixed = woody + herbaceous biomass; NUTS = Nomenclature of territorial units for statistics; n.d. = not defined; BA = Bajo Aragon, M = Matarrana, TR= Trasimeno, F = Friesland, R = Rotenburg (Wümme), K = Kněžice and T = Týn nad Vltavou.

<table>
<thead>
<tr>
<th>Country</th>
<th>LCMW classification</th>
<th>LCMW origin</th>
<th>Type</th>
<th>Biomass <em>SUST</em> (t/yr)</th>
<th>Biomass <em>THEO</em> (t/yr)</th>
<th>Moisture (%)</th>
<th>Density <em>SUST</em> (t/km²)</th>
</tr>
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<tr>
<td>Spain (ES) BA + M (NUTS &lt;3)</td>
<td>ES-LCMW 1: Track cleaning</td>
<td>Cleaning sides of agrarian &amp; cattle tracks</td>
<td>Woody</td>
<td>2381</td>
<td>2646</td>
<td>45</td>
<td>1.06</td>
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<tr>
<td></td>
<td>ES-LCMW 2: Fire belts</td>
<td>Fire protection belts along local paths and tracks</td>
<td>Woody</td>
<td>698</td>
<td>1148</td>
<td>45</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>ES-LCMW 4: Abandoned land restoring</td>
<td>Restoration of abandoned agricultural lands in valleys</td>
<td>Mixed</td>
<td>1331</td>
<td>1644</td>
<td>45</td>
<td>0.59</td>
</tr>
<tr>
<td>Italy (IT) TR (NUTS &lt;3)</td>
<td>IT-LCMW 1: Olive plantation</td>
<td>Olive grooves</td>
<td>Mixed</td>
<td>1123</td>
<td>1632</td>
<td>40</td>
<td>0.98</td>
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<tr>
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<td>IT-LCMW 2: Vineyards</td>
<td>Vineyards</td>
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<td>635</td>
<td>669</td>
<td>50</td>
<td>0.56</td>
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<td>IT-LCMW 3: Parks and gardens maintenance</td>
<td>Maintenance of parks and gardens</td>
<td>Mixed</td>
<td>0</td>
<td>109</td>
<td>50</td>
<td>0</td>
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<td>IT-LCMW 4: Roadsides maintenance</td>
<td>Maintenance of roadsides</td>
<td>Mixed</td>
<td>296</td>
<td>408</td>
<td>47.8</td>
<td>0.26</td>
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<tr>
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<td>IT-LCMW 5: Waterside</td>
<td>Maintenance of watersides</td>
<td>Mixed</td>
<td>219 T: 693 to 1980</td>
<td>292 to 366 T: 1386 to 3960</td>
<td>n.d.</td>
<td>0.16 to 0.25 T: 0.53</td>
</tr>
<tr>
<td>Germany (DE) F &amp; R (NUTS-3)</td>
<td>DE-LCMW 1: Hedge- and tree rows on banks</td>
<td>Maintenance of hedge- and tree rows on banks</td>
<td>Woody</td>
<td>F: 1840 to 10,100</td>
<td>F: 1960 to 10,780</td>
<td>45</td>
<td>3.02 to 16.61</td>
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<tr>
<td></td>
<td>DE-LCMW 2: Roadsides</td>
<td>Maintenance of hedge- and tree rows on roadsides</td>
<td>Woody</td>
<td>F: 70.1 to 366.8 R: 276.2 to 1438</td>
<td>F: 82 to 429 R: 323 to 1682</td>
<td>50</td>
<td>0.11 to 0.60 R: 0.13 to 0.69</td>
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<tr>
<td>Czech Republic (CZ) K &amp; T (NUTS &lt;3)</td>
<td>CZ-LCMW 1: Trees-urban</td>
<td>Trees from urban space maintenance</td>
<td>Woody</td>
<td>K: 3.2 to 5 T: 140</td>
<td>K: 4 to 5 T: 350</td>
<td>K: 0.16 to 0.25 T: 0.53</td>
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<tr>
<td></td>
<td>CZ-LCMW 4: Grass-urban</td>
<td>Grass from urban space maintenance</td>
<td>Herbaceous</td>
<td>K: 219 T: 693 to 1980</td>
<td>K: 292 to 366 T: 1386 to 3960</td>
<td>n.d.</td>
<td>K: 11.18 T: 2.64 to 7.54</td>
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<td>CZ-LCMW 5: Grass-road</td>
<td>Grass from roadside maintenance</td>
<td>Herbaceous</td>
<td>K: 36 T: 119 to 268</td>
<td>K: 120 T: 1190 to 2678</td>
<td>n.d.</td>
<td>K: 1.84 T: 0.45 to 1.02</td>
</tr>
</tbody>
</table>
Different types of potentials regarding to the biomass availability for bioenergy have been defined in various studies. In the EU FP7 funded BioBoost project, development of new or improved sustainable energy carriers were investigated to boost the biomass based fuel production in the European regions (www.bioboost.eu). As a part of the project, potentials of various types of feedstocks for EU-27 + Switzerland were assessed (BioBoost, 2013). This study included estimates of biomass from agricultural and animal residues, forestry residues, natural conservation matter, roadside vegetation and urban and industrial waste at level 3 spatial units within NUTS (nomenclature of territorial units for statistics) classification. In the greenGain project, out of seven model regions within four EU countries, only in Germany the biomass potential is assessed at NUTS-3 level and in the rest of the regions even smaller spatial units at municipality levels are contained within NUTS-3 regions. Vegetation density and the availability of biomass may vary in each subdivision of NUTS-3 itself which can highly influence distribution and collection of biomass. It is difficult to obtain datasets for LCMW biomass potential determined down to the local administrative units (LAU; formerly NUTS-4 & 5) from the existing databases. In a study, it was concluded that municipality resolution (NUTS-5) is much more accurate then spatially vast information of NUTS-3 that may lead to distortion of geographical potentials, uncertainty and deviations in data while assessing biomass (Garcia et al., 2007). For the validation of data, the biomass potentials of LCMW estimated in greenGain are compared with the biomass potentials of BioBoost project, assessed at NUTS-3 level. For a comprehensive comparison, it is reasonable only to compare the data of model regions Friesland and Rotenburg (Wümme) which are classified as NUTS-3 spatial units in Germany having a standard geocode DE937 and DE94A.

To examine and understand the biomass estimates by different studies, it is important to take into account the methodology used to assess the potentials. In the greenGain project, for the model regions Friesland and Rotenburg (Wümme), LCMW biomasses namely Hedge- and tree rows on banks (DE-LCMW 1), Roadsides (DE-LCMW 2) and Moor (DE-LCMW 3) are recognised as relevant potential sources of woody feedstocks for suitable conversion technologies. Theoretical and sustainable potentials were assessed for biomass from LCMW of Hedge- and tree rows on banks in Friesland and for LCMW of Roadsides in both Friesland and Rotenburg (Wümme). Theoretical and sustainable potentials of biomass generation from LCMW of moor areas could not be estimated as this kind of activity takes place only once or once in 20 years. Therefore, compatibility of potentials of the biomass types DE-LCMW 1 and DE-LCMW 2 assessed in NUTS-3 regions in greenGain project with BioBoost has been discussed in this section of the report.
4.1. Comparison of the biomass potential from hedge- and tree row maintenance from greenGain with the feedstock potential investigation of the BioBoost project

The biomass of hedge- and tree rows on banks consists mainly of bushes, trees or a mix of bushes and trees which is predominately woody and hence, recommended to be processed as woodchips for further utilization \(\text{(D5.2, greenGain)}\). In the BioBoost project, none of the described biomass categories are fully identical with hedge- and tree rows on banks. The woody biomasses nearest to this LCMW in BioBoost are characterised as:

1. Forestry residues: It includes stemwood from pre-commercial and commercial activities, logging residues and stumps defined as primary forestry residues, by-products and residues from wood processing under the category secondary forestry residues, woody biomass from short rotation plantations on forestlands as well as trees outside of forests such as trees of settlement areas, along roads and on other infrastructural areas.
2. Green urban: Biomass from conservation of green urban areas that includes leaves, shrubs and grass.

To compare the biomass potentials, it is important to have background information about similarities or dissimilarities between the methodologies used to calculate the potentials in both projects which are as following:

**BioBoost method**
The two important types of potentials which are discussed herein:
1. Theoretical potential which refers to the maximum amount of terrestrial biomass that is theoretically available for bioenergy production. It corresponds to the total primary production regardless of land usage, the upper ceiling of potential net productivity.
2. Technical potential refers to the theoretical biomass potential reduced by losses associated with the harvesting and conversion of primary biomass resources for energy feedstocks.

For the estimation of biomass potentials, various factors were considered for each category of biomass and were calculated with relevant formulas as explained below.

**Forestry Residues**

Main data source: Biomass Energy Europe (BEE) project carried out from 2008 to 2010 (www.eu-bee.com)
Factors: net annual increment, harvesting loss, biomass expansion factor for above ground non stem biomass without inclusion of needle and leave biomass, biomass expansion factor for stumps, average standing volume per ha, species specific wood density, moisture content of 35 % (assumption).

1. Theoretical potential was assessed with the following formula

\[
\text{THP}_{PFR,x,y} = \text{THP}_{LR,x,y} + \text{THP}_{Sx,y}
\]

Where,

- \( \text{THP}_{PFR,x,y} \): total theoretical potential of primary forestry residues in country \( x \) in year \( y \), (m\(^3\)/year)
- \( \text{THP}_{LR,x,y} \): theoretical potential of logging residues in country \( x \) in year \( y \), (m\(^3\)/year)
- \( \text{THP}_{Sx,y} \): theoretical potential of stumps in country \( x \) in year \( y \), (m\(^3\)/year)

2. Technical potential of forestry residues was assessed by assuming 50 % recovery rate of above ground forest residues, 20 % - 40 % recovery rate for stumps, 30 % as part of the surplus complementary fellings reserved for material use of wood, 5 % as part of the actual net annual increment reserved for an increase of standing volume to facilitate an increased carbon storage and for biodiversity purposes and 5 % as consideration of unrecorded harvests from industrial roundwood.

**Green Urban Areas**

The biomass that could be obtained from artificial, non-agricultural vegetated areas was considered for the potential assessment of green urban areas.

Main data sources: CORINE system to collect information on the forms of land use through satellite images (www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2). The assessment of potential is based on corine land cover (CLC) classes; green urban areas (class 10) and port and leisure facilities (class 11).

Factors: Analysis at a scale of 100x100 m, values of net primary productivity (NPP) (http://wdc.dlr.de/data_products/SURFACE), which were re-written for selected pixels

Biomass potential was assessed with the following formula and as a technical potential 50 % of NPP was assumed for each pixel.
IF CLC = 10 OR 11 THEN GUA = (0.5 * NPP) ELSE GUA = No data

Where:
GUA = Residuals of natural conservation of green urban areas
CLC = Corine land cover, classes: 10, 11
NPP = net primary productivity in location of 10, 11 class of CLC

greenGain method
The relevant potentials discussed in greenGain are theoretical and sustainable potentials. For comparison purposes, the sustainable potential is considered equivalent to the technical potential as defined in the BioBoost method and is calculated by reducing losses from theoretical potential considering technical and economic limitations, competitiveness, ownership, social as well as environmental constraints. The impact of each constraint was quantified with a coefficient of reduction (CR) and the assessment of sustainable biomass potential was carried out according to the following equation:

\[ \text{Bio}_{\text{sust}} = \text{Bio}_{\text{theo}} \times (1 - \text{CR}_{\text{tech}}) \times (1 - \text{CR}_{\text{eco}}) \times (1 - \text{CR}_{\text{imp}}) \times (1 - \text{CR}_{\text{sust}}) \]

Where,
\( \text{Bio}_{\text{sust}} \) = Sustainable potential of biomass
\( \text{Bio}_{\text{theo}} \) = Theoretical potential of biomass
\( \text{CR}_{\text{tech}} \) = Coefficient of reduction for technical constraint
\( \text{CR}_{\text{eco}} \) = Coefficient of reduction for economical constraint
\( \text{CR}_{\text{imp}} \) = Coefficient of reduction for implementation constraint
\( \text{CR}_{\text{sust}} \) = Coefficient of reduction for sustainable constraint

Hedge- and tree rows on banks

Main data sources: INTERREG IV A-project “Stoken op Streekhout – Energiequelle Wallhecke” (Stockmann 2012), Lower Nature Protection Agency Friesland-Untere Naturschutzbehörde and Landscape structure plan county Friesland. All hedge- and tree rows on banks in the region Friesland (DE-LCMW1) are registered at the Lower Nature Protection Agency Friesland, marked in a GIS system and are available as GIS-shape files (Friesland, 2014).

Factors: total length, vegetation species, density, hedgerow types, losses and gains during the last 30 years, ownership and history of treatment, moisture content of 30 to 45 % (average 37.5 %).

1. Theoretical potential (\( \text{Bio}_{\text{theo}} \)) was assessed with the total inventory of existing hedges and tree rows (\( \text{Bio}_{\text{exist}} \)) at a ratio of 40-220 tons of woody biomass per km of 490 km long
banks in the county Friesland which are maintained at a frequency of 10 years and calculated according to the following formulas:

\[
\text{Bio}_{\text{exist}} = (\text{Length hedge rows}) \times \text{ratio} \\
\text{Bio}_{\text{theo}} = \frac{\text{Bio}_{\text{exist}}}{\text{frequency}}
\]

2. Sustainable potential (Bio\text{sust}) was assessed assuming a CR\text{tech} = 0.05, as practically almost no technical constraints are present and according to the regulations biomass should not be left on site after treatment. There is no vegetation on 1.4% of banks, therefore, a CR\text{noveg} = 0.014 was further deducted during the calculations as below:

\[
\text{Bio}_{\text{sust}} = \text{Bio}_{\text{theo}} \times (1-\text{CR}_{\text{tech}}) \times (1-\text{CR}_{\text{noveg}})
\]

**Hedge-and tree rows on banks (greenGain) versus forestry residues + green urban LCMW biomass (BioBoost)**

The woody biomass of hedge- and tree rows on banks in greenGain was compared with nearest similar category of biomass described in BioBoost which is the biomass obtainable from forestry residues and maintenance of green urban areas (Figure 2). For the purposes of comparison, average values of the range of biomass potentials of DE-LCMW 1 (Table 1) and moisture content were taken and the value of dry weight was further corrected according to the 35% moisture content for Bioboot biomass.

![Figure 2: Comparison of estimated biomass potentials for woody biomass in BioBoost with DE-LCMW 1 Hedge- and tree rows on banks in Friesland (NUTS-3 DE94A). Moisture = 35% of total weight](image)
The cumulative theoretical potential (13724 t/y) of woody biomass i.e. forestry residues and green urban incorporates not only biomass obtained from LCMW but also from non-LCMW sources as described in definition of forestry residues (page 17), which is the reason for a 53 % increase in the theoretical biomass potential compared to the potential of hedge-and tree rows on banks. The main data sources used for estimation of biomass are different for each case, hedge- and tree rows on banks have a well determined existing inventory available through local administration. The methods involved in both projects differ in terms of formulas and to some extent reduction factors that may influence the calculations. Therefore, results vary widely in the estimation of theoretical potential of the woody biomass. Only few constraints exist in the harvesting of hedge- and tree rows on banks biomass, as a result- it is largely available for the possible conversion into energy and due to this reason the sustainable potential is very close to the technical potential. On the other hand, alone for the forestry residues in the same region, a difference of 65 % exists between technical and theoretical biomass potentials estimated in BioBoost project because a number of factors, as described in the methodology of biomass assessment (page 17-18), plays a crucial role in the actual availability of biomass as well as forestry residues could have a number of alternative uses. Surprisingly, the sustainable potential alone of biomass from hedge-and tree rows on banks was more than the combined forestry and green urban biomass. The use of spatially vast information may also lead to deviation in the data in comparison to the bottom-up approach of greenGain. In conclusion, because of considerable differences in the hedge- and tree rows on banks and the composition of forestry residues that include among others woody LCMW biomass from settlements areas as well as green urban areas, a comparison of potentials between these categories of biomass is not fully justifiable. The cumulative technical potential of forestry residues and green urban biomass estimated in BioBoost is near to the average sustainable potential of the hedge- and tree rows on banks in Friesland (after moisture correction) which may be because of the existence of almost no technical limitations for harvesting and processing of this type of biomass that may also constitute a major portion in the technical biomass potential of woody residues of BioBoost. The potentials of various biomasses e.g. agricultural and forestry residues etc. have been analysed and reported in a number of studies and these vary considerably among each other. For example, for forestry residues (Figure 3), the differences are due to the definitions of residues, different time, availability of data, various restrictions included in the models, method of assessment etc.
4.2. Comparison of the biomass potential from roadsides maintenance from greenGain with the feedstock potential investigation of the BioBoost project

The biomass which lines roadsides consists of fresh and loose woody biomass that is produced from branches and stems. In Rotenburg (Wümme) roads are loosely lined with trees and for full visibility of roads it is necessary to carry out maintenance activities apart from landscape conservation. Mainly woody biomass is obtainable from roadsides of Friesland and Rotenburg (Wümme). In BioBoost project, the potential of roadsides biomass was assessed for both of these NUTS-3 regions. The background information about methodologies to assess the potential of this type of LCMW biomass is presented as below.

**BioBoost method**

In the BioBoost project potential of biomass that can be obtained from cut grass, shrubs and trees grown by the sides of motor ways, primary ways, trunk ways as well as railways was assessed with the following criteria.

Main data sources: Vector maps of railway network and European roads network from OpenStreetMap (http://planet.openstreetmap.org/). Net primary productivity (NPP) data (http://wdc.dlr.de/data_products/SURFACE/)
Assumptions: Biomass could be obtained from 10 m wide roadside strips except trunk road type where width was reduced to 5 m. For biomass yield, average values of NPP for NUTS-3 were adopted. Moisture content of 15 % was taken.

Biomass potential was assessed by the following formula:

\[
RSV = 2*NPP*Wsp*[(LR1_{km}*10m) + (LR2_{km}*5m) + (LR3_{km}*10m) + (LRw_{km}*10m)]
\]

Where,
- \( RSV \) = biomass of roadside vegetation for NUTS-3 (in 1000 tones/NUTS-3)
- \( NPP \) = net primary productivity, t/ha (mean value of NUTS-3)
- \( Wsp = 104 \), it lets to obtain value as 1000 tones, (dimensionless)
- \( LR1 \) = motor way (km/NUTS-3)
- \( LR2 \) = primary way (km/NUTS-3)
- \( LR3 \) = trunk way (km/NUTS-3)
- \( LRw \) = railway (km/NUTS-3)

**greenGain method**

This LCMW biomass originates from the maintenance of vegetation along county roads.


Factors: Length of county roads in Rotenburg (Wümme) (647 km) and Friesland (165 km), share of roads with and without vegetation, vegetation types and density, moisture content of 50 % and frequency of treatments.

1. Theoretical potential: ratio 0.5 to 2.6 t/km*year

\[
Bio_{theo} = (\text{Length county roads})*\text{ratio}
\]

2. Sustainable potential: The LCMW biomass is removed immediately from the sites which results in low technical limitations, \( CR_{tech}= 0.05 \). Ten % of county roads have no vegetation on either sides of the roads for which \( CR_{noveg}= 0.10 \) was reduced from the theoretical potential to obtain the sustainable potential with the following formula:

\[
Bio_{sust} = Bio_{theo}*(1-CR_{tech}) * (1- CR_{noveg})
\]
Figure 4: Comparison of roadside biomass potentials between greenGain and BioBoost in NUTS-3 regions a) Rotenburg (Wümme) and b) Friesland

In addition to the roadways, assessment of vegetation along railways were also made in BioBoost project that contribute to the cumulative biomass potentials and partly explains the large difference between the biomass potentials assessed in greenGain and BioBoost for the same regions (Figure 4). This is why the biomass from roadsides LCMW as determined in BioBoost contains not only trees, shrubs but also cut grass. Whereas, LCMW roadside biomass is described as mainly woody in greenGain. Another factor which needs to be considered is that greenGain data is based on the bottom-up approach which consists of GIS spatially explicit data sources and detailed data on statistics regarding to local nature,
infrastructure inventories and geographical coverages obtained directly from county administrations of respective regions as well as from past studies. Wherever the detailed data was not available e.g. for the southern section of Rotenburg (Wümme), the potentials were assumed carefully by applying available values from similar landscape and administrative framework. For accurate calculations of the ratio of woody biomass per km of roadside, on-site experiences of the roadside maintenance agency Bremervörde were applied. Further, the occurrence of vegetation was determined to be 62 % on both sides, 28 % on one side and none on 10 % of roads and thus, the lengths of the roads were calculated anew according to the percentage of vegetation availability along the roads. Whereas, in case of BioBoost it was assumed that biomass is present on 10 m wide roadside strips and on 5 m wide trunk roadways. This may have led to the overestimation of the potentials comparing to greenGain method. In greenGain, with quantitative information and derived length of vegetation, the actual lengths of the structure and density types were calculated and based upon the collected data and literature studies, a range of theoretical and sustainable potentials of roadside biomass were determined for both counties i.e. Bio_{Theo} = 323 to 1682 t/year and 82 to 429 t/year and Bio_{Sust} = 276.2 to 1438 t/y and 70.1 to 366.8 t/year for Rotenburg (Wümme) and Friesland, respectively. For comparison with BioBoost, an average value of each of these respective wide ranges was taken after moisture correction (weight reduction to 15 % moisture as for BioBoost), which is also one of the factor that has caused differences in estimations of respective potentials in both studies.

4.3. Conclusion

The LCMW in seven model regions of Czech Republic, Germany, Italy and Spain generates three types of biomass that can be categorized as woody, herbaceous and mixed. Mostly woody biomass is generated from LCMW. The highest density of woody biomass is in Friesland, Germany, and of herbaceous biomass in Kněžice, Czech Republic. No data is available in literature on potentials of biomass originating from LCMW, assessed with bottom up approach, at local administrative units for model regions excluding Germany. Therefore, for validation of the data, only the German model regions Friesland and Rotenburg (Wümme) which are NUTS-3 could be compared with the potentials assessed in the BioBoost project. The categories of LCMW biomass described in greenGain do not comply fully to the biomass categories described in BioBoost. The theoretical potential of the most similar category of woody biomass described in BioBoost in Friesland i.e. Forestry Residues and Green Urban when compared to maintenance of hedge- and tree rows on banks (DE-LCMW1) showed considerable differences mainly because the spectrum of biomass sources placed under forestry residues is much wider than only hedge- and tree rows on banks LCMW. In Friesland for DE-LCMW1, the Biomass_{Sust} is very close to Biomass_{Theo} assessed in greenGain, indicating lack of constraints in the availability of this
biomass and theoretically available biomass is nearly fully exploitable for energetic usage. Even when comparing the exact similar category i.e. roadsides LCMW biomass potentials for Rotenburg (Wümme) and Friesland, BioBoost had 5 and 8 times, respectively more theoretical potential and similarly 3 to 4.6 times, respectively more technical potential than greenGain for both regions. The deviations are due to the method of assessment, factors considered and selection of biomass including that obtained from railway sides under the category Roadsides LCMW. Thus, it can be concluded that the bottom up approach of assessing biomass on LAU level and even on NUTS-3 level in similar categories of LCMW biomass is notconfirmable with the top down approach of BioBoost.
5. Feedstock conversion properties and suitable conversion technologies

Introduction

The technologies for the conversion of biomass into bioenergy including electricity, heat and fuel can be classified into two categories:

1. Thermochemical conversion
2. Biochemical conversion

The thermochemical technologies involve conversion of biomass to energy via chemical processes in addition to utilisation of heat in absence or presence of oxygen e.g. pyrolysis, combustion, torrefaction, gasification. In the biochemical technologies enzymes, bacteria and other microorganisms break down biomass molecules and convert them to liquid fuels or biogas e.g. anaerobic digestion, fermentation and composting. Several pathways within each category have been identified and explained in D4.1 of greenGain. The selection of conversion technologies for a particular biomass is - among others - dependent upon its physical and chemical characteristics which determine the suitability of biomass as a feedstock for the system. A number of pre-treatments have been developed which can improve the biomass characteristics for efficient conversion processing as well as to make handling, transport or storage of biomass cost effective.

5.1. Biomass properties and their influence on conversion technologies

The performance of conversion pathways relies on the use of appropriate biomass feedstocks. Tanger et. al (2013) described in their study the characteristics of lignocellulosic biomass which plays a major role on pairings of biomass feedstocks and advanced conversion technologies. Biopolymers (e.g., cellulose, lignin etc.), relative abundance of individual elements (e.g. C, H, O, N and S), relative proportions of fixed carbon (FC) and volatile matter (VM), moisture and elemental ash complete the mass balance of a unit of freshly-harvested biomass. Different combinations of these mass-based properties result in different bulk properties such as grindability (comminution), density and heating value.

The important feedstock properties that affect conversion effectiveness include:

1. **Heating or calorific value**: It is the energy available in the feedstock and is a primary measure of quality of a feedstock. High moisture content and high mineral content leads to a decrease in heating value because minerals contribute little energy during biomass
oxidation e.g. grasses and other herbaceous feedstock that can consist of up to 27 % ash have low heating values.

2. **Elements \((C,H,O)\) ratio**: The biochemical components in the cell wall influence the relative content of C, H, and O in biomass. Lignin has a lower H:C and O:C ratio than cellulose therefore, lignin is less oxygenated and has a higher heating value than cellulose or starch. High lignin containing biomass e.g. woody biomass is beneficial for thermal systems and advantageous for thermo-chemical conversion pathways targeting liquid fuels. Whereas, minimizing lignin in feedstock via pre-treatments improves hydrolysis and biogas yields. Feedstock with low lignin and cellulose and hemicellulose content, are more suitable for biochemical conversion technologies. Concentrations of non volatile fixed carbon and volatile matter are related to the relative yields and composition of solid, liquid, and gaseous products generated during thermochemical and biochemical conversion pathways.

3. **Mineral and elemental content**: Mineral content of the biomass directly influence the operation of thermochemical conversion equipment besides lowering the heating value of biomass. During combustion, minerals present in plant biomass form a liquid slag or solid deposits as they cool down. High concentration of elements Na, K, Mg, Ca, Cl, S and Si in biomass are problematic for thermochemical processes. The ash content of grasses has a high proportion of Si that reacts with alkali metals like K and forms alkali silicates which increases slagging during thermochemical conversions. Similarly, high Cl containing biomass leads to elevated HCl and dioxin emissions and form corrosive deposits that degrade components of the boilers.

4. **Moisture Content**: The amount of water in the biomass is usually expressed as percentage of total mass. The moisture content of biomass influence effectiveness of a conversion technology. Biomass with a moisture content of ~5 % is suitable for combustion or co-firing and for gasification biomass with a moisture content of around 20-30 % is acceptable. Wet biomass can be a suitable feedstock for hydrothermal combustion (HTC). Drying of biomass before transport maximizes its dry bulk density that allows more cost effective transportation. Reduction in moisture content of biomass may improve process efficiency for thermochemical pathways but it is not preferred for wet digestion processes. The grindability of biomass is also related to moisture content and composition of biomass.
Table 2: Conversion technologies and matching LCMW feedstock types

<table>
<thead>
<tr>
<th>Conversion Technologies</th>
<th>Feedstock type</th>
<th>Woody Biomass</th>
<th>Herbaceous Biomass</th>
<th>Mixed Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermochemical Combustion</td>
<td>☻</td>
<td>☻</td>
<td>☻</td>
<td>☻</td>
</tr>
<tr>
<td>Pyrolysis</td>
<td>☻</td>
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<tr>
<td>Gasification</td>
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<tr>
<td>Torrefaction</td>
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<td>☻</td>
<td>☻</td>
</tr>
<tr>
<td>Hydrothermal carbonisation</td>
<td>☻</td>
<td>☻</td>
<td>☻</td>
<td>☻</td>
</tr>
<tr>
<td>Biochemical</td>
<td>☻</td>
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</tr>
</tbody>
</table>

The degree of suitability of various conversion technologies with different types of LCMW feedstock is indicated briefly in the (Table 2). An online tool to match the biomass with optimized conversion pathways has been developed within the framework of the EU funded project S2BIOM and is available at www.s2biom.eu.

5.2. Thermochemical conversion technologies

Combustion is a process of oxidation, where carbon and hydrogen contained in cellulose, hemicellulose, lignin or other molecules like methane react with excess oxygen, releasing CO₂, water and heat. When biomass or biogas is combusted for electricity production, the recovery of excess heat is desirable. The integrated systems of combined heat and power generation (CHP) utilize the excess heat for heating, cooling, dehumidification, or process applications. Waste woody biomass from riverside and dike maintenance, from pruning or from urban green chopped to wood chips can be used as feedstock for combustion in a wood-chip boiler for heat production.

Pyrolysis is a process of thermal degradation of biomass under absence of any oxidising agents. The products are in solid (charcoal), liquid (pyrolysis oil) and gaseous form. The proportion of the fractions depends on process temperature, heating rate and residence time. At lower temperatures around 400 °C, the main product is charcoal, while at temperatures about 800 °C, mainly gas is yielded. Pyrolysis performed at high heating rates is known as fast or flash pyrolysis with residence time of seconds. In case of slow pyrolysis or carbonisation residence time of days is applied. Dry lignocellulosic biomasses such as perennial grass or wood can be converted to liquid fuels via a fast pyrolysis process in which
biomass is rapidly heated to about 500 °C in the absence of oxygen and then quickly cooled in a reactor. The process converts the biomass into carbohydrate-based compounds that include condensable vapors; these are condensed into liquid bio-oil, the primary product of fast pyrolysis. This process can convert up to 75% of biomass input into bio-oil, yielding about 135 gallons of bio-oil per ton of biomass. USDA-ARS have developed a FarmBio3 mobile pyrolysis system (Figure 5) that could be taken to on-site, simulating the real-world scenario of multiple on-farm units that convert feedstocks to bio-oil, which is delivered to a regional biorefinery (Brown and Harlow, 2015).

![Figure 5: FarmBio3 mobile pyrolysis system](credit: USDA-ARS Pyrolysis Team)

For conversion of woody biomass, the Netherlands based Biomass Technology Group (BTG) has designed a fast pyrolysis plant based on a rotating cone reactor developed by the University of Twente. In BTG’s technology, biomass particles at ambient temperature with an excess flow of hot sand particles, acting as carrier material, are introduced near the bottom of the cone reactor where the solids are mixed and transported upwards by the rotatory motion leading to rapid heating and a short gas phase residence time. After passing through several cyclones the vapours produced in the cone reactor enters a condenser where they are quenched by re-circulated oil. The pyrolysis reactor is integrated with a circulating sand system, a fluidized bed char combustor and a down-comer. The heat required for the pyrolysis process is provided by burning char in presence of air. The main product of this system is oil. The non-condensable pyrolysis gases are combusted and can be used e.g. to generate additional steam and excess heat can be used for drying the feedstock (BTG, 2016).

A BTG’s fast pyrolysis plant with a capacity of 2 t/h in Malaysia utilizes empty fruit bunches (EFB) as the feedstock, obtained from a closely located palm mill. About 6 t/h of wet EFB (moisture ~65 wt%) are sized and dried up to a moisture content of about 5-10 % to produce approximately 1.2 t/h pyrolysis oil. EMPYRO is another commercial scale poly-generation pyrolysis plant of BTG which is in operation at Hengelo (the Netherlands) with a capacity of
converting 5 t/h of wood residues into 3.3 t of pyrolysis oil, 4.5 MW steam and 435 KW electricity, excluding internal heat and power consumption. This plant was established as a result of EMPYRO project (2009-2013), co-funded by the EU under its FP7 programme. The total cost of this plant is around EUR 19 million which was generated from 33 % grants, 33 % loans and the rest from equity (Sherrad, 2015).

Dry woody biomass from LCMW of hedges and tree rows, olive pruning, riverbank maintenance e.g. reed could be utilized in pyrolysis systems.

Gasification of biomass takes place when the material is treated by high temperature (800 – 900 °C) under limited presence of an oxidising agent. The product of this process is called synthetic gas or syngas, a mixture of CO, CO₂, CH₄, H₂ and water. The energy content of the gas is given by the biomass type and the gasification agent (air, oxygen, steam or hydrogen). Air or oxygen produces syngas with low to medium energy content, which is used in combustion for generating heat and electricity. Landscape maintenance residues can be converted into high quality syngas via thermo-chemical gasification to generate CHP electricity via usual combustion engine and generator. For example, gasification from woodchips obtained from the landscape maintenance in Germany has been successfully demonstrated by the LiPRO-Energy GmbH & Co. KG in their small-scale power plant (30 kWₑₐ and 60 kWₑₐ) that is able to convert solid biomass fuels - like woodchips and other agricultural or landscape maintenance residues not suitable for biogas plants, into high quality syngas to generate CHP electricity via usual combustion engine and generator (Figure 6). The feedstock is heated up to ca. 700 °C by the process heat under a shortage of oxygen. The products are pyrolysis steam and charcoal, pyrolysis steam gets oxidized by about 1100 °C in the next step to crack long and ring shaped carbon-hydrogen molecules to avoid tar compounds in syngas. Third step is the reduction of CO₂ by reacting with the hot charcoal to CO, due to several further reactions like water steam shift, syngas has following components: 3 % methane, 20 % hydrogen, 21 % carbon monoxide, 12 % carbon dioxide and 44 % nitrogen and a calorific value of 5.7 MJ/Nm³. After filtering the gas by a simple dry fabric filter the high quality gas is ready for the combustion engine. During the procedure, the charcoal-ash mixture is produced and it is used in compost to improve ecological functions of soil. In 2015, during 7000 CHP operating hours, 210,000 kWhₑₐ were generated.

Half of the annual feedstock amount comes from hedges of a farm and the other half from nearby forest residues (5 km radius). If the plant is operated for 8000 hours per year, it needs about 240 tDM wood or other lignocellulosic biomass. Biomass from roadside pruning, bush mulching, tree falling, wood processing residues, etc. can be used. Fuel needs to be dried to 15 % moisture content, which is done with help of the waste heat. The simplest and most cost-efficient way to use roadside biomass or hedges in LiPRO plant is to manage these landscape biomass with a tractor equipped with a crane and a felling grapple. The trees are harvested from the thick end at about 20 cm diameter at breast height (DBH) e.g. every three years, and piled up at a place accessible to a truck. They are chipped with a
self-propelled chipper. The costs from harvest to storing place is about 9 € per loose cubic meter.

![Diagram of LiPRO Wood-Gasification CHP Plant](http://lipro-energy.de/en/)

**Figure 6: LiPRO Wood-Gasification CHP Plant. Photo source: http://lipro-energy.de/en/**

**Torrefaction** is a mild pyrolysis carried out by 200 – 300 °C, where the solid fraction represents the main product. It offers the possibility of making torrefied pellets representing an even more densified form of an energy carrier. Wood residues which compromise a largely available biomass resource are in the focus as feedstock for torrefaction as well as roadside grass and woody roadside biomass.

**Hydrothermal carbonisation (HTC)** is conducted in the presence of subcritical liquid water under temperatures between 180 – 250 °C. It converts the moist input material into carbonaceous solids without the need of previous drying. The water is kept liquid during the process by letting the pressure to come up with the steam pressure in a pressure reactor. Biochar is the main fraction among the products. The SunCoal® CarboREN® technology (based on hydrothermal carbonization) is able to use LCMW biomass as feedstock. Almost all plant-based biomass can serve as a source of biocoal. Whole plants can be used, even lignite or wood-based materials that are not applicable to fermentation. Biomass with high water content can be used, for example grass cuttings, which would not be applicable for direct burning. Even impure biomass can be used, as the process involves a washing step. The company AVA-CO2 Schweiz AG and a new HTC facility in Halle Germany operated by the Hallische Wasser and Stadtwirtschaft GmbH use urban green residual biomass, respectively green communal- and garden residues as feedstock for HTC.
5.3. Biochemical conversion

Anaerobic digestion is a biological decomposition process, where breakdown of organic matter occurs in absence of oxygen. It proceeds in four stages involving four different groups of microorganisms. The final product of the decomposition is biogas. The residues from the digestion can be used, after being stabilized, as fertiliser depending on the composition of the input material. Pehlken, et al. (2015) investigated the option to partially replace maize in biogas plants by grassy material from cultural landscape conservation by a stakeholder alliance in two model regions in Germany. Landscape conservation biomass was confirmed to be interesting for the use in digestion as it created more than 50% of the feedstock for the biogas fermenter in one of the their model regions in Germany (Pehlken, et al., 2015). Utilisation of unused biomass resources from grassland areas and landscape management in Europe, e.g. roadside green cuttings or endemic plants that suppress biodiversity via anaerobic digestion has been explored in INTERREG IV B funded COMBINE-Converting Organic Matters from European urban and natural areas into storable bio-Energy project (http://www.combine-nwe.eu). One of the aims of this project is increasing the efficiency of biomass supply chains, through the addition of a year-round heat sink in distributed biogas or AD plants by new harvesting and conditioning techniques. This project is based on IFBB technology which stands for the integrated generation of solid fuel and biogas from biomass, developed at the University of Kassel in the early 2000s.

The IFBB technology was successfully up-scaled from laboratory scale to 1:20 between 2009 and 2012 in the forerunner project PROGRASS. The mobile demonstration plant based on IFBB has been used as demonstration and exploration unit in PROGRASS, COMBINE and DANUBEENERGY projects of EU.

The first commercial full scale IFBB technology based plant has already started its operation in 2013 in Baden-Baden, Germany. The substrates processed at the Baden-Baden plant include branches, brushwood, leaves, grass, garden waste, municipal green waste etc. In the first step, the delivered material at receiving station of plant is sorted into three categories 1. grass and leaves 2. material contaminated with soil and 3. wood and brushwood. Larger wood and brushwood are chopped and passed through several sieving stages. The wood chips with 2-4 cm are marketed and smaller parts are compressed to briquettes or added to silage processing. The green material that consists of grasses, leaves etc. is minced and stirred within a tossing tub and afterwards pressed and packed in 500 kg silage bales that facilitate storage and transportation to the biogas plant located at a distance of 1.5 km otherwise, a clamp silo facility is on-site. At the hydrothermal conditioning unit, which is the core of IFBB processing, the silage is conditioned/mashed by adding warm water (~40 °C) in 1:4 ratio (silage:water). The material is mixed with pulper to open up the cell walls of the fibrous material of silage. With a pump line the mashed silage suspension is transferred to two buffering reservoirs and homogenized again to prevent segregation during pumping. Remaining sand particles settle to the bottom. From reservoirs, the mashed biomass suspension is pumped into the separation unit where the fibrous, lignin-rich solid part (press
cake) is separated from the silage liquid (press fluid) by a screw press. The press fluid contains not only the easily digestible ingredients but also minerals that are detrimental for combustion, > 80 % of Cl and K and > 50 % of S and Mg from the biomass is transferred in the fluid. To use the press cake for combustion and energy production, the separated press cake is then passed through a belt dryer in order to reduce its water content from 50-60 % to 15-17 %. The waste heat from the combined heat and power plant of the biogas plant is supplied to belt dryer. The dried press cake is then compressed to briquettes for easier transportation and could be blended with wood to further improve solid fuel and briquette quality. These briquettes are usable in furnaces suitable for wood firing, determined by the German Federal Pollution Control Act (4. BImSchV) and the corresponding control regulation TA Luft. To cover the complete internal heat demand of the facility, a portion of the dried press cake is combusted in the heating plant (2x 420 kW effective heat output) of the Eigenbetrieb Umwelttechnik of the city of Baden-Baden. The surplus heat could be exported into a district heating network. The easily biodegradable press fluid is directly fed into the hydrolyse stage of the biogas plant. A surplus of about 30 % electricity is available after covering the complete station supply of the facilities and the sewage plant with the produced electricity. In addition, the Baden Baden plant generates a wide variety of marketable products e.g. wood briquettes, wood chips, grass briquettes, un-pressed grass silage etc. (DANUBEENERGY, 2016).

Composting is the process where organic material is decomposed in the presence of oxygen by bacteria and fungi, producing CO₂, water, compost and heat. Compost is used as source of organic matter and nutrient for agriculture, gardens, as a component of flower soils (replacing peat) or for re-cultivation. A frequent treatment of the LCMW material is composting. The olive tree pruning residues are an excellent raw material for composting. In Spain, shredded olive pruning residues are also commonly ploughed directly into the soil as a fertiliser. Herbaceous e.g. grass and mixed biomass are also easily compostable but composting has the disadvantage that the process heat is lost (D4.1, greenGain).

Bio-Refinery: Within biochemical Bio-Refinery, lignocellulosic biomass is refined into intermediate outputs (cellulose, hemicellulose and lignin) to be processed into a spectrum of products and bioenergy. Since lignocellulosic biomass from LCMW has less competition with food and energy crops, it is expected to become an important future source of biomass available at moderate costs as the feedstock for Bio-Refineries. Usually, lignocellulosic biomass is given mechanical, thermal and/or chemical pre-treatments e.g. with acid or alkaline agents to release cellulose, hemicellulose and lignin from the cell structure. Cellulose and hemicellulose are further converted with enzymatic-hydrolysis into mainly glucose, mannose (C6 sugar) and xylose (C5 sugar). Currently, C6 and sometimes C5 sugars are predominantly used as feedstock for fermentation to produce biofuels such as ethanol, butanol, hydrogen and/or added-value chemicals. Lignin is utilized in production of
combined heat and power which fulfils internal energy demands of the units or marketed, if in surplus (de Jong and Jungmeier, 2015). Not only separated woody and herbaceous biomass but mixed LCMW from olive pruning, tree and hedge-rows, roadside and riverside maintenance could be well utilized within the concept of biochemical Bio-Refinery.

5.4. Conclusion

A number of thermochemical and biochemical technologies are available for the conversion of biomass into energy and fuel. The suitability of biomass as feedstock for a conversion process depends upon its composition and heating or calorific value.

Figure 7: Relationship between typical capacity of conversion technologies and feedstock demand (©SYNCOM)

The secondary X-axis indicates examples of biomass potential of selected LCMW biomass from greenGain model regions, selected countries and cumulative EU-27 + Switzerland.¹

Source =BioBoost, 2016
LCMW biomass containing high lignin content and low ash is suitable for thermal technologies and biomass with high moisture content is suitable for biochemical technologies as well as for hydrothermal carbonization. Advanced technologies are very sensitive to feedstock variations in terms of composition, humidity, ash content etc. The availability of technology does not guarantee the efficient feasibility of the entire process chain as the economy of scale is also one of the deciding factors. The suitable energy recovery plants are typically sized large in order to achieve viable economic operation and for that vast quantities of feedstock need to be supplied regularly in order to keep the plant running (Figure 7).

The economics of many systems appear to assume that feedstock of a known quality and quantity will be steadily and readily supplied to the plant, which is not the case with LCMW biomass. Many technologies that have been commercially proven in a full-scale plant, or that have at least demonstrated their viability have limited scope for LCMW biomass with potentials < 1000 t/y and for those mostly small scale conversion plants are favorable for recovery of energy from LCMW biomass to match the availability. For example, the amount of whole woody LCMW biomass i.e. sum of CZ-LCMW1+ CZ-LCMW2 available from the Czech model region Kněžice is only suitable for private use or in small boilers with a rated capacity of about 10 KW, whereas the woody biomass from DE-LCMW1 Hedge-and tree rows on banks from Friesland might be a suitable feedstock for heat and power plants with >1 MW capacity. Similarly, the cumulative LCMW biomass from countries e.g. like Spain and Germany with suitable transportation infrastructure have a potential utilisation as feedstock in large decentral biomass conversion plants (Figure 7). In addition, all applications are strongly influenced by regulatory measures e.g. subsidy programmes (natural conservation obligations) for hedge- and tree rows, EEG incentives (Renewable Energy Sources Act) for power and heat etc. in Germany. Thus, biomass potentials, constraints such as biomass quantity and quality, frequency of supply, spatial distribution, economy of scale and existing regulations are some of the criteria that influence the selection of conversion routes for LCMW biomass.
6. Conversion pathways on local scale

Introduction

When aiming to utilize LCMW biomass as feedstock for an energy supply chain a number of technical, environmental, socio-economic and legal factors have to be taken into account. During task 4.2 key success criteria were identified to match the LCMW feedstock types with the suitable conversion technologies and define LCMW pathways. The key success criteria are the potential and availability of feedstock type, suitability for conversion technology, costs of the pathway, and the environmental and socio-economic performance. Based on these criteria the LCMW pathways were assessed and their performance evaluated at local scale.

The following section describes two potential conversion routes from biomass harvesting to the energetic consumption on the example of feedstock type DE-LCMW 1 Hedge- and tree rows on banks in Friesland (FRI), Germany and CZ-LCMW 4 (Grass-urban) and CZ-LCMW 5 (Grass-road) in Kněžice and Týn nad Vltavou of Czech Republic (Table 1).

6.1. Maintenance of hedge- and tree rows on banks in Friesland (Pathway 1)

Origin and properties of the feedstock

In the model region Friesland maintenance of hedge- and tree rows on banks was chosen to be the most promising feedstock for the energetic utilisation of LCMW biomass in the region. The county Friesland (FRI) is located in North-West of Germany 130 km west of Hamburg and belongs to the metropolitan region of Bremen and Oldenburg. It has a total area of 60,785 ha and counts 96,937 inhabitants.

The landscape is dominated by the „Marsch“ (alluvial land), followed by Geest (slightly raised landscape with sandy soil) and moor. The widely spread Hedge – and tree rows on banks, form a part of Friesland’s cultural landscape. Agriculture is the main economic sector in the region, followed by tourism. (For further details refer to the greenGain deliverable D5.1)

Hedge- and tree rows on banks are a mix of trees and shrubs standing on earthen mounds/banks, which where build in historical land use to fence agricultural fields. Over time the hedge- and tree rows lost their function and they are often not maintained anymore. Wrong maintenance caused damage and some are even now scarcely stocked. (For further details refer to the greenGain deliverable D5.1)

Today Hedge- and tree rows on banks are protected by the Federal Law of Nature protection which regulates their maintenance. For example cutting and felling procedures are only allowed from October to February and should not be done more frequently than every seven years.
Most of the hedge- and tree rows on banks are privately owned by farmers. The maintenance and conservation is supported with legal programmes. The owners may upon request receive financial support for the maintenance work and in turn make sure, that the typical character of the hedge- and tree rows on banks (from ecological to historical aspects) is preserved.

**Maintenance work steps**

Harvesting takes place manually and mechanically and is either done by the owner of the hedge- and tree rows on banks or by a service company. The felling is done with felling scissors (pinching) or a cutting aggregate on an excavator, larger dimensions and trees are cut by chainsaw. It occurs that the vegetation is damaged by pinching machines, they rather should be cut. For short storage trunks, branches and shrubs are sometimes bundled on roadside. Chipping is usually done on site and the chips are directly blown from the chipper on a tractor with trailer or a truck. Trucks or tractors with trailer are used for the transportation depending on the tonnage acceptable for the nearest road. If the biomass is not further utilised it is chipped and blown directly on site. If it is further used, the material is often dried as fuel wood or woodchips in open air or in sheds. Table 3 gives an overview of the single maintenance steps.

**Table 3: Single steps of the DE-LCMW 1 hedge and tree rows on banks**

<table>
<thead>
<tr>
<th>Process Step</th>
<th>Equipment/Operation</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvest: Felling/Cutting</td>
<td>Felling scissors (pinching) Cutting aggregate on excavator, larger dimensions and trees with chainsaw</td>
<td>Owner or company</td>
</tr>
<tr>
<td>Storage</td>
<td>Short storage and bundling on roadside</td>
<td>Owner or company</td>
</tr>
<tr>
<td>Chipping</td>
<td>Chipper mounted on trailer</td>
<td>Service company</td>
</tr>
<tr>
<td>Sieving</td>
<td>Sieving to remove the small size fraction which is not suitable for use in combustion</td>
<td>Service company</td>
</tr>
<tr>
<td>Loading:</td>
<td>Blow from chipper on tractor with trailer/truck</td>
<td>Service company</td>
</tr>
<tr>
<td>Transport</td>
<td>Trailer/truck</td>
<td>Service company</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>Sieving or drying</td>
<td>Service company</td>
</tr>
<tr>
<td>Storage</td>
<td>Chips piled under shed</td>
<td>Service company</td>
</tr>
<tr>
<td>Combustion</td>
<td>Sell to burn: Fuel wood or wood chips to produce energy; mainly in small stoves and domestic heat and small pellet boilers</td>
<td>Service company</td>
</tr>
<tr>
<td>Burning</td>
<td>Disposed of in traditional Easter Fires of the region (restricted in Friesland since 2014)</td>
<td>municipality or private</td>
</tr>
</tbody>
</table>
Availability, properties, potential and use of the feedstock type

Most of the hedge- and tree rows on banks in Friesland are privately owned. Thus, no exact figures are available on the frequency of the treatments because every owner organises the LCMW on his own, which determines the amount of the harvested biomass. The cutting and felling of hedge- and tree rows on banks is allowed only from October to February and should not be done more frequently than every seven years. In most cases the LCMW is done every 7-15 years.

The biomass feedstock derived from hedge- and tree rows mainly consists of woody biomass from tree trunks, branches and shrubs. If the biomass from LCMW of hedges and tree rows are utilized to produce energy, they are sold as fuel wood or wood chips to produce heat, mainly in small stoves and domestic heat and small pellet boilers. In the past the biomass from this LCMW 1 in FRI was often disposed of or burnt in traditional Easter Fires of the region, which are now being regulated since 2014.

In greenGain task 5.2 a biomass assessment in the model regions of the most promising utilisation LCMW pathways was conducted. According to D5.2 on resource and sustainability assessment and description of pilot experiences utilisation pathways for model regions (categorisation of resources, strategy, sustainability and utilisation pathway strategies) the location and total length of the hedge and tree rows on banks in Friesland was assessed by analysing GIS-shape files, PDF maps of the Lower Nature Protection Agency in FRI, Landscape structure plan county FRI and further literature sources (see section 4.1).

The total length of the hedge- and tree rows on banks in FRI are 490 km and according to the calculations of the conducted assessment for this LCMW biomass type in greenGain D5.2, a range for the theoretical biomass potential of 24-220 t/km was estimated. The ratios derived from light and/or shrub-dominated vegetation were removed from further consideration.

Under this consideration the ratio was narrowed down on a value of 40-220 t/km. The wide range of this ratio can be explained by the different types of sources (newspapers, scientific research, projects) used for the assessment. The moisture content (moisture in wet basis) at which the ratio is referred to is 30 – 45 %.

In the biomass assessment in D5.2 different aspects regarding the feasibility of the extraction for the DE-LCMW biomass from hedge- and tree rows on banks, the technical and economic implementation and sustainability constraints are taken into account. Thus the theoretical biomass potential was reduced by the assumed reduction coefficients. Resulting in a sustainable biomass potential of 1,840 to 10,100 t/yr (Table 4).
Table 4: Biomass potential of DE-LCMW 1 hedge and tree rows on banks in Friesland (FRI)

<table>
<thead>
<tr>
<th>DE-LCMW 1 Hedge and tree rows in FRI</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total length hedges and tree rows in FRI</td>
<td>490 km</td>
</tr>
<tr>
<td>Harvest</td>
<td>Every 7-15 years</td>
</tr>
<tr>
<td>Theoretical biomass potential</td>
<td>40-220 t/km</td>
</tr>
<tr>
<td>Moisture content</td>
<td>30 – 45 %</td>
</tr>
<tr>
<td>Sustainable biomass potential</td>
<td>1,840 to 10,100 t/yr</td>
</tr>
<tr>
<td>Amount of wood chips per harvest of 1 km hedge row</td>
<td>350 LCM^1</td>
</tr>
<tr>
<td>Amount of wood chips each cutting once in 11 years</td>
<td>171,500 LCM</td>
</tr>
<tr>
<td>Amount of wood chips per year</td>
<td>15,590 LCM</td>
</tr>
<tr>
<td>1 lcm = 370 kg (45% moisture content)</td>
<td>5768.3 t/yr</td>
</tr>
<tr>
<td>Caloric value</td>
<td>14,420.75 MWh</td>
</tr>
</tbody>
</table>

^1LCM = Loose cubic meter

The total length of the hedge- and tree rows on banks in FRI are 490 km which yields an average of 15,590 LCM wood chips per year when assuming an average of 350 LCM wood chips per harvest of 1 km hedge row and that in most cases the LCMW is done every 7-15 years (Görig et al., 2015). One loose cubic meter (LCM) corresponds to the amount of wood which is purred loose to the volume of a cubic meter. One LCM of fresh wood chips (45 % moisture content) weighs 370 kg and has a caloric value of 2.5 kWh/kg (Görig et al., 2015). This would mean that the average harvest of hedge- and tree rows on banks per year would have a caloric value of 14,420.75 MWh.

The average heat consumption of a household in Germany with four persons is 25,000 kWh per year which is equal to a consumption of 2500 l heating oil or 25 LCM of wood chips (Görig et al., 2015). The average harvest of 15,590 LCM wood chips from the hedge- and tree rows on banks in Friesland per year would be sufficient to supply the yearly heat amount of about 623 households of four persons and to replace 1.56 Million litre heating oil.

Suitability of biomass from hedge and tree rows on banks LCMW for conversion technology

The biomass from DE-LCMW 1 hedge- and tree rows on banks mostly consists of woody biomass from trees and shrubs and can be used as logs and chips. Usually, it is not compatible with pelletizing or fermentation process. As firewood it is an appropriate fuel for fireplaces in the domestic sector. For the most promising energetic utilisation pathway in greenGain the processing to wood chips and a further combustion via a Combined Heat and Power plant (CHP) is chosen and further assessed. Figure 8 shows the process steps from the wood chips to the heating system. The wood chips are transported with a tractor with trailer or a truck to an intermediate storage where they are dried under a shed. To remove the small particle fraction and achieve a certain size range the wood chips are sieved and then transported to small heating systems. Medium-central heating systems are able to process
wood chips in a heterogeneous quality therefore sieving is left out. Small heating systems are often applied in large households and farms. CHPs often supply central heating systems of public buildings and district heating networks.

![Diagram of process steps](image)

**Figure 8: Process steps of woodchips from DE-LCMW 1 Hedge and tree rows on banks to the heating system source: greenGain, D5.2**

**Technology type**
Combined heat and power (CHP) is a highly efficient process that captures and utilises the heat that is a by-product of the electricity generation process. By generating heat and power simultaneously, CHP can reduce carbon emissions by up to 30 % compared to the separate means of conventional generation via a boiler and power station (Government UK, 2016).

It is mostly waste or used wood that is burned in the energy supply companies' installations, which in many cases are set up to have electrical capacity levels between 10 and 20 MW. Conversely, in cities' and municipalities' installations are set up for a capacity of < 5 MWel in most cases. Mainly assortments of forest waste wood and also wood from landscape conservation areas in the region, as well as wood material from municipal properties is used. Via local and district heating networks, the biomass installations' heat is made available to manufacturing, trade and service companies, as well as to housing cooperatives, private households and public buildings (FNR, 2016).

**Fuel quality**
For the combustion system and for the plant economy the quality of the fuel plays an important role. The key parameters that need to be taken into account for the fuel quality are the moisture content, the dimension of the chips, fines and dust content, origin of the chips and the ash content. The wood chips from hedge and tree rows have a moisture content of 30 – 45 % and usually a high proportion of bark and needles or leaves.

**DE-LCMW 1 Hedge and tree rows on banks in FRI as feedstock for a LiPRO gasifier**
To be suitable as fuel for the LiPRO CHP 50 KW the woodchips from DE-LCMW 1 Hedge- and tree rows on banks would need to be sieved to G30-G50 and dried to a water content of 15 %. This drying process requires an additional transport, handling and processing step.
Drying is typically performed at biogas plants which have excess heat and the technical equipment for drying services. These woodchips would be suitable to fuel for example a LiPRO gasifier and yield 50 KW power and 110 kW heat (LiPRO, 2016). Typical data of the gasifier are provided in Table 5.

**Table 5: Technical Data of LiPRO CHP** source: *LiPRO Energy (2016)*

<table>
<thead>
<tr>
<th>Description</th>
<th>HKW 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Electrical Output</td>
<td>50 KW</td>
</tr>
<tr>
<td>Nominal Thermal Output</td>
<td>110 KW</td>
</tr>
<tr>
<td>Engine hours / Year</td>
<td>8,000 h</td>
</tr>
<tr>
<td>Electrical Output / Year (at 8000h/a)</td>
<td>400 MWh</td>
</tr>
<tr>
<td>Thermal Output / Year (at 8000h/a)</td>
<td>880 MWh</td>
</tr>
<tr>
<td>Fuel Quality (mm)</td>
<td>G30-G50</td>
</tr>
<tr>
<td>Water Content (%)</td>
<td>&lt;W15</td>
</tr>
<tr>
<td>Small Fraction (&lt;10 mm in %)</td>
<td>&lt;30 %</td>
</tr>
<tr>
<td>Fuel Consumption/h (wood chips)</td>
<td>50 kg/h</td>
</tr>
<tr>
<td>Fuel Consumption/a (wood chips)</td>
<td>400 t/a</td>
</tr>
<tr>
<td>Electrical Output Voltage</td>
<td>400 V</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Thermal Outlet Temperature</td>
<td>max. 90 °C</td>
</tr>
<tr>
<td>Thermal Inlet Temperature</td>
<td>max. 75 °C</td>
</tr>
</tbody>
</table>

The average harvest of 15,590 LCM wood chips from the hedge and tree rows in Friesland per year would be sufficient to supply the yearly fuel consumption of nine LiPRO CHP 50 KW gasifiers with a yearly fuel consumption of 400 t wood chips (W15). This would replace around 1,559,000 litre of heating oil and avoid the respective CO₂ emissions.

The LiPRO CHP is most suitable for heat and electricity consumers who need large amounts of heat and have access to inexpensive fuels from own and nearby land. Income can be generated by supplying electricity into the network and receive the compensation from the respective subsidy programme (EEG). Agricultural and forestry enterprises, industrial and commercial enterprises with high heat and power demand, hotel and restaurant enterprises, district heating grid operators to supply several buildings (residential, public buildings, sport and pool facilities) are especially suited for installation and operation. Figure 9 shows possible locations and applications of the LiPRO plants in Friesland.
Figure 9: Possible locations and applications for nine LiPRO CHP 50KW in Friesland fueled by wood chips from DE-LCMW 1 Hedge- and tree rows on banks in FRI as stand-alone feedstock

GHG-Mitigation

The yearly harvest of 15,590 LCM wood chips from hedge and tree rows on banks has a caloric value of 15,590,000 kWh which if burnt to heat would emit 155,900 kg CO₂. The same heat amount 15,590,000 kWh achieved when burning fossil fuel oil to heat emits 5,129,110 kg CO₂. Compared to heating with fossil fuel oil, a CO₂ saving of 4,973 t CO₂ can be achieved when heating with wood chips from LCMW (Carmen-ev, 2016).

According to the GEMIS model the Global Emissions Model for integrated Systems by the International Institute for Sustainability Analysis and Strategy the emissions factor are (IINAS, 2016):

0.010 kg CO₂-emissions factor per kWh heat from Biomass (wood, pellets, Wood chips)
0.329 kg CO₂-emissions factor per kWh heat from fuel oil (fossil)
0.250 kg CO₂-emissions factor per kWh heat from natural gas
(Messerschmid-Energiesysteme, 2016)
Costs
All costs of the supply chain like the maintenance work, the harvest and the further processing steps like transport, storage, sieving and drying need to be calculated carefully. Essential in the calculation of the price for wood chips from LCMW are the costs for the applied technical devices during harvest and chipping and the duration of the maintenance work. To keep the costs as low as possible often specialized service companies are hired for the maintenance work (Stockmann et al., 2012).

The costs for the maintenance of 1 km hedge and tree rows depend on many factors like the applied technical devices, experience of the service company and the width of the hedge and tree rows. The empirical value for the costs for the maintenance of 1 km hedge and tree rows lies at 6 - 7 €/LCM. Through the additional process steps sieving and drying cost of 4 – 8 €/LCM can be accounted (Stockmann et al., 2012).

<table>
<thead>
<tr>
<th>Hedge and tree rows maintenance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs for processing to wood chips</td>
<td>6-7 €/LCM</td>
</tr>
<tr>
<td>Sieving and drying</td>
<td>4 - 8 €/LCM</td>
</tr>
<tr>
<td>Total</td>
<td>10 -15 €/LCM</td>
</tr>
</tbody>
</table>

The price of wood chips from landscape and maintenance work of lower quality lies between 60 – 80 €/t_absolute dry. Higher quality wood chips from LCMW can have a price of up to 150 €/t_absolute dry and more (Stockmann et al., 2012).

6.2. Conclusions (Pathway 1)

The figures and observations obtained during task 4.2 suggest that LCMW biomass in the regions cannot constitute by itself a main biomass source for dedicated energy plants. It can, however, be integrated in existing biomass supply chains. Local actors like forestry companies and other specialised service providers are key stakeholders needed to facilitate the harvest and use of LCMW biomass.

LCMW biomass as stand alone feedstock is feasible on a small scale like the example of the LiPRO CHP 50 KW. An installed LiPRO plant is operating on an organic farm in Grummersort, Germany. Half of the annual feedstock amount comes from the farm’s own hedges and the other half from nearby forest residues with a radius of 5 km radius. In 2015, during 7000 CHP operating hours, 210,000 kWh_{el} were generated. About 90,000 kWh_{el} were used at the farm and the rest was sold to the grid. The 420,000 kWh_{th} were used at the farm for heating, hay drying and greenhouse operation. The plant is very positively perceived in the public. It is not that visible as wind turbines, it does not compete to the food production and it uses local resources, which have to be handled anyway and now they can be valorised.
6.3. Herbaceous biomass in biogas plants (Pathway 2)

Introduction

The number of biogas plants in Europe is growing, especially in eastern European countries e.g. Hungary, the Czech Republic, Slovakia and Poland where an increase of 18% was observed in 2013 (EBA, 2015). Special incentives are paid to encourage the biogas production due to which many farmers started to grow energy crops e.g. maize, for its profitability. But the increase in maize cultivation areas led to the shortening of crop rotation which in turn has an impact on landscape characteristics, species diversity and soil and water quality (Phelken et al., 2016). In addition, energy crops as feedstocks for anaerobic digestion are posing a competition with food production. According to 2014 EBA Biogas report, there are > 14500 anaerobic digestion plants in Europe and 80% are using agricultural feedstocks. Therefore, a focus is put on finding alternative biomass sources e.g. biomass resulted from the landscape maintenance and conservation work (LCMW) which is currently an underutilized energy resource. To facilitate the utilization of LCMW biomass, Germany amended its legal framework (EEG 2012) according to which the biomass from cultural landscape management excluding grass from roadsides, is no longer required for further processing and is recognized as a renewable resource. In the present project, biomass from LCMW in four countries and seven model regions has already been recognized as promising alternative feedstock for gaining energy. As a part of the project, respective sustainable potential of various LCMW biomasses was calculated after subtracting technical, economical, implementation and social constraints from theoretical potential (see D5.1 and D5.2 of greenGain). In general, three types of LCMW feedstock i.e. woody, herbaceous and a mix of both woody and herbaceous biomasses are available from the study regions. A promising pathway for conversion of woody biomass originated from the maintenance of hedge- and tree rows on banks in the model regions of Germany has already been discussed in section 6.1. In this section, a possible pathway - anaerobic digestion for the utilization of herbaceous biomass available from model regions of Czech Republic is discussed.

Territorial origin and type of biomass

In model regions Kněžice and Týn nad Vltavou of Czech Republic, biomass originated from the maintenance of urban areas and roadsides are of particular interest. This biomass is further divided according to its properties into woody and herbaceous biomass i.e. trees and grass. The grassy biomass available from urban and roadside maintenance of both Kněžice and Týn nad Vltavou is classified as CZ-LCMW 4 and CZ-LCMW 5, respectively (Table 1). Kněžice is a municipality with an area of 19 km² located in Nymburk District of Central Bohemia. The public green spaces in this region constitute an area of 12 ha from where the grass is obtained during landscape maintenance work (CZ-LCMW 4). Cleaning of roadsides
incorporates only 1% of municipality area and the total grass area is estimated to be 4 ha along 10 km stretch of roadways (CZ-LCMW 5).

Týn nad Vltavou is located in South Bohemia and has an area of 262.43 km². Urban spaces e.g. parks, stadiums, squares etc. in this region have a grass area of over 80 ha (CZ-LCMW 4), whereas grass from its roadsides is available from an area of 85 ha spread along 720 km long roads in the region (CZ-LCMW 5).

**Seasonality and potentials of CZ-LCMW 4 and CZ-LCMW 5**
The grass is cut in both regions from April to October. The number of treatments for landscape maintenance varies between localities. In small municipality like Kněžice, at an average 3 treatments are carried out annually for both CZ-LCMW 4 and CZ-LCMW 5 grass. Whereas, in the region of Týn nad Vltavou urban area grass CZ-LCMW 4 is treated 3-5 times and roadsides grass CZ-LCMW 5 is treated 2-3 times per year.

In Kněžice, the sustainable potential for CZ-LCMW 4 (Grass-urban) is 60-75% of 292-366 t/yr of theoretical potential and for CZ-LCMW 5 (Grass-road) sustainable potential is only 30% of 120 t/yr of theoretical potential (Table 1), which is mainly because of technical and economical limitations (see Deliverable 5.2 of greenGain for details). Similarly, a significantly reduced sustainable potential is observed for CZ-LCMW 4 and CZ-LCMW 5 grass from Týn nad Vltavou region. About 90% of grass from roadsides is left on the ground as mulch and in urban areas only 50% grass recovery is possible due to technical and economic reasons.

With the present sustainable potentials, a total of 255 t fresh matter/yr grass is available in Kněžice and a total of 812 to 2248 t fresh matter/yr grass is available in Týn nad Vltavou from LCMW activities.

**Anaerobic digestion: a promising pathway for the utilization of grass**
Thermochemical conversion technologies are suitable for dry biomass as feedstock whereas, for conversion of wet biomass at lower temperatures, biochemical conversion pathways are more efficient. Studies describing the use of plant biomass for anaerobic digestion are available in the literature (Weiland 2010). Principally, the biomass obtained from LCMW activities with the exception of woody biomass could be converted to biogas via anaerobic digestion. Grass can be co-digested with different agricultural feedstocks without the requirement of major process change. The energy from biogas is recoverable and used for producing heat, electricity or biofuels whereas, the digestate can be used as manure. Grassy biomass as a raw material for biogas production is also considered within the concept of Green-Biorefinery which is a promising future pathway for energy generation (Prochnow et al., 2009).

Herbaceous biomass from LCMW or other agricultural residues confirms substantially to the known anaerobic degradation scheme involving four process steps namely hydrolysis,
acidogenesis, acetogenesis and methanogenesis. The structurally poor carbohydrates e.g. glucose can easily be attacked by microorganisms and are rapidly degradable whereas, substrates having a high percentage of structural carbohydrates e.g. lignocellulosic biomass require longer digestion periods as hydrolysis is a rate limiting step. The main components of biogas are methane (CH₄, 60-70 %) and carbon dioxide (CO₂, 30-40 %). Variable amounts of water (H₂O), hydrogen sulphide (H₂S) and some traces of ammonia (NH₃), hydrogen (H₂), nitrogen (N₂), and carbon monoxide (CO) may be present in biogas depending upon the properties of feedstock. Dry matter (DM) content of the substrate plays an important role in biogas production and depending upon DM, the anaerobic digestion process is distinguished in two methods namely:

1. Wet fermentation: It is regarded as the technologically advanced method and based on the input of substrate with 15 % DM content in anaerobic digesters.
2. Dry fermentation: The dry fermentation is based on the input of substrate with DM content > 25 % in anaerobic digesters.

Drying of fresh biomass is not required for wet fermentation, thus energy could be well saved in the process.

**Biogas production potential from grass of CZ-LCMW 4 and CZ-LCMW 5**

Biogas yield depends upon substrate properties e.g. dry matter (DM), volatile solids (VS), handling and storage methods of the substrate as well as upon environmental conditions. Since the availability of grass from LCMW activities is of discontinuous nature, the ensilage of grass may be required to ensure continuous availability of substrate. Use of grass as co-substrate in biogas plants running with agricultural substrates is recommendable.

For correct estimations of biogas yields, biomethane potential (BMP) assays need to be carried out with the desired feedstock. In a study, the biogas production potential of non-dried grass originated from LCMW in Italy with DM content of 39.4 % to 46.8 % and VS content of 89 % to 92 % was reported to be in the range of 526 to 576 m³/t VS. For grass ensiled for 30 days, the biogas yield was in the range of 618 to 659 m³/t VS. The DM and VS percentage of ensilated grass were almost similar to non-ensilated grass (Mattioni et al., 2016). Somewhat similar value for average biogas yield of 560 m³/t VS was also reported by Kosse et al. (2015), whereas SEAL (2016) reported a little lower biogas yield from grass i.e. 450 m³/t, may be because of its lower DM content of 18 % with 90 % VS. Considering an average biogas yield of 551 m³/t VS from grass and an average biogas yield of 638.5 m³/t VS from ensilated grass with an average of 43 % DM content of which 90 % is volatile, the possible biogas yields from fresh and ensilated grass available from urban and roadside LCMW in model regions could be calculated (Table 7). Thus, a ton of grass (fresh matter)
from CZ-LCMW 4 + CZ-LCMW 5 has a potential to produce 213.2 m$^3$ biogas or 117.26 m$^3$ methane, assuming average methane content of biogas to be 55%.

**Table 7: Possible specific biogas yields from LCMW biomass of model regions in the Czech Republic**

<table>
<thead>
<tr>
<th>Region</th>
<th>Sustainable potential (FM/yr)</th>
<th>Dry matter (t/yr)</th>
<th>Volatile solids (t/yr)</th>
<th>Biogas yield-Grass (dam$^3$/yr)</th>
<th>Biogas yield-Grass Silage (dam$^3$/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kněžice</td>
<td>255</td>
<td>109.65</td>
<td>98.69</td>
<td>54.38</td>
<td>63.01</td>
</tr>
<tr>
<td>Týn nad Vltavou</td>
<td>812 to 2248</td>
<td>349.16 to 966.64</td>
<td>314.24 to 869.98</td>
<td>173.15 to 479.36</td>
<td>200.64 to 555.48</td>
</tr>
</tbody>
</table>

1 dam$^3$ = 1000 m$^3$

**Biogas production of grass from CZ-LCMW 4 and CZ-LCMW 5**

About 90% energy of the fermented substrate is converted to methane in the biogas which is produced during anaerobic digestion. The energy content of the biogas could be calculated with equation 1 (Winter and Gallert, 1999).

\[
\text{CH}_4 + 2 \text{CO}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} + \text{Heat Energy} \quad (\text{Eq. 1})
\]

\[\Delta G^\circ = -891.6 \text{ kJ mol}^{-1} \text{ CH}_4\]

1 mol CH$_4$ = 22.4 L @ STP
therefore,
1 m$^3$ CH$_4$ = 39.8 MJ Energy

Assuming methane share of biogas produced from grass is 55%, the potential energy yield of biogas gained after anaerobic digestion of grass or grass silage obtainable from CZ-LCMW 4 + CZ-LCMW 5 in both model regions could be calculated (Table 8).

**Table 8: Possible energy yields from LCMW biomass (sustainable potential) of model regions in the Czech Republic**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kněžice</td>
<td>29.91</td>
<td>34.66</td>
<td>1.19</td>
<td>1.38</td>
</tr>
<tr>
<td>Týn nad Vltavou</td>
<td>95.23 to 263.65</td>
<td>110.35 to 305.51</td>
<td>3.79 to 10.49</td>
<td>4.39 to 12.16</td>
</tr>
</tbody>
</table>

1 TJ = 10$^6$ MJ
However, the above energy values are subjected to deviation due to operational conditions and actual methane content of the produced biogas. Also, values are calculated at STP conditions and in praxis bioreactors operate at 37 °C which affects the gas volumes.

For energy recovery, methane is usually converted into heat energy via the boiler or into electric and heat energy via combined heat and power (CHP) plant. Most of the internal combustion engine generators have methane to electricity conversion efficiency between 25 to 40 % (Electrigaz, 2016). Considering, 1 kWh energy is equivalent to 3.6 MJ and average conversion efficiency of CHP is 33 % for electricity, 50 % for heat with 17 % loses, the electricity and heat generation from the sustainable potential of biomass CZ-LCMW 4 + CZ-LCMW 5 of the model regions can be calculated (Table 9).

### Table 9: Annual potential of energy and electricity generation from LCMW biomass in biogas-combined heat and power plant (CHP)

<table>
<thead>
<tr>
<th>Region</th>
<th>Potential energy-Grass (MWh)</th>
<th>Potential energy-Grass Silage (MWh)</th>
<th>CHP Electricity-Grass (MWh)</th>
<th>CHP Electricity-Grass Silage (MWh)</th>
<th>CHP Heat-Grass (MWh)</th>
<th>CHP Heat-Grass Silage (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kněžice</td>
<td>330.63</td>
<td>383.14</td>
<td>109.11</td>
<td>126.44</td>
<td>165.32</td>
<td>191.57</td>
</tr>
<tr>
<td>Týn nad Vltavou</td>
<td>1052.84 to 2914.76</td>
<td>1220 to 3377.63</td>
<td>347.44 to 961.87</td>
<td>402.61 to 1114.62</td>
<td>526.42 to 1457.38</td>
<td>610 to 1688.81</td>
</tr>
</tbody>
</table>

The average electricity consumption in the Czech Republic is estimated to be 3500 kWh/dwelling (Lapillonne et al., 2015). Thus, the energy generated from CZ-LCMW 4 + CZ-LCMW 5 biomass of respective model regions can fulfil electricity demand of up to 36 houses in Kněžice and 318 houses in Týn nad Vltavou (Table 10).

### Table 10: Fulfilment of electricity demand from LCMW biomass in model regions of Czech Republic

<table>
<thead>
<tr>
<th>Region</th>
<th>Electricity for households-Grass</th>
<th>Electricity for households-Grass Silage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kněžice</td>
<td>31</td>
<td>36</td>
</tr>
<tr>
<td>Týn nad Vltavou</td>
<td>99 to 275</td>
<td>115 to 318</td>
</tr>
</tbody>
</table>

### Process chain and logistics

The steps involved in production of biogas from grass include:

1. **Mowing:** It can be done with tractors mounted with different mowing units assembled according to the type of operation e.g. mowing of roadsides or of parks.
2. **Harvesting and collection of grass:** The mowed grass can be collected with field choppers, absorbed with exhauster fitted on the mower, trailer wagons or balers.
3. Cleaning of grass: This step is only required if grass contains impurities e.g. sand or plastic bags, bottles, metal cans etc. especially in urban areas. Sieves, hydraulic stirrers or gravitational separation are generally used.

4. Transport: After optional cleaning, the comminuted harvested grass may be first collected in a container or baled or could be directly transported with a tractor, trailer wagon or a truck.

5. Storage in silos (or direct use): If the grass is intended to be preserved for later use then it is compacted and stored in airtight silos otherwise there is a danger of spoiling. Ensiling also serves as bio-chemical pre-treatment.

6. Anaerobic digestion: Grass or grass silage is supplied to anaerobic reactor mostly as a co-substrate. For wet-fermentation, pumps are required to feed the slurry in reactors.

7. Supply to CHP: The biogas produced is supplied to biogas CHP for the recovery of heat and electricity.

Economical grass recovery technologies and logistics are main factors while deciding energy recovery from LCMW grass. The optimum logistic system depends upon the distance to anaerobic digestion plant as well as upon mowing and harvesting methods. Loose grass requires larger transport volumes than comminuted and baled grass. Further, drying of grass after cutting may reduce volume but that may lead to a reduction in energy value. The density of loose grass typically varies from 50 to 70 kg/m³ DM and when pressed in bales the density increases up to 100-150 kg/m³ DM. Taking average densities of loose and baled grass, volumes of loose or baled grass available from both model regions can be calculated (Table 11).

Table 11: Estimation of average grass volumes available from LCMW in both model regions of Czech Republic. Average treatments/yr = 3

<table>
<thead>
<tr>
<th>Region</th>
<th>Dry Matter (t/yr)</th>
<th>Volume of loose grass (m³/yr)</th>
<th>Volume of baled grass (m³/yr)</th>
<th>Volume of loose grass (m³/treatment)</th>
<th>Volume of baled grass (m³/treatment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kněžice</td>
<td>109.65</td>
<td>1827.50</td>
<td>877.20</td>
<td>609.17</td>
<td>292.40</td>
</tr>
<tr>
<td>Týn nad Vltavou</td>
<td>349.16 to 966.64</td>
<td>5819.33 to 16110.67</td>
<td>2793.28 to 7733.12</td>
<td>1939.78 to 5370.22</td>
<td>931.09 to 2577.71</td>
</tr>
</tbody>
</table>

Proximity of storage or digestion plant to the harvesting sites is a primary economic issue and operational costs increase linearly with the distance. Beside mowing and harvesting costs, the final economic impact of the baling needs to be considered before transportation. Boscaro et al. (2016) investigated three different logistic scenarios for transporting grass to anaerobic digestion plant located at a distance from 5 to 30 km. They reported that under economic aspects, direct transport of grass after harvesting was most convenient for short distances (< 5 km), for longer distances (30 km) an interrupted transport chain consisting of temporary storage was better while transport of grass in round bales was less advantageous than interrupted transport chain.
Suitability of anaerobic digestion pathway for CZ-LCMW 4 and CZ-LCMW 5 in the Czech model regions

Figure 10: Map of biogas plants in the Czech Republic on the website of Czech Biogas Association (CBA, 2016)

The municipality of Kněžice already has a biogas plant combined with heat and power unit that has an installed electric capacity of 330 kW. This plant has won the 2007 European Energy Award for the innovative use of biogas district heating which has significantly reduced carbon dioxide emissions and promoted economic development in the area. The plant uses manure, sewage, straw, and food waste as feedstocks originated from local farms, slaughter houses and households. The Grass-urban (CZ-LCMW 4) is already utilized in this biogas plant as co-substrate but the Grass-road (CZ-LCMW 5) is partially utilized and rest is left on the roadside. Lack of necessary equipment e.g. for chopping, cleaning, collection and transport of the grass is the main hindrance for the full utilization of LCMW grass despite the close vicinity to the anaerobic digester and reduced transport distances in the region.

Týn nad Vltavou has two biogas plants of the company BPS Jarošovice in the region (Figure 10). The first plant was built in 2010 and has an installed electric power and heat capacity of 1263 kW and 1242 kW, respectively. The second plant linked with a composting unit was built in 2013 and has an installed electric capacity of 550 kW and heat capacity of 569 kW (CBA, 2016). The plant is built to serve 2000 t/yr pig slurry, 4000 t/yr grass silage, 14,600 t/yr of corn silage and 3200 t/yr of process water (Envitec biogas, 2016). In spite of its relatively larger energy potential comparing to Kněžice (Table 8), grass generated from CZ-LCMW 4 and CZ-LCMW 5 in the region Týn nad Vltavou is not utilized as feedstock in biogas plants. At present, a composting plant Kompostarna Jarošovice acquires CZ-LCMW 4 grass @ 5 €/t for compost and in general CZ-LCMW 5 grass is underutilized. Because of the presence of biogas plants in the region, there is a feasibility of short distance transport of grass to plants with...
tract. In the Czech Republic, the approximate price of transportation per kilometre with a truck having a capacity of 90 m³ is about 30 CZK (CZ Biom, 2011) that corresponds to 1.11 €/km according to current exchange rates, however for short distances as in this case prices are variable and fixed by operators. In a life cycle assessment (LCA) study of residual grass, it was found that the conversion of residual grass to biogas was environmentally beneficial than using it for composting as biogas allowed an 80% reduction of the global warming potential compare to composting (GR3, 2016). The grass is commonly used as 10-20% co-substrate with slurry or other crop feedstock. The addition of grass may also help in to increase the DM content in digester if main feedstock has a low DM content. In the case of feedstock with high nitrogen content e.g. pig slurry or manure, co-feeding of grass helps in bringing down the nitrogen levels mitigating ammonia toxicity and possible upsetting of the reactor. Since the LCMW grass is seasonal and harvesting is in small batches, this biomass might be a suitable co-substrate without storage requirement. However, some problems may arise while using grass in digesters which includes increased energy requirements for mixing grass with slurry if grass tends to float on the surface, impure grass needs cleaning to avoid abrasion as well as wrapping of long grass around moving devices may lead to dysfunction. Therefore, for wet digestion, usage of grass only as co-substrate is recommended. Besides technical issues, there is insufficient awareness among the stakeholders in the region regarding the LCMW grass to biogas value chain. The economic feasibility of digesting LCMW grass can be increased if the digestate is sold as manure especially for organic farming. An estimation of energy balance by determining annual net energy gain (NEG) and the energy return on energy invested (EROEI) can favour the recovery of untapped LCMW grass in Týn nad Vltavou as feedstock for biogas production.

6.4. Conclusion (Pathway 2)

The potential energy yield per annum via anaerobic digestion of Grass-urban (CZ-LCMW 4) and Grass-road (CZ-LCMW 5) is up to 383.14 MWh in Kněžice and 1220 to 3377.63 MWh in Týn nad Vltavou. This could meet electricity demand of 36 houses in Kněžice and 115 to 318 in Týn nad Vltavou beside supplying heat. Economical grass recovery technologies and logistics are the factors to be considered for energy recovery from LCMW grass. The optimum logistic system depends upon the distance to anaerobic digestion plant as well as upon harvesting methods. The municipality of Kněžice has a biogas plant combined with heat and power with an installed electric capacity of 330 KW, where Grass-urban is successfully utilized as co-substrate. Due to lack of transportation facilities, Grass-urban is mostly left on roads which may be utilized for energy recovery, a) if transportation could be improved and b) if Czech regulatory framework is favourable for use of roadside grass for energy production. The energy potential of LCMW grass in Týn nad Vltavou is untapped despite the presence of two biogas plants in the region which also utilize grass silage as co-
feedstock. Anaerobic digestion has clear advantages in term of energy production and reduction of greenhouse gas emissions by over 80% as compared to composting of grass, further digested sludge can be used as manure and thus, it is recommended pathway for LCMW grass generated in both model regions of Czech Republic.
7. Lignocellulosic biofuel pathways on national and European scale

Introduction

The main question addressed here is:
Are there economic viable and environmental sustainable LCMW biomass value chain(s) for biofuel production?

Beside the widely implemented biodiesel (fatty acid methyl ester) and ethanol (starch or sugar fermentation) biofuels, some processes emerged or are under development, which are not based on food commodities. These are:

- Hydro-treated esters and fatty acids (HEFA). Neste pioneered this process and produces a significant share of its 1 million tonnes per year NEXBTL with fatty residues and wastes (flotate sludge and used cooking oil). LCMW biomass is not a suitable feedstock for this process.

- Tall oil biodiesel. The wood used for pulp production contains pitch and fatty acids which can be skimmed as tall oil (~2% of wood amount) from the black liquor and hydro-treated to transport fuels. UPM and SunPine operate the process on a scale of about 100,000 t/a each. The woody part of LCMW biomass would be suitable as feedstock if processed in a pulp mill, which is typically not feasible for technical and economic reasons.

- Lignocellulosic ethanol. Lignocellulosic biomass like straw is digested by thermochemical or enzymatic means to make the cellulose and hemicellulose accessible for enzymatic breakdown to sugars and subsequent fermentation to ethanol. One of the pioneers is Beta Renewables with a production of 75,000 m³ ethanol per year in its Crescentino plant. The grassy and herbaceous part of LCMW would be a suitable feedstock if dried and large square-baled. This is typically not feasible for technical and economic reasons.

- Natural gas (methane, CH₄) from anaerobic fermentation. Under the absence of oxygen, biomass can be fermented by anaerobic microorganisms, which give rise to 'biogas' that typically consists of CH₄ (50-75%), CO₂ (25-50%) and traces of gases like H₂S, NH₃. After purification from CO₂ and trace gases the methane can be compressed and fuelled to natural gas vehicles. Wet lignocellulosic grassy or herbaceous biomass as in LCMW can be used as feedstock in dedicated plants but does not reach the high space velocity of the typical feedstock richer in starch, sugar or fat.

- Thermochemical biomass gasification for Fischer-Tropsch synthesis, Methanol-to-Gasoline fuels or methane. Biomass is gasified with oxygen or steam at 850 to 1200 °C to a mixture of H₂, CO, CO₂ and methane. After gas cleaning and CO₂ separation, the synthesis gas reacts to paraffin, methanol, dimethyl ether (DME) or...
methane, depending on the catalyst used. In the EC-FP7 project BioDME4 Chemrec constructed a demo-plant for black liquor entrained-flow gasification at the Smurfit Kappa pulp mill in Piteå, Sweden with a DME capacity of 4 tonnes per day. Further commercialisation of the technology e.g. at the Domsjö plant was stopped for economic reasons. The BtL-pioneer CHOREN constructed a 45 MWth demo plant in Freiberg, Germany, for entrained-flow gasification of wood to FT-fuel (a paraffinic drop-in diesel fuel, 45 tonnes per day). It went into receivership in the commissioning phase. A consortium with the TU Wien and the Biomassekraftwerk Güssing, Austria, developed a wood fueled gasification plant for heat and power production and trialled several synfuel applications to go for tri-generation. On base of this Göteborg Energi, Sweden, started the GoBiGas demo-plant project for conversion of forest residues to synthetic natural gas at a rated capacity of 20 MW. The plant went in operation in December 2014 and the technology shall be further commercialised to a gas production of 80 to 100 MW on site. Woody LCMW biomass would be a suitable feedstock for thermochemical gasification processes. However, currently these are in operation only at demo-scale.

- Biomass pyrolysis and upgrading to transport fuels. An alternative to gasification is pyrolysis, a thermal biomass degradation at 400 to 600 °C under absence of oxygen. In fast pyrolysis processes, the feedstock is rapidly heated and the emerging vapours are cooled within seconds. Condensation yields a high share of liquid products, which are rich in oxygen and highly reactive. The oil is highly corrosive and tends to polymerize, which prevents its use as diesel- or fuel oil-substitute in standard applications. The Canadian Ensyn runs its RTP-technology on a scale of 100 tonnes wood per day mainly for chemicals and food flavours. BTG commissioned the Empyro-plant in Hengelo, The Netherlands, for generation of heat, power and biooil. The latter is used as fuel for a dedicated boiler in a plant for dairy products substituting a gas-fired boiler. Hydrotreatment is an option to improve the fuel quality by reduction of the oxygen content. This is expensive due to H2 production costs and the high share (40 – 50 %) of oxygen in the pyrolysis oil. An alternative is the catalytic cleavage of oxygen as CO2 or water in the pyrolysis reactor. The US based pioneer KiOR upscaled a process similar to FCC (fluidized catalytic cracking) which is applied for upgrading of heavy oils to gasoline. However, the company went into receivership due to technical problems in their commercial plant. The similar CatOil-process was studied in the EU-FP7-project BioBoost by CERTH, Grace, DSM and Neste. Biomass was converted with FCC-catalysts from Grace in the pilot plant of CERTH to a biooil with an oxygen content between 10 to 15 %. Separation of small acids and phenols by DSM further decreased the hydrogen demand for upgrading to transport fuel. With forest
residues as feedstock the costs for production of transport fuel were calculated to be around 1.15 EUR/l in promising regions. This pathway would be compatible for woody LCMW biomass as feedstock. Several initiatives and ventures try to further develop and commercialise this technology in Europe and abroad. As CatOil combines regional pre-treatment by catalytic pyrolysis to an energy intermediate with upgrading to a drop-in biofuel in central, existing oil refineries, it fits well to the scattered occurrence of biomass (especially from LCMW) in combination to a clever use of existing infrastructure and the scale-of-unit-effect to keep production costs relatively low. This is why it will be studied in the following section for LCMW biomass as feedstock of biofuel production.

The process chain is split into the production of an intermediate bioenergy carrier produced in a region with good feedstock supply. Several of such plants supply a high energy density, liquid energy carrier to an existing fuel refinery for further processing to a drop-in biofuel compatible with the existing market. According to the production slate of the refinery, this includes diesel, kerosene or gasoline. In the regions a rather small to medium scale pre-treatment plant will be build producing an intermediate energy carrier which can be easily transported to new or existing fuel production facilities. This approach is generally referred to as the decentral approach in contrast to the central approach where large amounts of feedstock need to transported to one central place for conversion to fuel. It is well known that technologies used are expensive and need high efforts. Therefore, the economy of scale plays a dominant role in these applications. For the purpose of this investigation the pathway is studied on economic and logistic properties, including fuel production cost and added value for the regions involved. The geographic scope chosen was Germany. There were two reasons for choosing Germany as the study area: First, NUTS-3 in Germany are relatively small in scale with more than 1000 NUTS-3 regions. Second, the physical and chemical properties of LCMW biomass from the maintenance of hedge- and tree rows on banks in Friesland and from fruit prunings are similar to forestry residues and thus suitable for catalytic pyrolysis.
7.1. The pathway descriptions

Wood chips - catalytic fast pyrolysis - transportation fuels
This pathway is based on CatOil-technology developed by CERTH (Centre for Research and Technology Hellas), Royal DSM and Neste. Detailed information is available under (BioBoost, 2013): http://www.bioboost.eu/results/public_results.php

Feedstock 1: Forest residues (CatOil reference feedstock)
Forest residues are co-products of forest cultivation and wood harvest: Thinning wood occurs as whole tree or delimbed stems in the thinning of young stands. Final felling yields logs for the production of timber, wood pulp or boards; co-products are tree-tops, branches and off-spec logs (bent or rotten), which may be used for energy generation. In some countries stump excavation is allowed to prepare the ground for tree planting. Depending on the site conditions, soil fertility and eventual ash return a certain share of forest residues can be taken from the forest without threatening its productivity. This sustainable amount is collected and stored at the forest road for chipping into trucks or transport in whole for chipping at the plant. Depending on site and duration of storage, the water content of forestry residues is between 30 and 50 %. In 2015, the maximum allowable weight of forest trucks was between 40 and 76 tonnes in European countries. Optional feedstocks are other wood commodities (timber processing residues, waste wood and short rotation coppice) and other ligno-cellulosic residues.

Feedstock 2: Wood chips from hedge- tree row maintenance
The main difference between the feedstocks forest residues and hedge- and tree rows on banks is that forest residues are mainly from evergreen softwood (spruce, fir, pine) while chips from hedge- and tree rows on banks are mostly from deciduous trees and bushes. Similar to forest residues the chip quality depends on the diameter of the input material, this commands for sieving, if high quality chips are required. Chipping is either on site or after transport to a yard.

Feedstock 3: Prunings
Prunings from fruit or nut orchards and vineyards are characterised by a high share of thin material, with higher ash content compared to forest residues. Different procurement technologies exist, some of which use baling. Bales can be stacked for air-drying, which reduces feedstock degradation compared to chipping and storage of fresh material. On the other side, chipping of dry baled biomass is difficult and the bale dimension (typically 120x125 cm) requires XL-chippers or crushers. Prunings are not the preferred feedstock biomass in the scope of greenGain, however the diffinitions are not always clearly defined between agricultural residues and biomass from landscape management as in the examples of maintenance work of abandoned olive groves.
and the restoration of abandoned agricultural land. As qualified feedstock potential data of these biomass types is not available for the further analysis with the BioBoost optimization tool, the pruning data from Europruning project with similar density and potential has been used. The pruning potential data is available for all EU 27 member states + Switzerland on NUTS-3 level and can be considered as having similar feedstock properties as biomass feedstock from e.g. the maintenance work of abandoned olive groves and the restoration of abandoned agricultural land.

First conversion step: Catalytic fast pyrolysis
The catalytic fast pyrolysis (CFP) starts with the drying and milling of forestry residues (e.g. thinning wood, tree-tops, branches). The biomass is pyrolysed at about 500 °C in absence of oxygen in contact to a catalytic material. The catalyst splits off a high share of the oxygen which is contained in the biomass molecules (about 45 % by weight) as carbon dioxide, carbon monoxide or water. The pyrolysis vapours are rapidly cooled. The condensed biooil contains 50 % of the liquid biomass energy, is low in oxygen content (15 to 20 %) and has a heating value of about 30 GJ/t. CFP off-gases and the catalyst coke are combusted to supply the reaction heat for pyrolysis and produce power (0.83 MWh per tonne of biooil). Another co-product is crude acetic acid of which about 50 kg are produced per tonne of energy carrier. The decentralised CFP plants are erected in areas of high feedstock availability: They are expected to have a capacity of 160,000 to 520,000 tonnes forest residues per year which relates to 28 to 92 truck loads per day. In regions of good availability, transport distances would be between 60 and 120 km. Straw, lignocellulosic energy crops (e.g. Miscanthus, Switchgrass) or waste wood are alternative feedstocks for this process. Use of these biomasses as co-feedstock would shorten the average transport distance. The decentral CFP plant produces between 45,000 and 147,000 tonnes biooil per year.

Biooil energy carrier transport
With regard to transportability, a truck load of 25 tonnes forest residue chips (14 to 17 tonnes wood dry matter, the rest is water) is converted to 4 to 5 m³ of a pumpable energy carrier. A freight train of 40 railway tank wagons with a payload of 65 tonnes each could transport the energy carrier produced from 570 truck loads forest residues. This is a very cost- and environmental efficient transport mean to bring the bioenergy from several rural areas to a central refinery for upgrading by co-processing with crude oil. The energy carrier is moderately corrosive and compatible to standard crude oil transport and storage vessels.

Upgrading to transportation fuels
The good transportability of the energy carrier enables long distance railway transport for upgrading in refineries with capacities between 200,000 and 850,000 tonnes of biooil in European countries. The energy carrier is stabilized in two hydrotreatment steps consuming about 70 kg hydrogen per tonne of transport fuel. One co-product is light gases (180 kg per...
tonne fuel) another might be phenol(-ics) which have a higher market value for the chemical industry than for biofuel production. Due to changes in the European refining sector, it is expected that the CP biooil may replace 2% of fossil crude. This enables use of existing capacity for steam methane reforming and hydrotreatment for the deoxygenation of the biooil. The product is co-processed with the fossil streams and distilled to the conventional transportation fuels gasoline/kerosene/diesel according to the production slate of the refinery. All fuels purely consist of hydrocarbons which guarantee drop-in blending. The fuels are fully engine compatible and do not require changes in the distribution infrastructure, two points very important for consumer acceptance. The fuels have a GHG-avoidance potential of 81% compared to fossil fuels.

The Figure 11 and Figure 12 show the catalytic fast pyrolysis reference pathway in terms of energy flows (Sankey-diagram) and logistic flows; its steps were translated to the greenGain biomass value chain format in the following Table 12.

Figure 11: Sankey-diagram on energy flows of a design-size (100 MW) catalytic fast pyrolysis plant and respective upgrading capacity in a refinery (67.7 MW instead of design size 260 MW).

Numbers indicate the energy flow in MW. Transport efforts are given for reference case. Colour code: Green-biomass; blue-FP-biosyncrude; red-transport fuel; orange-power, pink-natural/combustible gas, grey-process steps (from left to right): forest residue piling, forest residue chipping, feedstock pyrolysis, biooil upgrading. (S. Kühner, SYNCOM)
**Figure 12:** The description of a biomass value chain (reference pathway) for catalytic fast pyrolysis in the BioBoost-project (S. Rotter, FHOÖ).
Table 12: The biomass value chain of catalytic fast pyrolysis; shaded in green is an optional intermediate storage in a biomass centre.

<table>
<thead>
<tr>
<th>What?</th>
<th>How?</th>
<th>Where?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Starts with:</strong> Thinning wood or logging residues in forest, hedge row management or fruit prunings</td>
<td><strong>Forest residue forwarding</strong></td>
<td>Forwarder</td>
</tr>
<tr>
<td><strong>Storage logging residues</strong></td>
<td>Pile un/covered</td>
<td>At roadside landing</td>
</tr>
<tr>
<td><strong>Chipping</strong></td>
<td>Truck-mounted chipper</td>
<td>At roadside landing</td>
</tr>
<tr>
<td><strong>Transportation</strong></td>
<td>Hook-lift containers, truck</td>
<td>From roadside landing to intermediate depot</td>
</tr>
<tr>
<td><strong>Handling - unloading</strong></td>
<td>Tipping</td>
<td>At intermediate depot</td>
</tr>
<tr>
<td><strong>Handling</strong></td>
<td>Telescopic handler</td>
<td>At intermediate depot</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td>Covered in warehouse</td>
<td>At intermediate depot</td>
</tr>
<tr>
<td><strong>Handling - loading</strong></td>
<td>Telescopic handler</td>
<td>At intermediate depot</td>
</tr>
<tr>
<td><strong>Transportation</strong></td>
<td>Truck and drawbar trailer</td>
<td>From intermediate depot to decentral conversion plant</td>
</tr>
<tr>
<td><strong>Handling</strong></td>
<td>Tipping</td>
<td>At decentral conversion plant</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td>Covered in warehouse</td>
<td>At decentral conversion plant</td>
</tr>
<tr>
<td><strong>Handling</strong></td>
<td>Telescopic handler and Screw conveyor</td>
<td>At decentral conversion plant</td>
</tr>
<tr>
<td><strong>Decentral conversion process</strong></td>
<td>Catalytic fast pyrolysis</td>
<td>At decentral conversion plant</td>
</tr>
<tr>
<td><strong>Handling - loading</strong></td>
<td>Pumping</td>
<td>At decentral conversion plant</td>
</tr>
<tr>
<td><strong>Transport pyrolysis oil</strong></td>
<td>Tank wagon (railway transportation)</td>
<td>From decentral conversion plant to central conversion plant</td>
</tr>
<tr>
<td><strong>Handling - unloading</strong></td>
<td>Pumping</td>
<td>At central conversion plant</td>
</tr>
<tr>
<td><strong>Central conversion process</strong></td>
<td>Deoxygenation/transport fuel</td>
<td>At central conversion plant</td>
</tr>
</tbody>
</table>

This procurement chain is compatible to forest residues from thinning and logging as well as for woody biomass from land management, roadside cleaning and in a first approach also to fruit prunings.

7.2. Results of cost optimization

The Figure 13 shows the pruning potential per NUTS-3 in Germany originating from the EU-FP7-project EuroPruning supplied by CIRCE. In the case of Germany it shows considerable potentials e.g. 12,000 t/a of fruit prunings in a small area in the North (Stade, Hamburg) known as the “Altes Land” a centre of apple and cherry production and in larger areas in the South-West of Germany, which consist among others of the wine areas Baden and Pfalz. In all grey and dark blue areas the potentials are negligible.
Figure 13: Pruning potentials in Germany. Grey, blue: negligible; light blue >1000 t/a; green: 10,000 t/a; red (maximum): 14,260 t/a

Regarding the amount of prunings per hectare of land surface shown in the Figure 14, high densities are observed in the broad wine producing areas as e.g. the Weinstrasse (wine street) in Rhineland-Palatinate with 200 to over 300 kg/ha*a. For comparison, the fruit production area ‘Altes Land’, which covers a part of the Kreis Stade, achieves only about 75 kg/ha*a after normalisation over the whole area of the NUTS-3.
Figure 14: Pruning density expressed as tonnes per hectare surface area and year. Dark blue: less than 10 kg/ha*a; green: 100 to 250 kg/ha*a; red: 324 kg/ha*a (maximum, Landau/Pfalz)

The model optimizing biofuel production via the catalytic pyrolysis pathway has been described in detail in the BioBoost project (www.bioboost.eu). The basic principle is a profit*amount-maximisation oriented approach of producing biofuel from biomass available in the NUTS-3 regions. The model optimizes the cost and fuel amounts with regard to the biomass sourcing, the logistics, the plant locations and their capacity.

The Figure 15 shows the optimization result for biofuel production from prunings in Germany. The highlighted areas are the regions from where the model sources biomass and shows the utilisation ratio, which is nearly 100 % in these regions although cost per tonne of the feedstock increase to 200 % for 100 % utilization compared to lower costs for sourcing ratios below 50 % due to less competition. Due to the limited total amount (~270,000 t/a) and the low density of feedstock available, the cost optimum is one medium-sized catalytic pyrolysis plant for Germany located in Frankfurt. It sources about 250,000 t prunings (90 %...
of total potential) from all over Germany. On first glance this is surprising, because the long-distance feedstock transport from Hamburg or Saxony must be expensive. However, the potentials in these areas amount to several 100 tonnes per year, and the sourcing which has only a negligible impact on the total production cost and amount. However, shipping of 10,000 t/a over 500 km from Stade to Frankfurt makes a difference, which is why the algorithm eliminated this option.

Figure 15: Sourcing ratio of pruning as feedstock. Shading: orange – 100 %; blue arrow – feedstock transport to CP; red arrow – CP oil transport to refinery for upgrading to transport fuel
The cost distribution of this optimization is displayed in Figure 16.

![Figure 16: Cost composition of biofuel production with prunings in Germany. The total amount is 43,000 tonnes per year at a price of 2310 EUR/t transport fuel](image)

The bars show the different components attributing to the costs of 2310 € per tonne of fuel. These production costs correspond to 1.73 €/l fuel from prunings without taxes and profit, whereas the cost of fuel produced from forest residues are in the order of 1.20 €/l.

The main reasons are the low density and wide distribution, the logistic cost related to the transport of the pruning feedstock to a pretreatment plant. For the production of one tonne of transport fuel 7.25 tonnes of wood chips (40% water content) are required, therefore transportation cost of low density pruning feedstock is very high (334 EUR/t fuel compared to 126 EUR/t with forest residues). Also the cost of the feedstock at source increases strongly as the model sources as much as possible – in general 100% – which doubles the feedstock cost (673 EUR/t fuel at pruning, 290 EUR/t at forest residues). In both situations the economy of scale of the decentralized conversion is stronger than the increase in the supply cost which leads to only one pruning-CP-plant built for whole Germany. Upgrading of the catalytic pyrolysis oil would yield 43,000 t transport fuel per year from prunings as feedstock. With forest residues as feedstock 11.8 million t/a (64% of total technical potential), 21 catalytic pyrolysis plants would be fuelled in Germany depicted in Figure 17, each plant with an average capacity of 70,000 t/a CP-oil; leading to an overall transport fuel production of over 1 million tonnes per year after upgrading in the 6 refineries.
Figure 17: Forest residue potentials in Germany and transport to catalytic fast pyrolysis plants

Figure 18 presents the results for the average, the most expensive, the least expensive and the case of the largest capacity and smallest capacity of the EU-28 optimisation run with forest residues as feedstock.
Figure 18: Cost composition of biofuel production with forest residues in Germany at NUTS-3. The total transport fuel production amount (blue dark bars below cost composition bars) is displayed on the top axis, the costs on the bottom axis. FR= Forestry Residues

The Figure 18 shows the relationship between the production capacity of the plant and the cost of biofuel production for forestry residues. As can been seen from the figure the plant with the largest production capacity in DE401 (NUTS-3) region has the cheapest production costs and vice versa in the region DEA23 indicating in this case that the production costs are influenced by the plant capacity. The average production costs for the forestry residues come out to be 1606 EUR/t.

The use of road-side LCMW biomass, a feedstock with low geographical density but twice the total amounts as feedstock compared to prunings for transport fuel production would result in production cost of 2301 EUR per tonne of fuel. This is 9 EUR/t less than for prunings but a considerably more than the 1606 EUR/t average production costs with forest residues. Taking combined woody biomass generated from forest residues, pruning and roadside LCMW, the production costs amounts to 1588 EUR/t, a drop of 18 EUR/t is due to slightly lower costs for feedstock purchase and logistics. The total amount of transport fuel remains unchanged, because the CP-oil upgrading in the existing refinery capacity is limited. Larger amounts would require construction of dedicated units, which would somewhat increase production costs.

This is also reflected in the average transportation distance of feedstock to the pre-treatment plant which is 229 km for road-side LCMW biomass, 192 km in the case of pruning and 65 km in the case of forest residues.

This result has been achieved with keeping cost for purchase and transport per tonne of forest residues, LCMW biomass and pruning feedstock at the same level.
7.3. Results of pruning as feedstock for biofuel production on European scale

The main question investigated on European level was:
Can LCMW biomass from fruit, wine and olive pruning make a substantial contribution to the economic production of biofuels on European scale?

To investigate this issue the cost optimization model described in the previous section for Germany has been fed with the EU-28 feedstock potential data on the resolution level NUTS-3. Potentials originate from the EuroPruning project and were supplied by CIRCE\(^5\). All parameters for the feedstock (price, transport and conversion) have been assumed to be identical to those of forestry residues. This allows investigation of those supply chain parameters, which depend on the feedstock density. The overall technical available potentials of fruit pruning are compared to forestry residue potentials in the following table for EU-28, Germany and Spain.

<table>
<thead>
<tr>
<th>Feedstock type</th>
<th>EU-28</th>
<th>Germany</th>
<th>Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Technical potential [t/a]</td>
<td>Relative amount [t/km(^2)]</td>
<td>Technical potential [t/a]</td>
</tr>
<tr>
<td>Hedge- and tree row-, roadside-</td>
<td>3,169,000</td>
<td>0.73</td>
<td>545,223</td>
</tr>
<tr>
<td>LCMW biomass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prunings</td>
<td>15,370,000</td>
<td>3.5</td>
<td>267,487</td>
</tr>
<tr>
<td>Forestry residues</td>
<td>117,893,000</td>
<td>27</td>
<td>18,489,000</td>
</tr>
</tbody>
</table>

As can be seen in Table 13 above there is an increase of about one order of magnitude each between hedge- and tree rows and roadside LCMW biomass potentials, prunings and forest residues on the level of total potentials for EU 28. However, on a regional scale there are strong deviations from the European pattern, depending on the degree of land use for forestry, orchard and wine yards and the road network. In the Figure 19 the pruning potentials are shown. It is obvious that Spain, Italy and Greece have substantial potentials in the order of several 100,000 t/a in certain NUTS-3 regions whereas the potentials in Germany are relatively small.

\(^5\) www.europruning.eu
These potentials have been used to optimize biofuel production using the catalytic pyrolysis pathway as one example.

From the total pruning potential the model identifies the most effective sites and sizes for biomass conversion to catalytic pyrolysis oil with respective feedstock supply regions and degree of sourcing. The Figure 20 shows the feedstock cost in the supplying regions. Feedstock in southern Spain where the total potentials are high is sourced at around 50 % of the available potential with cost of about 70 €/t, whereas the feedstock cost in regions with less potential are around 100 €/t or even higher. This is due to a trade-off between plant capacity and feedstock costs. The conversion costs per unit decrease with increasing production capacity of a plant (scale-of-unit law). On the other side the feedstock price rises with increasing competition (at 100 % sourcing to more than twice the price at 50 % sourcing). A second trade-off exist between feedstock price increase due to higher
competition in a region and lower purchase price but higher transport costs due to procurement in neighbouring regions. Overall, the general trend is towards large plants.

**Figure 20:** Regions from which feedstock is sourced and respective procurement costs in the run of the optimisation model. Dark green - 50 EUR/t (minimum); yellow – 100 EUR/t; orange – 140 EUR/t (maximum)

The Figure 21 shows the best solution of this optimization. The blue arrows mark the feedstock transport from the sourcing regions to CP plants. The red arrows indicate the supply of CP-oil by train to existing mineral oil refineries for upgrading to transport fuel in the highlighted regions. The model optimizes cost*amount of produced transportation fuel by identifying best location and capacities of CP plants to deliver biocrude to existing oil refineries who have a spare capacity of 10 % of hydrogen production, and co-process the CP-oil. The number of feedstock-supplying regions depends on the available feedstock amount and supply costs and the CP-plant capacity. Similarly, smaller refineries (100 - 200 kt/a CP-transport fuel production capacity) are supplied by one or two CP-plants, the largest refinery in Rotterdam, The Netherlands (500 kt/a) is supplied by nine CP-plants from all over Europe. The four Spanish refineries are close to their maximum upgrading capacity and two Spanish CP-plants supply the Normandy-refinery in France. The two large Italian refineries are located on Sicily and Sardinia. However, ship transport is not implemented in the optimisation model and thus, the Italian CP-oil is upgraded in Karlsruhe (Germany) and Rotterdam. The only refinery in south-east Europe in Burgas (Bulgaria) is a 100 % of its upgrading capacity with supply from a Greek and a Romanian CP-plant. The other five CP-plants ship their products to Vienna (Austria), Ingolstadt (Germany) and Rotterdam. Several
other refineries located in Belgium, France, Germany, Poland, Lithuania, Finland, Sweden and the United Kingdom are not supplied.

Figure 21: Supply of prunings to CP-plants (blue arrow) and transport of CP-oil to refineries (red arrows) for upgrading to transport fuel at the given total production costs per tonne of fuel (yellow – 1900 EUR/t, minimum; orange – 2238 EUR/t, maximum)

The first plants for pruning-based production of CP-oil for upgrading to transport fuel would be situated at the best sites, which are in Spain. The Figure 22 shows that CP-plants are situated in regions with high pruning potential and are able to source feedstock in relative low distance at ratios of 50 to 65 % avoiding high purchase costs due to competition. This leads to total transport fuel production costs of 1633 EUR/t at the Gibraltar refinery and 1726 EUR/t at the Cartagena refinery, see Figure 22.
Figure 22: Total pruning potential and logistic network of first, most cost effective CP-plants and refineries for upgrading to transport fuel

Total production costs per tonne of transport fuel would be 1633 EUR/t at the Gibraltar refinery and 1726 EUR/t at the Cartagena refinery. Blue arrows: Transport of prunings to CP-plants; Red arrows: transport of CP-oil to refineries for upgrading; Shadings indicate the pruning potential: Blue - less than 10,000 t/a; green: 180,000 t/a; orange – 338,000 t/a (maximum).
Figure 23 presents the results for the average, the most expensive, the least expensive and the case of the largest capacity and smallest capacity of the EU-28 optimisation run with prunings. The most expensive (DE211 Ingolstadt) and the cheapest plant (ES612 Gibraltar) have a similar production capacity of 122 and 125 kt/a, respectively. The least expensive production is clearly there where the feedstock density is high and nearby.

The comparison of smallest (PT181, Sines refinery, Alentejo Litoral) and largest capacity (NL339, Rotterdam) demonstrates that in the case of pruning the smaller refineries can have a competitive production as they are only slightly more expensive than the cheapest one (1940 €/t compared to 1900 €/t). The largest refinery profits highly from economy of scale but has the disadvantage of long transport distance from the pruning-rich southern regions. This is different to results for forestry residues with high feedstock density closer by, which makes it typically one of the most cost-competitive plants.
The Figure 24 shows the overall results on the average fuel production capacity and the composition of transportation fuel production cost. For the first plant (Figure 24, right) constructed at the best location.

![Cost composition of average fuel production pruning](image1)

**Figure 24:** Composition of transport fuel production costs with prunings in average (left) and for the first plant at the best site (right).

The transportation fuel production capacity is 190 kt/a at cost of 2018 EUR/t for the EU-28 average. Under optimal conditions assuming that the first CP-plants would be build in the best region in southern Spain, 180 kt/a transport fuel could be produced at 1633 EUR/t at the Gibraltar refinery. Due to location in regions with high pruning potentials the feedstock costs free CP-plant are below 500 EUR/t transport fuel and contribute only 30% to the total production costs. In the EU average, the cost for feedstock free plant gate amount to 788 EUR/t or 39% of total costs. Cost of CP-oil production, transport to the refinery and upgrading are relatively similar for the average and the best plant. Fuel production from a pruning feedstock in best regions would be possible at a price level comparable to wood chip-based production in favourable regions. High production costs originate solely from increase in feedstock sourcing cost (~200 €, Figure 24, Blue) due to sourcing of more than 50% of available potential or from the higher efforts for feedstock logistics (~100 €, Figure 24, orange); both due to low feedstock availability. A combination of all suitable biomass feedstocks (forest residues, prunings, LCMW biomass and land management material) would increase the potentials in more regions to favourable levels, further supporting the production of transport fuel.
7.4. Conclusion on the use of fruit pruning for biofuel production in Europe

The mostly lower feedstock density of pruning leads to an increase in average production cost of fuel by 500 €/t. In regions with high pruning potential the production cost are similar to those with forest residues.

The major cost is arising from the feedstock cost and feedstock logistic cost. For the sourcing cost the same parameter as for wood residues (cost 70 €/t_{dry} at the place of harvest, at 0-50 % utilization increasing to 140 € at 100 % utilisation) was chosen which led to average feedstock cost of 100 €. The feedstock logistic costs are also calculated with the same data as wood chips. A detailed analysis of the logistic properties of fruit pruning supply to the decentral plants would be needed to achieve more realistic results.
8. Conclusion

8.1. Chances and challenges of lignocellulosic biomass from LCMW of hedge- and tree rows on banks and road side maintenance

1. In Friesland the clean, lignocellulosic fraction of LCMW biomass which is harvested from hedge- and tree rows on banks and from roadside cutting is already utilised by 90 % for heat and power generation within distances of 15-30 km.

Estimations of the service providers are that around 90 % -95 % of this high-quality LCMW biomass is utilised today in Germany. The amounts of woody biomass that will become available will change. Main factors are new laws and their implementation. Enforcing stricter obedience of air emission regulations will prohibit combustion of biomass in a high number of Easter fires. From 2016, only few Easter fires will be allowed whereas in previous years more than 500 were announced only in the country Friesland. As an alternative, places to bring and deposit the biomass from cuttings are offered to farmers and private landowners from which service companies will collect the biomass, chip and utilize it.

Increasing natural conservation measures for farmers and land owners will lead to a more periodic maintenance of hedge- and tree rows. On the other side the German emission law (BimSchG) sets stricter particle emission limits which demands for higher feedstock quality, with less bark and lower ash content reducing significant amounts of LCMW feedstock. Alternatively new combustion technology or particle filters need to be installed.

A common barrier to further cost effective utilisation of biomass is the heterogeneous ownership of hedge- and tree rows on banks. On one side, this leads to use of biomass elsewhere than the nearest plant, when over-regional subcontractors are awarded e.g. in procurement of tenders. Here, efforts to raise awareness for material from LCMW purchasing facilities would increase the cost-effectiveness and reduce the transport burden. On the other side LCMW biomass of a small area might fuel several different facilities and thus lower the density (amount per area) depending on long term contracts or farmers perform maintenance themselves. This is not a problem as long as LCMW biomass is used instead of being discarded, but makes procurement difficult for facilities with a large feedstock demand.

2. The most common application of the lignocellulosic biomass from hedge- and tree rows on banks is combustion in boilers of below 50 KWth. For heating, followed by combustion in CHP of up to 20 MWth, for generation of power and heat.
The most common pathway is direct chipping at the place of harvest followed by transport to a storage place, where the biomass is usually sieved to remove small sized fraction.

3. Harvest, treatment, trade and sales are performed by a couple of specialized and experienced small service companies creating jobs in rural areas.

In Friesland maintenance work of hedge- and tree rows on banks is the business of several small and medium sized companies operating dedicated machinery able to comply with special treatment requirements set by natural conservation authorities. These SME provide the flexibility needed for this kind of business. Private owners of hedge- and tree rows on banks are often organised in the “Forstbetriebsgemeinschaft”. It organises LCMW-management measures for its members in a way, that all jobs in one area are done in one go once per year to improve economy of scale, contracting and performance of the service companies. Special hedge row subsidy programmes on province and NUTS-3 level provide incentives for hedgerow owners to perform periodic hedge row maintenance. Such support programmes proved to be very effective and form one example for best practices.

4. Sustainability is a key issue in this supply chain.

Compliance with environment rules and natural conservation laws is a key issue for all actors in the chain. Applying for the subsidies for the hedge row maintenance leads to the compliance with the rules and regulations by the owners of the hedges. These include special requirements for cutting and harvest like coppicing of bush and small trees in a certain height (to safeguard re-growth by shoots from the stool), the use of bio-degradable oils and lubricants in machines, avoidance of densification of soils and compliance with total load limits of streets used. These are also controlled by the Forstbetriebsgemeinschaft organizing the operation. Maintenance can be done only between October and February and cutting of hedges needs special expertise and equipment. Compliance with all rules is monitored by the natural conservation authority before the subsidies are transferred.

5. Lignocellulosic biomass from LCMW is a suitable fuel for biofuel production however in central Europe only in addition to larger amounts of forestry residues. It could lead to a reduction of feedstock cost in the order of 100 €/t biofuel. Except for some areas with orchards and vineyards, LCMW biomass is too highly dispersed and as such not alone suitable to fulfil needs of biofuel production plants. The potentials of LCMW biomass has been evaluated by greenGain partners in the model regions and compared with results achieved by other investigations in European projects BioBoost and S2Biom.
The often low geographic density of such feedstock (several kg per ha) leads to high logistic costs and therefore high fuel production costs. The small total amounts available and the demand of economy of scale in biofuel production leads in an optimisation of the overall fuel production costs to only one pyrolysis plant and upgrading in one refinery nearby for the whole of Germany. Production cost of fuel would be around 1000 €/t more expensive that with forest residues. However if the LCMW feedstock is utilized additionally to the forest residues the total feedstock potential is increased by approximately 10 % which leads to an overall cost reduction due to economy of scale effects of around 50-100 €/t of fuel. Similar investigations have been performed with fruit pruning biomass and show similar trends for Germany.

Countries like Spain and Italy with much higher LCMW biomass amounts from fruit pruning and less dense transportation infrastructure offer chance to build up de-central pyrolysis plants for utilisation as a biofuel.

8.2. Chances and challenges of herbaceous biomass from LCMW

6. Herbaceous biomass from LCMW can be used as feedstock in dedicated biogas plants.

In general herbaceous biomass from LCMW is suitable to anaerobic fermentation to convert it into power, heat or gas. Typically, permission certificates specify the type of feedstock allowed in the plant. This means that dedicated biogas plants are necessary to utilize the herbaceous material in anaerobic fermentation. The German waste treatment legislation prohibits the direct application of grass on soils and stipulates thermophile composting or digestion treatment, however in some European regions grass is still allowed or tolerated to be landfilled or directly applied without treatment (mulched) on soils (GR3, 2016). In Germany, around 30 % of the biogas plants have permission to use grass as a substrate others are dedicated to the use of wastes from food and agriculture. However while in 2011 around 1100 biogas plants in Germany were dedicated to organic wastes, only 320 plants use grass from agriculture and biomass from landscape conservation. While grass from intensive greenland agriculture offers high biogas productivity- almost comparable to maize- grass from LCMW, landscape maintenance and natural conservation does not. This is usually used as a co-substrate. This relates to the high logistic efforts and the typical high lignocellulosic content of the LCMW grass.

7. Matching demand and supply of dedicated biogas plants with LCMW feedstock is challenging.
A biogas plant needs continuous supply of the same feedstock over time. The LCMW biomass supply is not periodic and the amounts and types vary. It is therefore difficult to supply a dedicated plant year round with fresh LCMW feedstock. Technical solutions like ensiling need to be installed to enable smooth operation under all loads and feedstock types. This proves to be difficult in terms of planning, sufficient supply, economics and the management of biogas plants.

Small amounts of herbaceous feedstock delivered to the plant by service companies or the road maintenance authorities can be used as a feedstock, however with no payment. Savings may occur in comparison to other utilisation pathways.

8.3. Chances and challenges of LCMW biomass in composting

8. Grass from road banks and other diverse LCMW biomass with high moisture content can often be composted directly or in combination with anaerobe fermentation.

Very often communities offer local composting sites for organic residues and wastes, where private garden owners and commercial businesses can deposit their material either for free or paying a small fee.

9. Composting of biomass is generally considered to be sustainable as it closes the nutrient cycles and affords low cost infrastructure only.

10. The economics of making and selling compost is challenging not only if made from LCMW material.

Compost although important for soil fertility is usually a cheap product and consumer markets are very limited. New market chances for high quality compost are initiated as a substitute for peat in garden soils. Authorities are more and more restrictive in allowing peat digging in dedicated areas because of natural conservation. Consumers are more aware of the problems peat digging is causing to the landscape and tend to avoid garden soils with peat. As peat used to be the main component in most garden soils, a big part can be replaced with compost, which has similar physical and chemical properties. The achievement of a “greenGain” -a financial compensation of efforts- by utilising LCMW biomass in composting is unlikely.
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