Accelerating Renewable Energies through

Valorisation of Biogenic Organic Raw Material

FINAL OUTCOME REPORT

Development of closed loop systems of biomass valorization by local authorities

– 2015 –

Colophon

This report was compiled in the framework of action 4 of the ARBOR* project.

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This report further received input from the other ARBOR partners on specific aspects related to the regional transferability of the investigated case study results.

Arbor is an Interreg IVB NWE project with 13 partners from 6 European regions dealing with the development of technological solutions and regional strategy development for improved sustainable biomass utilisation. ARBOR is cofunded by local authorities from the United Kingdom, Flanders, Saarland, Luxemburg, the Netherlands, and Ireland.

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Please check www.arbornwe.eu for the other reports that have been compiled within ARBOR:

- Benchmark report 2015 on biomass for energy use in NWE
- Five case study reports dedicated to specific ARBOR subjects i.e. nutrient recovery, low impact energy crops, agro-side streams, synergy parks and biomass closed-loop systems.
- ARBOR Strategy Report
- Inventory: Techniques for nutrient recovery from digestate
- Small-scale anaerobic digestion - case studies in Western Europe
- Green heat with small-scale wood combustion for agriculture, SME and industrial plants
- An overview of pilots and investments
- Four fact sheets: Buffer strips for biomass sourcing, Cover crops for energy production, Digestate treatment systems for nutrient recovery, Energy from Short Rotation Coppice

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1 ARBOR project – Supporting biomass strategy development

1.1 Aim and structure of the project

The ARBOR project (Interreg IVB NWE) was launched by 13 partners from 6 European regions dealing with the development of technological solutions and regional strategies for improved sustainable biomass utilisation. ARBOR stands for “Accelerating Renewable Energies through Valorisation of Biogenic Organic Raw Material”. ARBOR was unique in the way it analysed the whole biomass energy supply chain. The project dealt with concepts and implementations of biomass sourcing (WP 1) and efficient conversion systems (WP2). These were complemented with policy, economic and environmental assessment and summarized in the created strategy guideline (WP3).

ARBOR activities included:

- A state of the art analysis of biomass for bioenergy initiatives and projects in NWE
- Pilot and demonstration actions on the use of agricultural residues for bioenergy, closed loop organic residue valorisation systems managed by local authorities, industrial biomass based synergy parks, sourcing and energetic conversion of low-impact energy crops such as biomass from buffer strips, cover crops or contaminated soils
- A market analysis of biomass equipment providers, manufacturers and investors in NWE
- An up-to-date inventory and technology watch on biomass conversion technologies and side stream valorisation options
- An analysis of the political and legal framework conditions on bioenergy utilisation in NWE
- An environmental and economic assessment of the developed ARBOR bioenergy implementation schemes
- A strategy development for the ARBOR pilot regions and the examined value chains

The project was co-funded by local authorities from the United Kingdom, Flanders, Saarland, Luxemburg, the Netherlands, and Ireland.

Source: ARBOR Consortium, Final Conference Brussels, 2015

ARBOR aims in particular at the development of sustainable closed loop strategies for the valorization of energy and material recovery from organic wastes by local authorities. The research focus is addressing the organic waste management by local authorities, as they are officially responsible for the management and recycling of these waste streams. As public entities they can integrate organic waste recycling principles in their internal policies and reflect their experiences in higher-level policy development processes (federal/ provincial and state level) as well as public tender systems for implementation by third parties.

The current state of the art of public waste management in Northwest Europe reflects rather a disposal character instead of a full activation for inherent potentials for material recycling and energy production. The case study oriented research analyses drivers and barriers and has accompanied and consulted the regional transformation processes to shift the general public disposal order into resource efficient supply services by local authorities and private sectors. All data gathered for the Transferability Chapter are provided and in responsibility of the ARBOR partners from the target regions.

ARBOR responds to the heterogeneous situation of municipal organic waste valorization in United Kingdom, Ireland, Belgium, the Netherland, Luxembourg and Germany, addressing the following public owned and steered organic waste streams:

- ***Separate collected bio waste from households***
- ***Collected greenery cuttings***
- ***Landscaping material from nature conservation areas***
- ***Collected sewage sludge***

Three regional ARBOR strategies have been developed for the German Federal State of Saarland and one EFRE cofounded investment was realized for the City on Stoke-on-Trent in the United Kingdom. These case studies for regional strategy development have been supported and implemented by the corresponding public authorities, as the Saarland Ministry for Economy, Employment, Energy and Traffic, the Saarland Ministry for Environment and Consumer Protection, The Disposal Association Saar and the City Council of Stole-on-Trent:

- ***Saarland strategy development for a sustainable organic waste and greenery cuttings valorisation***
- ***Saarland strategy development for a sustainable landscape material valorisation in the UNESCO Biosphere Reserve Bliesgau***
- ***Saarland strategy development for a sustainable sewage sludge valorisation***
- ***Investment: Implementation of a closed loop woody biomass supply chain in Stoke-on-Trent, United Kingdom***

The analyzing and comparison of the situation in Northwest Europe on organic waste stream valorization by local authorities and its transfer of the findings has been conducted through:

- ***Mutual development of findings and review by Transnational Advisory Board Meetings***
- ***Comparative study on main findings by the methodology of questionnaires***
- ***Mutual on-site visits to best-practice technology and management sites in Northwest Europe***

2 Closed loop systems of biomass valorization by local authorities Saarland strategy development for a sustainable organic waste and greenery cuttings valorisation

2.1 Case study description

The case study is conducted in the German Federal State of Saarland to analyze and evaluate the current organic waste management scheme with ARBOR's optimized scenarios. The purpose of the research is to demonstrate sound regional sustainable closed loop solutions for the acceleration of bioenergy from organic residues. The main evaluation indicators are that the investigated scenarios prove better ecological and socio-economical outcomes for the region than the current system.

In terms of organic wastes the study considers mainly the following types of waste biomasses as

- wooden and herbal biomasses from greenery cuttings and verges
- separately collected organic wastes from households.
- organic wastes from industrial and commercial sectors including partially integrated waste wood (as much as the current situation of data gathering was sufficient).

The applied research doesn't provide investments for the implementation but will deliver all necessary reliable data and information service to main decision-makers. However, the monitoring towards implementation is covered by ARBOR. The case study is under the patronage and financial support of the Ministry for the Economy, Employment, Energy and Traffic Saarland, the Ministry for the Environment and Consumes Protection Saarland as well as the Disposal Agency Saar (EVS) in order to mutually develop a strategy and action plan ready for implementation (main decision makers and key stakeholders to organic waste treatment). Special attention is required for all project activities on the active involvement of regional stakeholders (development of regional value chains) and to early communication with the public (acceptance).

The developed strategy will be upscaled for interregional transfer to ARBOR partner's countries. The main findings are grouped by key factors for implementation (drivers and barriers), as framework conditions and derivations of target countries and were finally discussed at the Transnational Advisory Board (TAB) Meeting. The TAB meeting is established to identify and discuss with national experts the drivers and obstacles for regional implementation of bioenergy concepts from the perspective of country-specific political, economic and administrative framework conditions. The feedback of national experts is essential to evaluate the regional bioenergy strategies developed within ARBOR and to facilitate their transfer to other European regions. The final outcome will be concrete recommendations for the sustainable energetic and material valorization of organic wastes in the target regions of ARBOR.

ARBOR Objectives:

- Strategy development and implementation monitoring for a sustainable regional recycling strategy of organic wastes in the Federal State of Saarland, Germany.
- Development of sustainable value chains for energy and material recovery from organic wastes, economic and ecological assessment of current situation and proposed scenarios, development of optimized regional material flow management structures (circular economy). All research findings are conducted on the actualized biomass potential analysis for the Federal State Saarland, Germany.
- Information and participation of involved stakeholders. Project mainly addresses administrative responsible public entities as ministries (Ministry for the Environment and Consumers Protection; Ministry for the Economy, Employment, Energy and Traffic; down-level administrations); Disposal Association Saar (EVS) and municipalities as well as parties of Saarland government. The direct public involvement is not targeted to that stage of strategy development.
- The developed strategy will be upscaled for interregional transfer by headlining the key factors (drivers and barriers) for implementation, as framework conditions, derivations of target countries to be compared

2.2 Benchmarking

2.2.1 Potential

Food and kitchen waste from households: In Saarland, the separately collected organic waste container system was introduced for the first time in 1993. Until the year 2001 the entire federal state Saarland was connected to a separated collection system for organic household wastes. The responsible legal public entity is the Disposal Association Saar (EVS), which is generally obliged to undertake organic waste recycling in Saarland. The collection system was carried in the form of a so-called "soft" connection, in which the citizens may be exempted from the compost bin system unless they are capable of own home composting or other relevant circumstances. The separate organic waste collection system has become an important pillar of the Saarland's waste management strategy. The collected organic waste volume in 2001 was around 50,000 Mg / a and hence fulfilled the German objectives of the Technical Guidance for municipal waste / Waste Disposal Ordinance mid-2005. In the year of 2012 the collected volume increased to 52,278 Mg/ a.

Greenery Cuttings from private and public garden and park areas: The recycling of municipal green waste is processed - as well as nationwide - to a large extent in composting plants, which are often operated poorly in terms of efficiency and circular economy as well as regional added value. Partly the process no longer conforms to the law of the amended Organic Waste Ordinance. The common praxis of taking away the wooden part of the greenery cuttings for energy recovery via heat generation determines the structural component of the remaining quantities (compostability). That finding has also been urged by the Federal Composting Association (Humus und Kompost eV). In 2011, about 85,000 Mg and 85 kg / E * a 35 decentralized (local) green waste composting plants are recycling the collected and recycled greeneries in Saarland.

The quantities given are based on volume estimates from the local Government with subsequent extrapolation of the bulk density and are subject to some error accordingly. The wood portion is on average 30 - 35 wt -%, the remaining ingredients are more herbaceous and accordingly suitable in principle for biological treatment (composting / fermentation). The local specific volume and the partial existing material flow allocations are illustrated in the following figure 2.

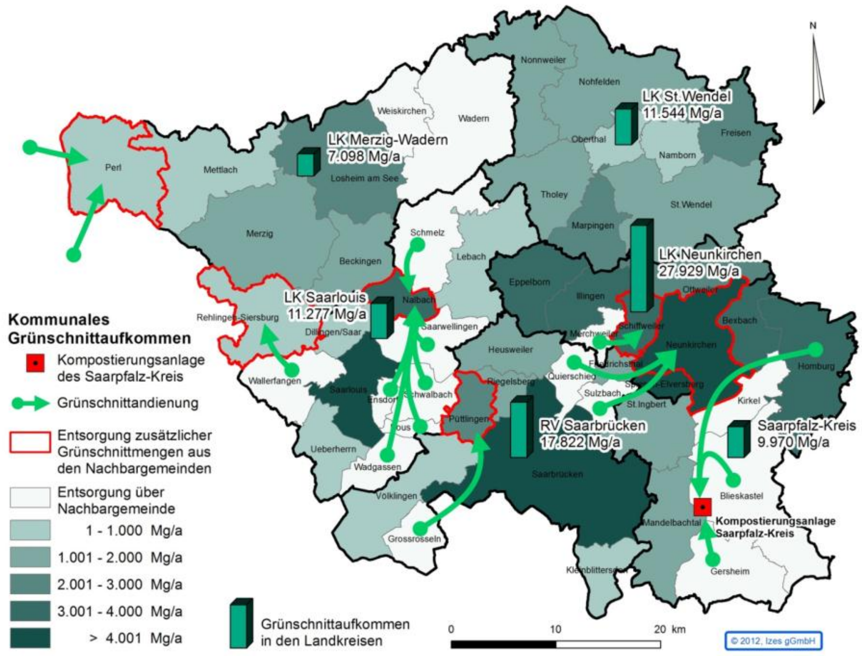

Figure 1: Status 2010: collection areas and quantities greenery cuttings Saarland

2.2.2 Current applied technology and management

Food and kitchen waste from households: For the recycling of separately collected organic wastes (2012: 52,278 Mg), a small scaled quantity of 5,000 mg is recycled at EVS own composting capacity at Mandelbachtal-Ormesheim location. The remaining amounts are awarded by the appropriate invitations to tender to a third party and sold nationwide on the spot market. Considering the situation in 2012, the organic waste was transported out of the Federal State Saarland via three transfer stations to 10 different plants. The transport routes are on average about 185 km (max. 438 km). The corresponding material flows and transport routes are illustrated in the subsequent Figure. The organic waste recycling situation in Saarland was already classified as suboptimal since there are sufficient amounts of organic wastes available for the operation of a Saarland organic waste treatment plant under high technical standard for material and energy recovery.

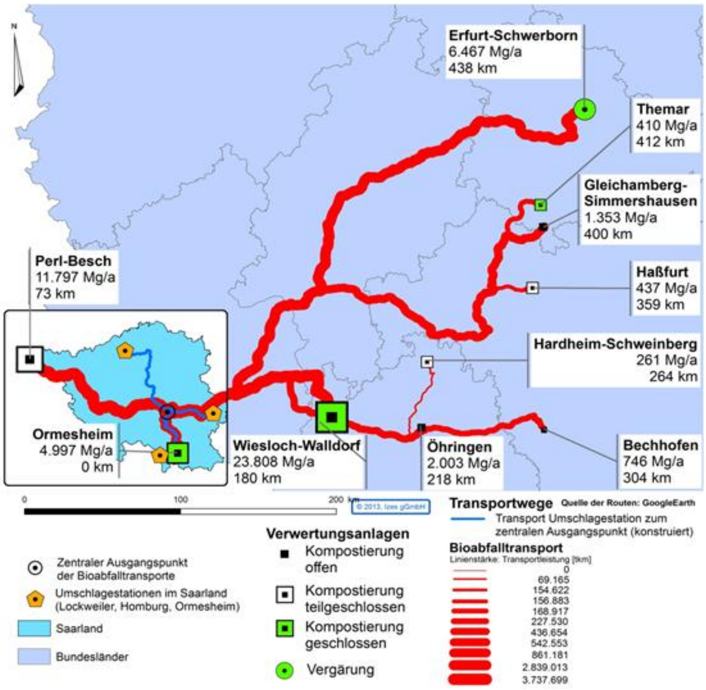

Figure 2: treatment routes for organic waste from Saarland 2012

Greenery Cuttings from private and public garden and park areas:

The previous Saarland waste law enforcement in accordance with § 5 paragraph 2 SAWG, where the municipalities are responsible as a public waste management authorities for the greenery cuttings recycling, has led to decentralized plant concepts with relatively low mass flow rates and correspondingly more likely lower efficiencies. As part of the discussions on the Partial Plan Biomass (Saarland Concept Study 2011), a reorganization of the defined responsibilities for green waste recycling in the sense of creating larger “catchment areas” was recommended. It states that the Disposal Agency Saar should be responsible for the green waste for areas in Saarland to which they are obliged in the organic waste sector from households. This amendment of the Saarland waste legislation came in force in the year 2014 in the ocntext of ARBOR recommendations.

2.3 ARBOR scenarios

On the background of the evaluated potential and current treatment paths (organic wastes from households as well greenery cuttings) the Ministry of Economy, Employment, Energy and Traffic, the Disposal Agency Saar in cooperation with IZES the following scenarios have been determined. The scenarios have been evaluated economically and ecologically for introducing the most efficient and sustainable scheme. Exclusively, those technologies have been selected which represent the current state of the art processes. Highly innovative technologies in the green waste area such as the pyrolysis technology for the production of biochar, the black soil production ("Terra Preta") and the hydrothermal carbonization were not taken into account because they are

- allocated towards the state of the science and

- there is no reliable data on the emission behavior as well as environmental, economic and market-specific effects.

The following technical processes have been selected for assessment: Dry fermentation plant with post-rotting process was selected for organic household waste with greenery fermentation. Thermophile composting process as mandatory and minimum standard treatment process for greeneries. Decentralized woodship-combustion installations with 500 kW_{th} representing the best technology to convert lower quality greenery wood. Organic Rancing Cycling (ORC) was selected as one alternative technology to treat full wooden greenery potential in one plant with 1,5 MW_{el}. All technologies are state of the art and market ready technologies.

2.3.1 Food and kitchen waste from households

The collected data represents an annual volume of 60,000 Mg. As process technology a dry fermentation plant was provided with post-rotting. The corresponding procedure can be represented as follows (see Figure 3):

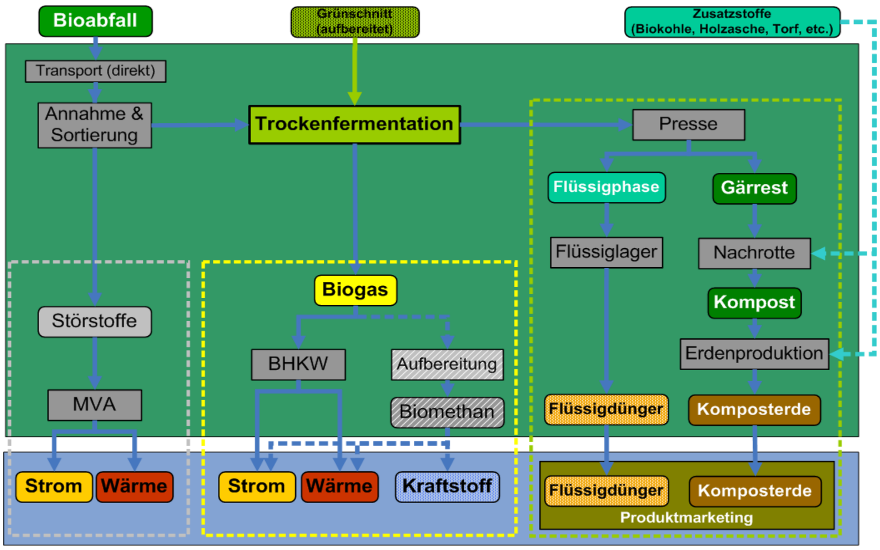

Figure 3: process chain for organic wastes

The above approach applies under the following investigations carried out on a newly designated plant location (Völklingen Fürstenhausen site).

Alternatively a connection to an existing Waste Incineration Plant (e.g. Velsen) could show the following advantages:

- Use of existing infrastructure / operational cost savings
- Use of the MVA heat for digester heating
- Independent use of biogas by feeding in the methane gas into the natural gas network
- Avoidance of methane slip (use exhaust and supply air for the incineration)
- At least potentially lower approval and acceptance problems

The distances of the conditioning location Velsen to gas networks are depicted in the following figure 4.

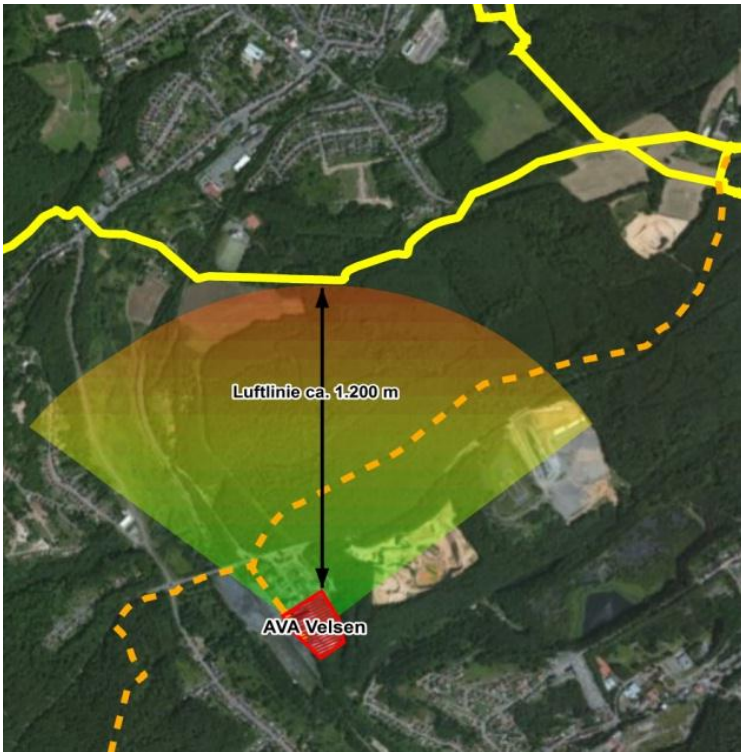

Figure 4: Location of the site of the AVA Velsen to gas networks (mine gas: dashed; natural gas: yellow)

According to the interregional aspect of the designated scenarios, the maintenance / enhancement of the existing cooperation with the SYDEME in Lorraine, France is prosperous. The SYDEME operates in Forbach, France at the boarder to Saarland, an organic waste digestion plant. This plant is capable to accept (long term) masses from Saarland.

<u>The following scenarios were ultimately determined for the organic waste recycling:</u>

- **BioAbf_0: Status Quo**
  Maintaining the current recycling methods

- **BioAbf_1: central variant (60,000 Mg / a)**
  Implementation of a new centralized biogas plant eg at the location VK-Fürstenhausen, or AVA Velsen

- **BioAbf_2: central (40,000 Mg / a) + Additional Location (20,000 Mg / a)**
  Implementation of a new centralized biogas plant eg at the location VK-Fürstenhausen, or AVA Velsen and the establishment of an additional (decentralized) recycling route (eg SYDEME, Neunkirchen)

- **BioAbf_3**: **decentralized (3 x 20,000 Mg / a)**
  Biowaste recycling at three locations (eg UK Fürstenhausen, Neunkirchen, SYDEME)

2.3.2 Greenery Cuttings

Municipal green waste was estimated at 90,000 metric tons, which is composed to 60,000 Mg of fermentable / compostable (herbaceous) and approximately 30,000 Mg from woody biomass. In addition to the energetic use of the wood (only heat-CHP), the biological treatment of the herbaceous materials as anaerobic digestion with post-rotting and composting technology have been evaluated.

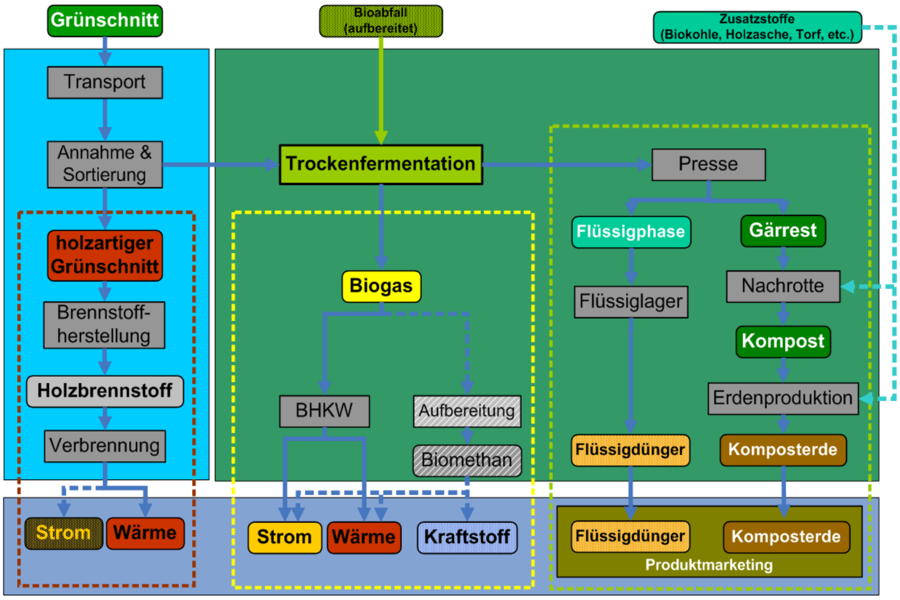

Figure 5: Process chain of greenery cuttings; AD with post-rotting

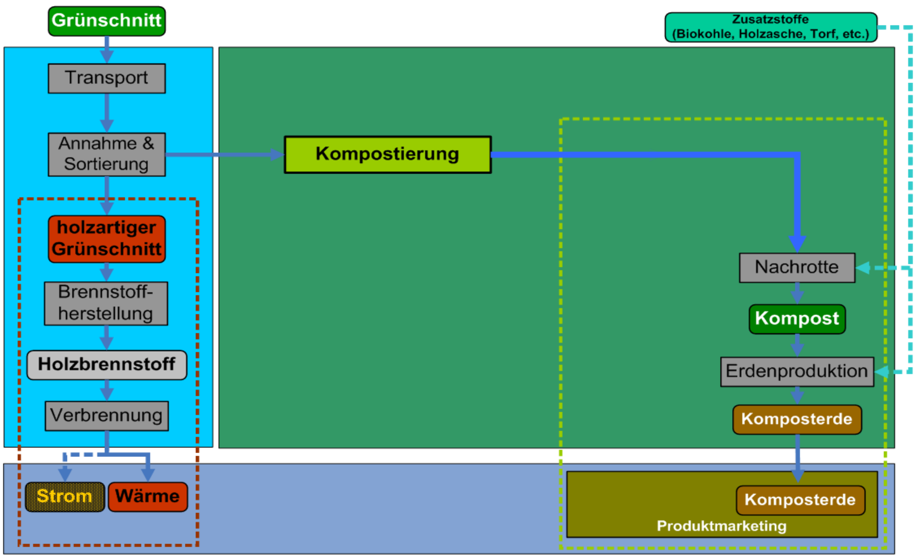

Figure 6: Process chain of greenery cutting: composting

For the herbaceous green waste fractions (60,000 Mg / a) were determined following scenarios:

- **Grün_k_0 : Status Quo**
  Maintaining the current recycling methods

- **Grün_k_1 : co-digestion with biowaste (reference : Variant BioAbf_2)**
  40,000 Mg / a organic waste and 20,000 Mg / a green waste and 20,000 Mg / a borganic waste and 40,000 Mg / a green waste recycled in two anaerobic fermentation plants (á 60,000 / year throughput)

- **Grün_k_2 : co-digestion with biowaste + decentralized monofermentation**
  Co-digestion in two plants with 40,000 Mg / a organic waste and 20,000 Mg / a and 20,000 Mg / a organic waste and 10,000 Mg / a green waste fraction; in addition, two pure green waste fermentation plants, each with 15,000 Mg / a (together with other biomass eligible for German EEG tariffs)

- **Grün_k_3 : monofermentation decentralized (4 x 15,000 Mg / a)**
  Construction of four new anaerobic digestion plants with post-rotting, each with 15,000 tons of annual throughput

- **Grün_k_4: Composting decentralized (4 x 15,000 Mg / a)**
  Construction of four composting plants (or use of efficient inventory plants), each with 15,000 tons of annual throughput.

For the wooden greenery cutting fraction the following scenarios are defined:

- **Green_h_0: Status Quo**
  Approach of the current recovery situation (13% in energy recovery); Assuming 30 decentralized woodship-combustion installations with 500 kW_{th}

- **Green_h_1: decentralized**
  60 decentralized woodchip-combustion installations with 500 kW_{th} (eg recycling in municipal properties or heat networks)

- **Green_h_2: decentralized CHP + central**
  30 decentralized woodchip-combustion installations with 500 kWth and a central heating plant HHS (ORC) technology with 750 kW_e

- **Green_h_3: central CHP**
  Implementation of a central heating plant HHS (ORC) technology with 1.5 MW_e

Note: The electricity generated – depending on the scenarios processes – is calculated according to the 2012 feed in Tariff EEG (start-up 2015). For the heat use different options are chosen (district heating connection, commercial heat recovery, use of heat for drying purposes, etc.).

2.4 Legal Assessment

The German Federal Circular Economy Act postulates the highest possible recycling standard for organic waste under the barriers of economical and technical reasonability. As an incentive, the German Renewable Energy Act emphasizes anaerobic digestion of organic waste with one of the highest biomass feed-in tariff for electricity production. The German Federal State Saarland had introduced the separate collection of organic household waste already in 2001. In Saarland the collection of organic waste is divided into municipal and state-level responsibilities. Organic household waste is collected and treated by the Disposal Association (EVS) Saar for the Federal State Saarland. The collection and composting/treatment of municipal greeneries was at ARBOR project start in the responsibility of each municipality, where the greeneries are mowed. Based on ARBOR policy recommendation, an amendment in 2014 of the Saarland waste legislation was published, to treat all organic wastes (households and greeneries) by the EVS in order to realize a sound closed loop system by Saarland waste authorities. The collection duty of the greeneries remain by the municipalities. In Germany the state of technology for organic waste (household) recycling prohibits landfilling since 2004 but leaves diverse options for treatment processes. Anaerobic digestion and thermophile composting are valid treatment options. Until the year 2015 a treatment of greeneries was not obligatory in Germany, providing the baseline for high quality recycled fertilizer. The new treatment order for greeneries (hygienization and stabilization) needs to be applied in Saarland. To commission third parties for treatment activities, European public tender law warrants the option to include regional and environmental criteria (e.g. GHG reduction).

2.5 Economic assessment

The economic analysis was performed for the scenarios definition treatment facilities. All assumptions and the detailed cost estimates are based on experience of IZES gGmbH, which were verified by plant manufacturers and operators. All cost estimates relate to newly constructed plants.

2.5.1 Food and kitchen waste from households

The economic analysis the fermentation of unmixed collected, municipal organic wastes (green bin) in Saarland. For reasons of operational stability, to reduce the vulnerability and the reduction of 'impurities', which must then be disposed of in waste incineration plants, only the dry fermentation process has been considered in the present analysis. Due to partially clear environmental benefits and because of the higher efficiency (biogas yield, etc.) only continuous dry digestion processes have been studied (eg provider of Axpo Kompogas, STRABAG, OWS Dranco, etc.). Since the location discussion is still ongoing, it was assumed, that in all biogas plants there will be a cogeneration (CHP) unit. he investment costs are based on indicative price quotations of relevant equipment manufacturers and include all costs of the detail and implementation planning through to commissioning (including construction, construction supervision, etc.) - only costs for the necessary land, as well as risk and profit were not in approach brought. The costs shown below are net costs.

Assumptions:
As the market price of the required plant operation is current over the recoverable EEG feed-in tariff, the internal consumption of the biogas plant will be delivered by the own produced biogas or electricity. With regard to the feed-in tariff law (EEG), a start-up in 2015 was assumed. Regarding the heat, it was assumed that 80 % of the excess heat can be sold with 0.03 € / kWh_{th} (remaining produced amount of heat is needed for the fermenter heating). According to the recoverable compost revenues a conservative approach was followed up. In discussions with organic waste fermentation plant operators it was confirmed, that the composts and soil produced as well as the liquid digestate are of good quality and for the substrates there is a market existing. However, it was also noted that a regional market needs to be established. Here it must be first invested in market research, brand marketing measures, public relations, sales, etc.. Only after a few years, the first revenue can be generated. Against this background, it was considered, that for the liquid digestates, due to the lower nutrient levels, an additional payment of 5.00 € / m^3 needs to be accounted. The income of compost were set equal to zero, since it is assumed that the costs and revenues over the observation period of 20 years will offset each other. The tendency is that rather positive result can be achieved over the period -under consideration of the costs and revenues balance. Reasoning of the expected price developments in the field of mineral fertilizers, any restrictions concerning the mining of peat / the use of peat for soil production and by the work already done on regional / national promotion of the use of composts.

Under the given assumptions, the economic analysis comes to the result that the organic waste fermentation plant size and the specific treatment costs between 118-52 € / Mg FM (net) can be realized in the Saarland context. The current net disposal price is according to EVS currently at almost 62 € / Mg.

In particular, the large plant of 60,000 tons per year appears interesting and competitive with respect to the currently market prices for the disposal / recycling of organic waste and taking into account the national medium-term worsening minimum / quality requirements for recycling of organic waste (prior art , minimum composting period , etc.), which will tend to result in higher disposal costs.

The existing level of connection to the green bin in Saarland is only 47% (see Waste Balance 2011 - MSW), which suggests that there is still immense potential. With regard to the target in the circular economy law with a separate collection of organic waste from 2015- it is to work towards this target with innovative instruments as eg steering on fees system, public relations, etc. This would result, that the separately collected organic waste quantities will increase in the short to medium term in the Saarland.

2.5.2 Greenery Cuttings

The economic assessment summarizes the results of the economic analysis with regard to the fermentation of treated, municipal greenery waste in a quantity-reduced form and compares it

with the cost of an alternative composting. Since the EEG allows the joint fermentation of municipal green waste and organic waste from kitchen and households, a variant was compared in the form of a co-digestion with organic waste in accordance with the scenario of green cut-monofermentation.
The green waste is shredded and then sieved to 10 and 60 mm. The undersize (<10 mm) is directly composted or post-rotted, since large parts of the inert fraction (soil , sand, etc.) are here located, which can lead to problems in the biogas plant and abrasion. The sieve fraction from 10 to 60 mm is characterized by the grass and herbaceous material and is generally suitable for digestion in biogas plants. To compensate for seasonal variations in quality it can / should be promptly treated and ensiled during the growing season. The fraction greater than 60 mm consists of the woody fraction that can be used for thermal processing.

The investment costs are based on indicative price quotations of relevant equipment manufacturers and include all costs of the detail and implementation planning through to commissioning (including construction, construction supervision, etc.) - only costs for the necessary land, as well as risk and profit were not in approach brought. The costs shown below are net costs.

Assumptions:
All assumptions and cost estimates were made analogous to organic waste consideration , but numerically partially adapted to the changed circumstances. The treatment of municipal greeeries (shredding, sieving , transportation) were taken into account . Only the costs associated with the decentralized collection (Provision collection area, staff costs, etc.) were not charged, as this might remain in the budget and competence of the municipalities. As an additional approach in comparison to organic waste recycling, the wooden part/timber revenues were considered in the green section. It is assumed that 25% of the municipal wooden greeneries (> 60 mm) can be separated (thus preventing impairment of composting processes and ensuring high quality of fuel). This wood is then marketed and brought to the new installed greenery treatment and preparation areas- as a quality fuel further refined (drying, fine screening, etc.). According EUWID and local plant operator data prices between 50 and 60 € can be achieved / mGlu tro for the treated wood in the region. As part of its cost-effectiveness € 40 / mGlu - tro – was assumpted.

Result:
The pure greenery cutting fermentation, according to specific treatment, costs almost 70 € / Mg (net). The current cost for greenery cutting treatment in Saarland are between 50 and 60 € / Mg (incl. detection; gross), or roughly between 4-5 million € / a. Therefore, the pure fermentation of municipal green waste from economic point of view appears - at least in terms of a comprehensive approach - currently as unreasonable.

The co-digestion of greenery cuttings with organic waste results (amount of 40,000 Mg / a organic waste and 20,000 Mg / a greenery cuttings) to specific treatment costs of almost 35 € / Mg greenery cuttings, if the organic waste reference price with 40,000 Mg plant see table 1 is taken (€ 70.55 / Mg). If, as in the last column of the current cost of disposal of greenery cuttings in amount of 50 € / Mg (gross) or € 42.02 / Mg (net) used as reference price, the cost of treating organic waste is reduced to almost 67 € / Mg.

While a mono -fermentation of greenery cuttings is rather critical assessed- from an economic perspective based on the current framework conditions (in particular EEG payments). However, a pro rata recovery in a co- fermentation plant, in which the organic waste is the main input, according to the above derivations, this can be quite reasonable. The risks associated with the implementation of a central organic waste digestion plant with a capacity of 60,000 tonnes per year are buffered by the provision of a sufficient amount of organic waste. In addition, it results in a certain degree of flexibility, which allows an adapted material flow management eg the maintenance or enhancement of the existing cooperation with the SYDEME from a strategic perspective.

As an alternative to fermentation, the cost of an adapted and more central greenery cutting composting were determined according to the prior state of the art. Considering an appropriate high standard composting plant with a throughput of 15000-20000 Mg / a, a specific treatment price of just under 33 € / Mg (net) can be assumed (investment around 1.4 - € 1.5 million).

In total- depending on the approach and location-4-5 treatment specific options and treatment centers for municipal green waste with a respective processing capacity of 15000-30000 tons per year in the Saarland could be implemented.

Existing plants could be integrated according to their suitability, which should result in an improvement in the cost situation. One of the collection and treatment centers could be designed as an (extra funded) innovation center with pilot model technologies to provide on the basis of their own experience an improvement of the overall system . The combination with the site of the central organic waste digestion seems to be suitable.

2.5.3 Wooden greeneries

Many Saarland municipalities are currently – also based on their local climate protection concepts – implementing regenerative heat supply of own real estate, or districts to provide them with warmth. The woody portion of the municipal greenery section is often used. A (still incomplete) overview of the stock of wood combustion and known plans provides the following figure.

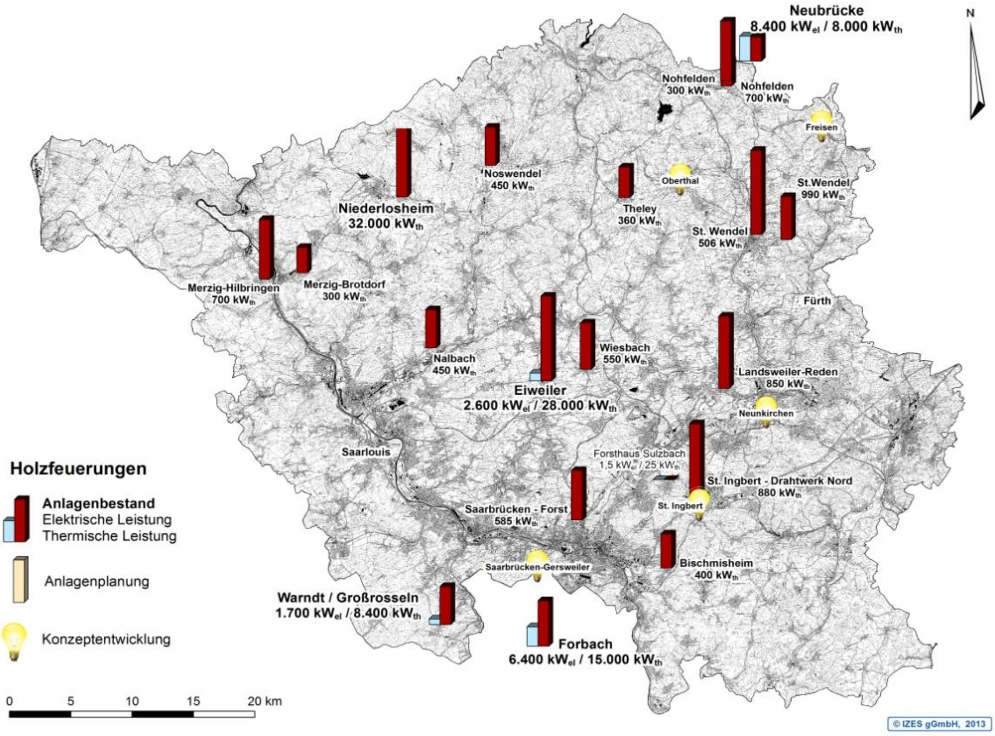

Figure 7: Energy recovery from (wooden greenery cuttings) in Saarland - inventory, planning, concepts

Finally, it seems unproblematic to combust the assessable 20,000 - 25,000 Mg / a wooden greenery cuttings in the existing or currently planned Saarland wood combustion plants. Taking into consideration, however, is that

- a high-quality fuel (eg in terms of moisture, contaminants, fines / ash contents) is provided
- and the installed furnace harmonizes with the fuel blends (eg rust, thermal minimum power 500 kW) .

Competitive heat production costs in a range from 8.7 to 10.6 cents / kWhth can be derived.

The green waste-based CHP application, in comparison to a purely thermal use shows (due to the higher reduction effect in greenhouse gas emissions) significant environmental advantages. Accordingly, economic feasibility studies for CHP applications have been carried out both by means of ORC technology, and by means of steam power process. The ORC technology was significantly higher in inefficient area, which can be justified in particular by the omission of EEG technology bonus (the German ORC market is totally broken since 2012). Something better was the outcome in the study of steam power process, but it was also still negative, so that overall the CHP application tends to be viewed critically from an economic perspective.

2.6 Environmental assessment (Life Cycle Analyses)

To assess the environmental impact of the current as well as of the defined scenarios, an environmental assessment analysiss based on DIN EN / ISO 14040/44 was carried out. The evaluation of the life cycle are only for the environment category of greenhouse gas emissions. The accounting was done with the material flow software Umberto ®.

The data basis for the current Saarland recycling situation on organic waste and greenery cuttings for the years 2010 to 2012 refers to information that has been provided by the Disposal Association Saar (EVS) and the Statistical Office of the Saarland. This includes the current municipality- specific quantity of organic wastes and greenery section as well as the organic waste treatment facilities in Germany, delivered and commissioned by the EVS and supplied by a logistics company.

Using geographic information system (GIS) the transport distances between the Saarland and the recycling plants have been determined. The necessary information on the treatment plants are sourced on the "manual book organic treatment" (Rettenberger, et al. , 2012) and have been specified as needed via telephone interviews. In addition data to the records of the Swiss Centre for Life Cycle Inventories ' ecoinvent ' to composting , anaerobic digestion , incineration and logistics processes were used and measurement data of the gewitra Engineering Company for transfer of knowledge were applied (see Table 4 in Appendix 1). This gewitra emission data are currently discussed, however, to this extent and level of detail for the scenarios, these are the only pre- existing data to be used.

Currently, a new onsite survey (municipal composting sites) takes place, the results are, however, not yet published. Due to a possible inaccuracy, the data are differentiated calculated. For the existing installations, ie for the status quo scenario, the determined average values were fixed because here must be assumed that not all facilities are matching the state of the art. Plants in the optimization scenarios have been calculated towards the minimum values as new plants meant to be run on the current state of the art.

The accounting includes not only the single process steps, such as waste collection (measured from the geographic center of the municipality to the transfer stations), and the waste transport (measured from the transfer stations to the recycling plants), waste treatment and the market relevance of the final products (biogas utilization, provision of electrical and thermal energy from the fermentation) and the upstream processes and the needed infrastructure (eg truck to transport the waste). For example the treatment of the biological waste does not only account direct emissions from the anaerobic digestion or composting process, but also a share of the treatment plant , the needed equipment / materials , etc. Furthermore, the end products of biowaste and green waste treatment, ie electricity, heat and digestate or compost, liquid fertilizer, are counted with respect to their substitution of fossil fuels, fertilizers or compost or peat emission credits (see Table 5 in Appendix 1). The generation of electrical energy in the status quo scenario displaces the German electricity mix (563 g CO2eq/kWh_{el}), since the power generation takes place exclusively in plants in Germany. In the scenarios, which represents a regional (Saarland) recycling, the concrete Saarland electricity mix is credited (828 g CO2eq/kWhel). In the scenarios BioAbf_2 and BioAbf_3 ,the French system of SYDEME is alternatively being integrated, hence the power generated there is accounted with the French electricity mix (67 g CO2eq/kWh$_{el}$). The emission credits procurement for all other products is summarized in Table 5.

2.6.1 LCA scenarios for food and kitchen waste from households

In the BioAbf_0 scenario the status quo as well as three designed scenarios for organic waste treatment were calculated. The status quo scenario causes total greenhouse gas emissions (GHG) in amount of around 10 million kg CO_{2eq} per year, this corresponds to a biological waste volume of approximately 52,000 Mg per year, approximately 196 kg CO_{2eq}/Mg organic waste.

In comparison to BioAbf_0, scenario BioAbf_1 results in the maximum greenhouse gas savings of about 16 million kg CO_{2eq} per year, with a planned organic waste volume of 60,000 Mg leads to CO_{2eq}/Mg organic waste with a specific saving of approximately 269 kg. figure 7 shows the four scenarios BioAbf_1 -3 and the status quo with respect to (BioAbf_0).

The scenarios 1-3 lead from an ecological perspective (GHG -related) all to a significant improvement over the current organic waste treatment, whose enormous emission charges are mainly due to the high transport distances of up to 440 km. The emission loads in the scenarios BioAbf_1 to 3 occur mainly at the stage of dry fermentation (process emissions and infrastructure expenses). The pollution caused by organic waste transport within Saarland, whether at a central plant or several decentralized systems, are insignificant and rather negligible. The largest share of the credits is caused by the current substitution.
The dashed boxed columns shares in the scenarios BioAbf_2 and 3 represent the variant ' cooperation SYDEME ' , so to utilize approximately 20,000 Mg organic waste in the French system of Sydeme in Forbach.

In both scenarios, the total savings (green marker) are reduced, caused by the French energy mix, up to about 4,400 Mg. In BioAbf_2 the CO_{2eq} emissions of 15,900 Mg CO_{2eq} is reduced to about 11,600 Mg CO_{2eq} / a and in BioAbf_3 from 16,200 Mg CO_{2eq} to about 11,800 Mg CO_{2eq} / a.

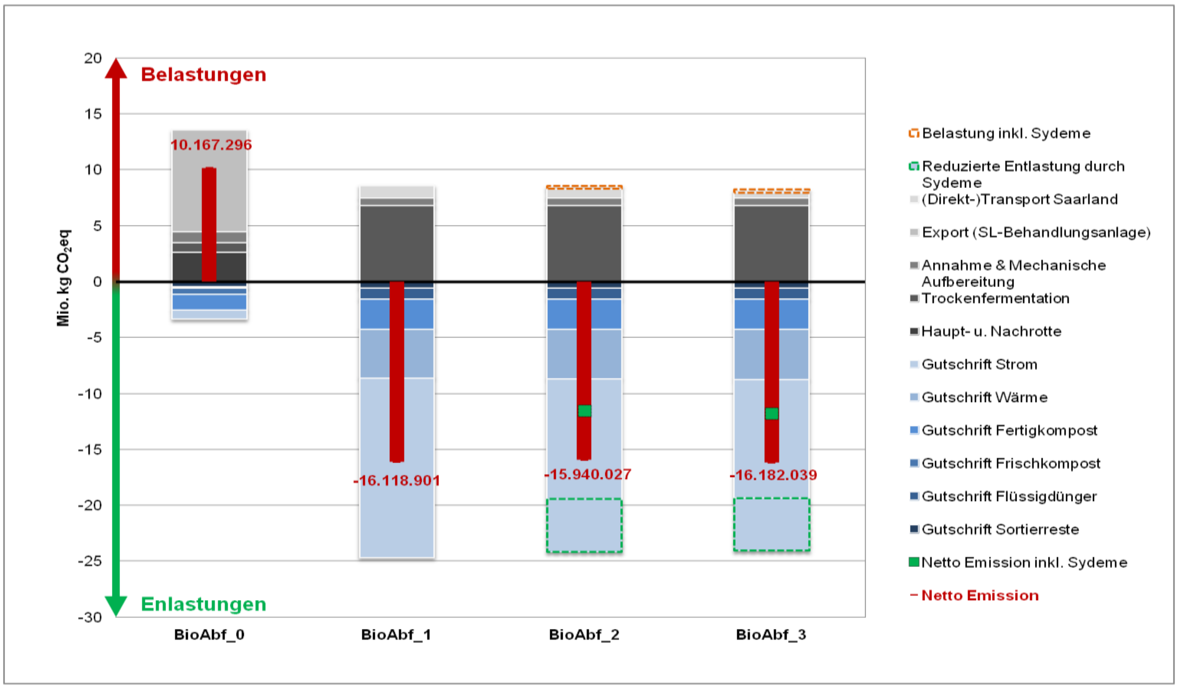

Figure 8: Evaluation of the organic waste scenarios (absolute)

Conclusion organic waste:

In total about 26,000 Mg / a GHG emissions could be reduced by technology changes/optimization. The central concept causes additional emissions in the area of transportation within Saarland, nevertheless this surplus is compensated by the higher efficiency of the larger systems (eg CHP efficiencies, waste-air management, water supply systems, etc.).

2.6.2 Greenery cuttings (herbal, grass-like)

This Figure compares the scenarios of grass means herbaceous greenery cutting treatments. The current treatment of grass-/ herbaceous green sections causes greenhouse gas emissions with approximately 5.1 million kg, which leads by a greenery cutting volume of approximately 86,000 Mg to approximately 85 kg CO_{2eq}/Mg. In contrast to this, the four optimization scenarios result in greenhouse gas savings. The most accounting is Green_k_1 scenario with net emissions of around 19.5 million kg CO_{2eq} or -326 kg CO_{2eq}/Mg.

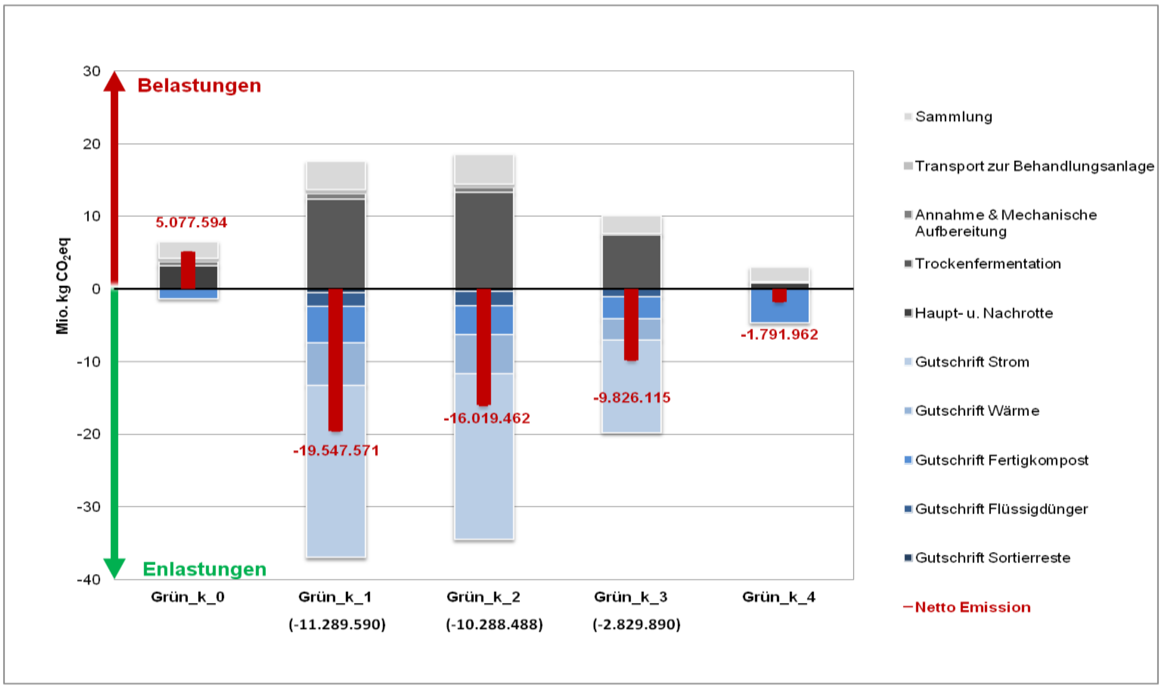

Figure 9: Evaluation of grass- herbacious scenarios (absolute)

The different results of each scenario resulted primarily from the additional input materials and quantities (see scenarios definition). The numbers in parentheses for the scenarios Green_k_1 to Green_k_3 relate to savings of greenhouse gas emissions based on the pure green waste quantities (in kg CO_{2eq} / a). In the scenario Green_k_3 the credits are correspondingly low, as only a small proportion of additional input materials support the production of biogas and thus credits for electricity and heat substitution also be credited only to a small extent. With the Green_k_4 scenario are four decentralized composting plants on the current state of the art in direct comparison to the current utilization (Grün_k_0) and have a potential for optimization alone on the field of composting of approximately 6,900 Mg CO_{2eq} savings per year.

Conclusion herbaceous greenery cuttings:

An optimized composting can contribute to a significant improvement in GHG emissions. However, the fermentation -and in particular in the context of larger co-fermentation plants - leads to significantly better results.

2.6.3 Wooden greeneries

This figure portrays the four scenarios for the treatment of wooden greeneries. Already in the status quo scenario (Green_h_0) with an estimated 50% thermal utilization of wooden greeneries CO_{2eq}, savings of approximately 9.3 million kilograms per year (approximately 360 kg CO_{2eq}/Mg) can be achieved. These savings can be doubled by a follow up expansion (Green_h_1; approximately 720 kg CO_{2eq}/Mg) or even tripled (Green_h_3; approximately 1200 kg CO_{2eq}/Mg).

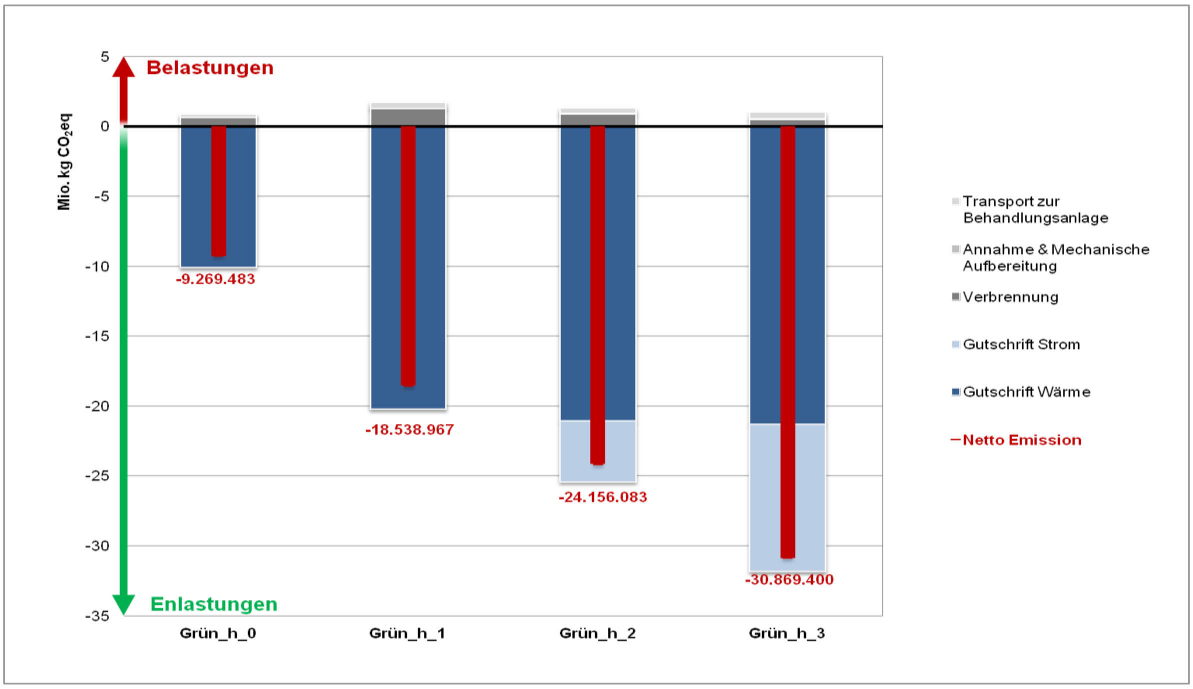

Figure 10: Evaluation of wooden greenery cutting scenarios (absolute)

Due to the very high emission credits due to the substitution of electrical and thermal energy based on fossil fuels, the emission loads in this discussion seem almost negligible. In the status quo scenario in comparison to Green_h_1, however, only approximately half of the currently available wooden greeneries are currently used, accounting for estimated installed 30 out of 60 possible plants. Therefore, the heat credit is to be awarded doubles in Scenario 1 in accordance to scenario Green_h_0 Within scenarios Green_h_2 and 3, the heat output are less, due to the efficiencies of the CHP solution, than in the woodchip firing- but here have been applied different reference systems for credit accounting.

The decentralized woodchip firing plants are substituting decentralized gas heaters (270 g CO_{2eq}/kWh_{th}), that emit lower amounts of carbon dioxide. In comparison, the central ORC plant substitutes the Saarland district heat connection with 418 g CO_{2eq}/kWh_{th} For this reason, the net credits in the scenarios Green_h_2 and 3 are higher than in scenario Green_h_0 and Grün_h_1 . In the scenarios Green_h_2 and 3 additionally the credit will be added from the substitution of fossil power generation.

Conclusion wooden greeneries:

In the case of the highest possible use of heat, cogeneration solutions will lead naturally to larger GHG savings. The decision criterion is therefore the economic evaluation.

2.7 Conclusion and regional strategy recommendations

The Federal State of Saarland has created its own National Task Force (NTF), set up to guarantee transfer of the project related knowledge to regional stakeholders, which can benefit through enhancing their biomass production, collection and conversion into energy. The NTFs comprised the Saarland Ministry for the Economic, Employment, Energy and Traffic; Saarland Ministry for the Environment and Consumer Protection, Disposal Association Saar and IZES gGmbH. Further hearings and consultancy were given by the Saarland government/parliament; French disposal association Sydeme, Lux. Environmental Ministry and Environmental Committee of the Grand Region SaarLorLux. The ARBOR Saarland Task Forces “Organic Waste” met in the timeframe between 2011 and 2015 over 10 times and by mutually discussing the Saarland strategic recommendations, more intensified collaboration amongst public entities, municipalities and ministries concerning material flow management strategies on organic waste have been established.

The third Transnational Advisory Board (TAB), has been set up on NWE level and consisted of national and regional experts representing the European, governmental, regional and local administrations, sector companies, universities, research institutes and consulting companies. The TAB meeting on closed loop systems by local municipalities was held in November 2014 in Saarbrücken, co-organized and hosted by the Saarland Ministry for the Economic, Employment, Energy and Traffic. The TAB- and NTF-based feedback was essential to evaluate the regional bioenergy concepts developed within ARBOR and to facilitate their transfer to other European regions.


Figure 11 The Dissemination and know-how exchange channels Saarland Closed Loop concept for organic waste recycling

Strategic Recommendations

Based on Arbor vision, to increase the material and energy efficiency for municipal organic waste recycling. to shift the general public disposal order into regional resource efficient supply services by local authorities and to strengthen cross-border synergies in the waste sector with the French region of Lorraine and the German Federal State Saarland, the following strategic recommendations have been published and accepted by the Saarland decision making boards:

Grass/herbaceous greeneries

In order to provide the individual green waste fractions in the best possible quality and at reasonable costs at more central locations, it requires a logistics concept for Saarland. The favoring investments in the Saarland needs to be developed. For the interfaces between local municipalities and the EVS, shown in the following figure, this allocation of tasks is proposed. The acquisition at the collection points should still remain in the responsibility of the municipalities. The acquisition logistics and greenery cutting processing and recycling are then in the responsibility of the EVS. With regard to the (inter-regional) marketing of the products produced, the involvement of private sector structures is recommended.

Wooden greeneries

The preparation of wooden greeneries and the biological treatment of herbaceous material should be centralized at only 4 - 5 locations. For dealing with the interesting woody fraction – also from a communal perspective- two models are conceivable:

• Model 1: the Municipality takes out the woody fraction already at the collection site for the use in its own firing. This poses the problem that in general, the required fuel quality for the respective furnaces cannot be guaranteed and the EVS remains only the most cost-heavy herbaceous fraction.

• Model 2: the whole green section is passed to the EVS. The desired woody component can be re-acquired by the municipality in the form of an edited Quality fuel. This model allows for the purposes of a regional material flow management greater flexibility and is likely more an efficient approach.

From a technical perspective, the following procedures are recommended: •

1 Establishment of 4-5 treatment centers (possibly modified existing facilities) where a green waste composting and the preparation of a quality fuel according are practiced
2 The size cut for material flow separation (woody and herbaceous component) is in conformity with nationwide experience at 50 - down 60 mm.
2.1 < 50-60 mm material for biological treatment (herbaceous)
2.2 > 50-60 mm material for energy recovery (woody)
3 A mono-digestion of greenery cuttings cannot be displayed for economic reasons (due to the current framework conditions of the EEG). A co-digestion of material from the organic waste fermentation plant is however, conceivable.
4 One of the above sites should be developed to a (subsidized) Innovation where innovative technologies such as Pyrolysis / Biochar production, black earth production, HTC, mono-digestion , etc. to be able to test.
5 Marketing of different soil substrates (product label) with the involvement of regional actors (eg gardening , gardeners) .
6 Especially in connection with the recycling of greenery cuttings , there are still a number of open questions, which needs to be further elaborated in a follow up study.

Implementation (09/2015):

The following outcomes have been implemented to the end of the project lifetime (09/2015):

- Commitment for political patronage to drive regional organic waste recycling

- Amendments in Saarland Waste Legislation about collection and treatment responsibilities of greenery cuttings to implement high efficient and regional treatment hubs (Law amendments 2014);
- Publishing of public tender by Disposal Association Saar (EVS in 2014-2015) to further elaborate a greenery recycling concept for Saarland;
    - Redesign of greenery collection and recycling hubs (submitted concept in 2014 and implementation process until 2016)
    - Regional product chains and marketing (high quality fertilizer, wooden fuels, biogas to power and heat) for energetic by products (conception until 2016)
- Publishing of public tender for 2 job offers by EVS for greenery management
- Scientific support on building and operation of mono-fermentation plant for French-Saarland municipal greenery cuttings (Saargemünd, France).
- Strategy design for anaerobic dry digestion plant with post rotting of combined bio-waste and greenery cuttings; thermophile composting plants for herbal greenery cuttings; wooden greeneries for near district heating systems (min. 500 kW_{th} or ORC); Planned increase of organic waste from households (Saarland) to already running anaerobic digestion plant Methavalor (Sydeme);
- Next step challenge: Integrated hydrothermal conversion technologies and anaerobic digestion/ composting for energy and biochar production (Concept design Innovation Center);

3 Closed loop systems of biomass valorization by local authorities-wood from municipal parks and land -- Case Study United Kingdom, Stoke-on Trent

3.1 Case study description

The Stoke-on-Trent woody biomass closed loop supply chain pilot aims to demonstrate that it can be economically and environmentally feasible to recover waste wood from aboricultural processes for use as wood fuel at a scale that would suit Local Authorities and other public bodies in North West Europe.

The increase in number of biomass boilers within UK local authority estates has risen dramatically in recent years due to both increased gas prices and the introduction of the Renewable Heat Incentive (RHI). The RHI is designed to increase the roll out of heat generation from renewable sources by bridging the gap between the cost of fossil fuel heat installations and renewable heat alternatives. This forms a key part of the UK government's objective to meet long term renewable energy targets. Four years on from its introduction, the initiative has been a success in the non-domestic market with installations with a total heating output of 1.215GW now accredited as shown in figure 14. The percentage of RHI installations which are classed as Solid Biomass is also shown as being the predominant technology. Liquid and gaseous biomass makes up less than 1% of the RHI market to date.

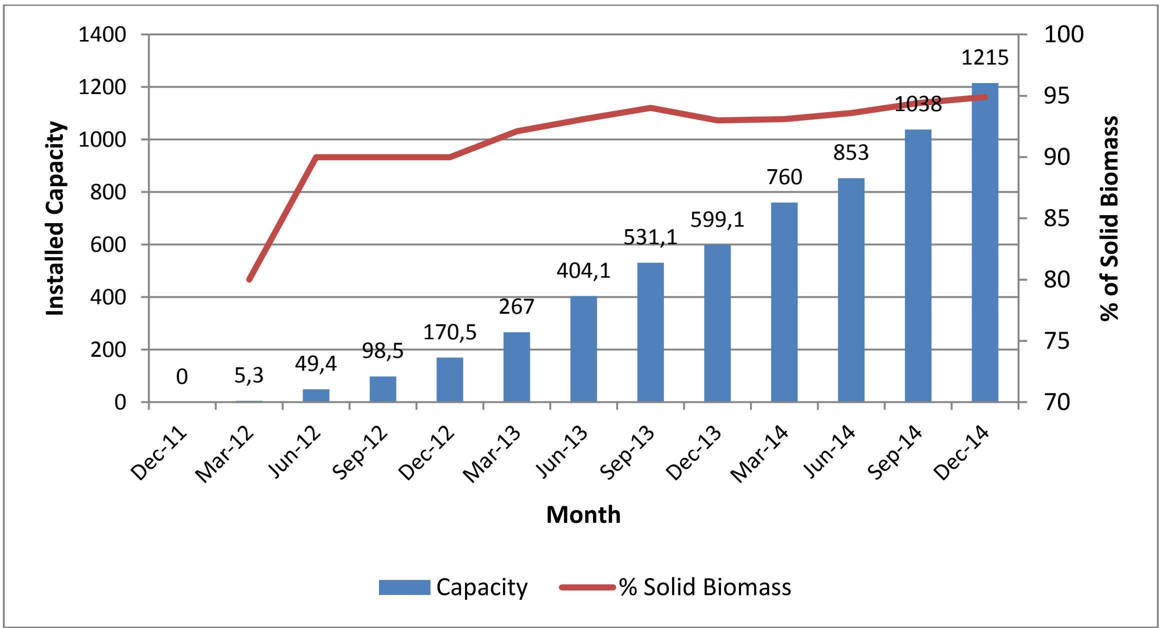

Figure 12 - Installed capacity of non-domestic RHI installations and % of which are solid biomass[1]

As the number of boilers has increased, the quantity of timber required to fuel the boilers has also risen, leading to supply bottlenecks. Biomass providers now have to go further afield to

[1] As taken from scheme administrator OFGEM - https://www.ofgem.gov.uk/environmental-programmes/non-domestic-renewable-heat-incentive-rhi/non-domestic-renewable-heat-incentive-rhi-public-reports

secure timber and as such increased costs are being passed on to the end users. The introduction of a domestic RHI in 2014 has only served to increase the pressure on availability.

At the same time, Local Authorities have responsibilities to carry out tree maintenance on public land and will typically generate significant quantities of waste virgin timber. As it tends to be generated in small quantities and at various frequencies, this timber is typically either chipped at the roadside to be used as mulch or, when good quality round wood is produced, sold on as logs for fuel to the public.

As there is a clear demand for wood within the local authority areas and a steady supply available, the creation of a closed loop supply should be able to both reduce costs and the carbon emissions associated with the used of biomass. Barriers to such supply chains have typically revolved around the transport of such timber to a central processing station. Although the fuel might be available at low/no cost, the cost of transporting heavy weights of timber can make any such project economically unfeasible very quickly. The City of Stoke-on-Trent is in a unique position to demonstrate how this can be overcome as not only does it have more than 13.8km^2 of park and open spaces but they are also located within 15km of the centre of the city.

3.2 Benchmarking

To implement the closed loop supply chain the following basic process was identified:

- An analysis was undertaken to identify the quantity and value of the waste wood available within the City
- Several different methods for conversion of raw material to heat were examined to determine the most economically viable based on the material available
- Demand for biomass within the City was stimulated through the installation of a biomass boiler in the Stoke-on-Trent City Council corporate estate
- With the source, method and the end user identified, the most effective way to process the raw material was explored
- The supply chain was implemented and the results reviewed

As the project progressed and problems were encountered and overcome the methodology at individual stages was modified accordingly.

3.2.1 Available wood waste

A review of the waste wood available within the City was undertaken with a view to understanding quantities, types and suitability as wood fuel prior to making a decision on the conversion method to be utilised. The price of the available streams was also explored as non-council sources could prove to be attractive should a low price be available for large quantities of available wood.

The quantity of available wood was determined by interviewing a sample of local tree surgeons in Stoke-on-Trent including the Council's incumbent contractor. Waste producers and owners of forestry holdings were also approached and generally provided annual quantities and felled timber. All respondents were asked if they would consider providing fuel for the supply chain and if so what price they would likely make it available for.

A review was also undertaken of the species and quantities of waste wood made available through the City Council's tree maintenance works to understand the potential caloric value of the potential wood waste.

3.2.2 Conversion method

The selection of the timber source to be used for the closed loop supply chain depended primarily on ease of ability to transfer the raw material into raw energy. This was dependent on the mechanism used to undertake the transfer and the two main considerations were pyrolysis or direct combustion. At the outset of the project pyrolysis had been identified as the preferred option as closed loop supply chains of this type and at this scale were not known to have been trialled in the EU at this time.

Due to the limited knowledge of the technologies (particularly pyrolysis) both within the Council and the wider project partners, a review of the suitability of the technologies by a third party was commissioned. Within the brief the consultants were challenged to determine the appropriateness of the technologies from both a technical and operation aspect of deployment. Three sites were provided as examples to which the technology would be deployed and the consultant was tasked with providing costs of both installation and operation of the systems at each site.

3.2.3 Demand

Stoke-On-Trent City Council did not have any operating biomass/biofuel boilers prior to the start of the project therefore it was necessary to install a unit to stimulate demand for the supply chain.

To select an appropriate site the following were considered key criteria:

- Medium/high thermal demand – A building with high heat demand was preferred as it would in turn increase the economic viability of the supply chain.
- Technically feasible – The selected building had to have enough room to install a boiler and store and have suitable access for a large delivery wagon. In addition, the site had to be in an area which would not present planning issues. This excluded buildings in significant residential areas and those in urban areas that may have required additional equipment to mitigate air quality issues.
- Carbon and cost offset – To increase the viability of the overall scheme; a site with a heating system with high running costs and carbon emissions was preferred.
- Positive community impact – Sites that could demonstrate a positive impact on the community were preferred. This could come in the form of lower cost heating to residents/tenants or an increase to internal conditions such as temperature.

With the boiler in place, an assessment of the timber required to meet demand was undertaken to understand the scale of the processing capacity required both immediately and in the short term.

3.2.4 Processing

The selection of a site on which a wood fuel hub could be built was dependent on several requirements of the site itself as well as budgetary constraints. Principally, no budget was available to buy or lease a site therefore only sites owned by the City Council were considered. For the site itself, local biomass processors were consulted to determine the requirements of the site and it was determined that the following would need to be satisfied to allow for a site with the ability to process up to 1,000 tonnes per year:

- Suitable size: A minimum of 4,000m^2 was required to allow for an area to build a shed/pole barn and for outside storage for seasoning of round wood. This would include 500m^2 of hard standing
- Security: At a minimum a tall fence is required and ideally the site would be collocated with other Council services to decrease likelihood of members of the public getting access
- Planning: Not in close proximity to housing or to sensitive locations such as HV power lines due to fire risk
- Access: The roads leading to the site and entrances would need to be able to withstand the frequent movement of heavy vehicles. The turning circles of these vehicles on the site would also need to be considered
- Proximity to parkland: Ideally the site would be to the North East of the City as this would locate it close to the areas that are likely to generate the highest quantities of good quality wood waste

3.3 Implementation

3.3.1 Available wood waste

Waste wood was found to be available throughout the City in various different formats including from Council tree maintenance processes and that which is accrued as general wood waste at recycling centres by members of the public or traders. Additionally, waste wood streams are potentially available from the private sector within the City although these are likely to only be made available at a cost. Table 6 shows the estimated quantities of different sources of wood fuel that are available within the City and the potential cost for those originating from the private sector.

Table 1: Quantity and cost of available wood waste in Stoke-on-Trent

	Source of wood	Tonnes/year	Price (€/tonne)
City Council Stock	Civic amenity sites	Unknown	0
	Parks maintenance	750	0
Private Sector within the City	Local tree surgeons	2,236	~€34.75
	Local wood processing businesses	14	Unknown
	Forestry Holdings	33,000	€55.60
	Waste Wood Recyclers	7,000	€13.90
	Estimated Total	**43,000**	

Each of these sources however presents quality issues which limit usage as a source of woody biomass fuel:

- *Civic amenity sites/waste wood recyclers* – the waste wood deposited at City Council or private recycling centres can comprise all types of woody materials from used pallets to furniture and household items. This is typically contaminated with both paints and metal items such as hinges or nails and would not be suitable for chipping without significant processing. The use in pyrolysis or gasification would be possible although screening would still be required particularly to remove any metal.
- *Park maintenance/tree surgeons* – The is the cleanest of the available sources of wood fuel however there is still some risk of contamination through nails or smaller pieces of metal. There could also be large proportions of leafy material or bark which would impact negatively on the calorific value.
- *Wood processing businesses* – wood processing businesses such as timber mills or furniture manufactures produce significant quantities of off-cuts which are potentially useful. These may contain large proportions of bark though which again would impact on the CV of the resultant fuel.
- *Forestry holdings* – The virgin timber potentially available from forestry holdings is the cleanest however is accordingly expensive.

Based on this information it was clear that the timber from the parks and green space maintenance process was the most appropriate as it was available at no cost, would be relatively uncontaminated and is available in significant quantities.

The review of the timber being felled by the tree maintenance contractors found that in the 2014/15 financial year the proportion of species accrued was as per table 7. This is only considered an estimate as the wood waste is not weighed after each felling and species type is not always identified when undertaking the work. The review shows that the species available have a moderate level of embodied energy but would not compete with typically available virgin timber species such as Beech which has a CV greater than 3.50kWh/kg at 30% moisture content. This would simply increase the volume required to deliver the same amount of heat.

Table 2: Proportion of wood waste by species and average calorific values of each[2]

Species	Proportion	Net Calorific Value by mass (kWh/kg @ 30%)
Lime	40	3.18
Beech	15	3.28
Chestnut	15	2.83
Oak	10	3.25
Willow	5	2.97
Poplar	5	3.16
Other species	10	n/a

3.3.2 Conversion method

With the non-processed waste timber from Council parks maintenance accepted as the most appropriate form of waste wood, the challenge was then to determine the most appropriate method to convert the woody biomass into fuel to be converted to heat.

At the outset of the pilot the use of pyrolysis was considered to be the most advantageous technology as the quality of woody biomass that could be employed was far more variable. This would have allowed the use of not only waste timber from tree maintenance processes but also from select waste originating from community recycling centres.

A review of the practical application of both pyrolysis and direct combustion was undertaken in 2011 and a summary of the findings is displayed in table 8.

Ultimately it was determined that pyrolysis was not a suitable technology for the supply chain. This was due to two main reasons:

- The pyrolysis combustion technology is not mature at the small scale. Bio-oil burners with a capacity of less than 1MW were thought to be available and no bio-oil CHP under 300kWe had been employed at the time of the study in 2012. Systems of this size would have been far larger than the units required at even the largest Council sites.
- The production technology was not available at small scale. Commercially operating units typically produce around 50 tonnes of bio-oil per day, more than 10 times the level that would be required by single boiler planned for.

[2] As taken from A. Höldrich, H. Hartmann, M. Schardt (2006): "Rationelle Scheitholzbereitstellungsverfahren" (Efficient Methods for Preparing Firewood), Report 11 TFZ Straubing and Vito Francescato et al. (2008) Wood Fuels Handbook AIEL Legarno

Table 3: Summary of the findings of the technology review of pyrolysis or direct combustion

	Pyrolysis		Direct Combustion
	In Production	**In Use**	
Maturity of technology	Low - no commercial systems in UK	Low – no commercial systems in UK	Medium > 2,500 systems in UK
Suitability to on-site application	Production facility requires dedicated industrial site	Similar as oil fired boiler or CHP plant	Requires more space for fuel store and boiler than fossil fuel system
Feedstock requirement	Chipped or pulverised fuel to specific requirements of pyrolysis technology	n/a	wood chip or wood pellet
Capital cost	High costs with high technical risk		Medium
Operating cost	Insufficient data available	Insufficient data available	
Fuel efficiency	Maximum 70% yield	Less than 65%	Maximum ~ 90%
Technical suitability for onsite generation	Low - as conversion process presents extra conversion stage	Low – no commercial availability of competitive bio-oil fuel	High - financial mechanism designed to incentivise biomass boilers
Financial suitability for onsite heat generation	Low - as conversion process presents extra conversion stage	Low – limited knowledge of bio-oil within CHP suppliers	Medium – few proven systems at small and medium scales
Technical suitability for onsite CHP	Low - production even at small scale not suitable for non-industrial sites	Low – limited knowledge of bio-oil within CHP suppliers	Medium – few proven systems at small and medium scales
Financial suitability for onsite CHP	Low - production even at small scale not suitable for non-industrial sites	Low - high fuel costs and low technology maturity	Medium - low cycle efficiency and high capital costs for small scale systems

Therefore direct combustion was recommended as the being the preferred technology. A further decision was then required to ascertain whether this should be a wood chip or pellet system. No other systems such as log burning units were considered as an automated system with little or no user interaction was required.

The primary difference between the two forms is the additional equipment required to process the waste wood into the fuel that would be accepted by commercially available boilers. Whereas wood chip needs only to be dried and chipped to the appropriate size, wood pellets typically need to be dried, milled, heated and then forced through a die to create the pellet shape. The processing of wood pellets therefore requires significantly higher capital and operational costs. As the typical benefits of utilising wood pellets (high energy density and ease of storage) were not likely to be significant, it was decided that wood chip would be more appropriate.

3.3.3 Demand

With the most appropriate source of waste timber identified and the conversion method selected, a site was required at which a boiler could be installed to stimulate demand for the supply chain. Against the critical site selection criteria four city council buildings were selected as possible locations as shown in table below.

Table 4: The City Council buildings identified as the most suitable for the installation of the boiler

	Site Type	Estimated Demand
Central Boiler House	Small District Heating System	High – 1,467MWh
St. James House	Enterprise Centre	Medium - 150MWh
Fenton Manor	Leisure Centre	Very High – 2,768MWh
Abbots House	Residential Care Home	Medium – 360MWh

Following detailed investigation of these four buildings, all sites with the exception of the St James House Enterprise Centre were ruled out for the following reasons:

- Central Boiler House – due to the location of the site within a built up urban area, a flue measuring more than 40 meters would have been required to overcome air quality issues and thus was not achievable within the available budget
- Fenton Manor – Significant additional expense would have been incurred as the existing boiler room was not suitable. This would have required the construction of a new external boiler room and associated subterranean pipework which made it less economically attractive. A large gas fired CHP unit was also in operation at the site and the installation of a biomass unit would have competed with this unfavourably
- Abbots House – A new boiler house would again have to be built which would increase the cost considerably. When compared with the expected consumption this made the site an unattractive option

St. James House is an Enterprise Centre located in a former Victorian school which provides high quality office space on short term lets to start-up businesses and community groups. The heat demand at the site is particularly high as tenants are able to occupy the building 24 hours a day, 365 days a year.

Following a detailed business case and design, a 130kW ETA Hack Wood Chip boiler was installed in October 2013 along with a full wet heating system. A radiator system was required as the site was previously heated by an antiquated electric storage heater system which provided little control and often struggled to get the building up to a comfortable temperature. In addition, the system was very expensive to run and led to higher than average carbon emissions for a building of this type.

A ‘Biofuel Intake’ fuel feed system was designed and installed by Perry of Oakley Ltd to allow the use of several different vehicle types in delivery. This was essential to ensure that however the supply chain processing capacity was to be provided, various different vehicle types could be employed to deliver the wood fuel.

In the 18 months following the installation of the biomass boiler, it has generated 320 MWh of heat which has led to an annual demand of approximately 55 tonnes of wood chip. It is noted that this is much higher than the design parameters allowed for as the heating at the site is being used considerably more than was first projected.

3.3.4 Processing capacity

With the supply of waste wood identified and the end user in place, the final piece of the supply chain was to put in place the capacity to process the raw timber into fuel grade wood chip. Two delivery options were identified; that the City Council build and operate a wood fuel hub or that an external contractor delivers the processing capacity at a location already used for the purpose. From the outset the preferred option was to keep the processing capacity within the direct control of the Council at a purpose built facility as this was expected to lead to lower operating costs and increase the long term economic viability of the project.

The development of a wood fuel hub was dependent on two issues; being able to find a suitable site within the City on which a hub could be built and an assessment of the economic viability proving that such a scheme was viable with only the initial demand.

Utilising the key criteria for the site as shown in section 2.1.4, more than 80 City Council owned sites were reviewed to determine suitability for construction of the Wood Fuel Hub. The review found that two sites were suitable to locate hub at which 1,000 tonnes of wood waste could be processed per year:

Table 5: Site review

Former Park Hall municipal golf course	A detailed assessment of the former municipal golf course at Park Hall to the south of the City showed that although it satisfied the initial criteria, significant issues were identified that needed to be overcome. These included the limited size of hard standing which was at the lower end of that required and a legal covenant on the land specifying that it could only be used as a golf course. Although these could be overcome, it became apparent that the primary issue was that the single lane road which led to the site would need to be widened. This condition, which was specified by the City Council Highways Team, led to the determination that the hub could not be delivered on this site when considering the budget available for this stage of the project.
Former colliery at Chatterley Whitfield	The former colliery at Chatterley Whitfield in the North East of the City was an ideal location for the wood fuel hub despite part of the site being a Scheduled Ancient Monument. A feasibility study was undertaken with a view to refitting one of the large former workshops to allow the building to be utilised as the hub alongside a large area of hard standing. It was determined that the site was suitable and although the work required would need to be sympathetic to the special nature of the site, it was possible to achieve this within the specified project budget. It was however also determined that the site had a legal covenant that stipulated that the land could only be used as a mining museum. Although it was thought possible that this could be relaxed, it presented a risk to the project being completed within the available time that was not acceptable.

With no site found on which to build a wood fuel hub with the capacity to process 1,000 tonnes of wood fuel, it was decided to scale back the capacity of the site to allow for a hub to be created which would prove the supply chain concept. This entailed creating a hub that would serve as a pilot to service the wood fuel requirement of the boiler at St James House only. As demand for wood fuel in the City increases following the installation of future boilers, the capacity of the supply chain could be increased when economically viable. As the pilot site would require a capacity of only 100 tonnes, the key criteria was revisited and smaller Council sites with areas as little as 1,000m^2 were considered for the purpose.

Only one additional site could be identified from the Council's corporate estate; the former Excelsior Works in Cliffe Vale, Stoke-on-Trent. This site comprises a large warehouse which is owned by the Council and is partly leased to a third party. This property was initially considered to be suitable as although some internal alterations would be required the cost could be met within the allocated budget. Unfortunately it was determined that the site would require significant flood risk mitigation works and boundary security improvements; the costs of these and the time that would be required to get approval from the flood management authority led to it not being selected.

Ultimately, it was decided that the only way to ensure that an economically viable closed loop supply chain could be delivered was by utilising the services of an external operator to provide the wood fuel processing. This Hub would be owned and operated by a third party who would receive virgin waste wood from the City Council's tree maintenance contractor, season the wood, process it into chip and then deliver it to the Council for use in its boiler system as required.

Following soft market testing it was evident that there were several suppliers within the area that were capable of and interested in undertaking such a contract. The key aspects of the tender were to:

Ensure that there is a legal change of title when the wood goes to the processor to ensure that no unnecessary risk is taken by the Council

Allow for any wood fuel processed beyond that required for the boiler to enter into the contractor's normal fuel stream. This is essential to ensure that fuel from the supply chain is always available for the boiler.

Commit the supplier to maintain the quality of the wood fuel delivered to the boiler to the necessary standard

Following an ERDF compliant procurement process, a four year contract was awarded to Midland Wood Fuel, a locally based wood chip and pellet supplier, in 2015. The contract was based on the supply of 100 tonnes of wood waste for processing and 65 tonnes of wood chip being returned to the boiler. To allow scale to be increased at a later date, both of these figures are indicative only and can be increased in agreement with the contractor. The processing contractor collects the wood waste as round timber when 25 tonnes is accrued which means that smaller arisings are left to enter the wood waste stream as they had previously.

Wood waste is currently being processed and the first delivery is expected to be made to the boiler in early 2016. In the interim, the tender allowed for fuel from the contractors normal stock to feed the boiler.

3.4 Legal Assessment

3.4.1 Legislation pertaining to woody biomass as fuel

The **Climate Change Act (2008)** was created with the aim 'to improve carbon management, helping the transition towards a low-carbon economy in the UK and to demonstrate UK leadership internationally, signalling that we are committed to taking our share of responsibility for reducing global emissions in the context of developing negotiations on a post-2012 global agreement at Copenhagen in December 2009'. It states a legally binding target of 80% cut to greenhouse gas emissions from 1990 levels by 2050 and by 34% by 2020. An independent Committee on Climate Change was also established to advise government on producing annual reports.

Under the **EU Renewable Energy Directive (2009/28/EC)**, the EU has committed to generating 20% of its total energy needs by renewable sources by 2020. In implementing the Directive, each member state has declared within national renewable energy action plans how they will contribute to this target and the UK has stated a target of 15% in the **UK Renewable Energy Strategy (2009)**. Subsequent to this, within the **UK Renewable Energy Roadmap (2011)** the viability of various renewable technologies was examined from both an economic and a practical point of view. Within this document deployment scenarios were detailed and biomass was deemed to have realistic potential to deliver 30% of the overall reduction target. This would be in the form of both liquid and solid biomass led heating and electricity generation with 12% of the overall heat demand in the UK expected to be met from non-domestic biomass boilers.

The **CRC Energy Efficiency Scheme Order (2013)** provides for a mandatory carbon emissions trading scheme which applies to large businesses and public sector organisations within the UK which are thought to produce around 10% of the UK emissions. Participants must monitor and report carbon emissions from non-transport sources and purchase credits for each tonne of carbon which is emitted. Biomass (liquid and solid) is deemed as carbon neutral and thus is an excluded fuel, further incentivising the uptake of this energy source.

The **Energy Act (2008, 2013),** concentrates policies around the decarbonisation agenda in electricity generation but also includes measures to increase electricity capacity and manage subsidies amongst others. Crucially, the Act provides for Electricity Market Reform which includes a change to the way that subsidies for large scale renewable electricity generation are paid. Large scale biomass that is used to create electricity is covered under a part of this scheme called Contracts for Difference. The CfD provides for variable subsidy levels based on market conditions but still offer a guaranteed minimum price to provide certainty to investors.

The Energy Act also provided the mechanism for the **Renewable Heat Incentive (RHI)** in 2008. The RHI provides set tariffs for installers of heating systems that are powered through renewable sources. These include heat pumps, solar thermal and both liquid and solid biomass amongst others. Now available to both domestic and commercial installations, the RHI is designed to meet the target for heat derived from renewable sources as stipulated within the UK Renewable Energy Strategy. Introduced in 2011 for commercial applications and 2014 for domestic, the scheme was modified in both 2014 and 2015 to tighten the requirements for those receiving the subsidy to ensure that those installations utilising biomass is taking fuel from environmental and ethically sustainable sources. This is achieved through two criteria:

- The biomass fuel must represent a 60% reduction in carbon emissions when comparing to the EU fossil fuel average (34.8gCO_2e/MJ in 2015)
- The source of the fuel must meet critical land principles as set out in the **UK Timber Standard for Heat and Electricity (2014)**. The principles stipulate that the timber must be from both legal sources and that a percentage must be shown to be taken from responsibly managed sources (i.e. FSC certified)

This criteria is not dissimilar the non-binding recommendations on sustainability criteria for biomass issued by the European Commission in its report from 2010 (SEC (2010) 65/66). Although those recommendations are meant to apply to energy installations of at least 1MW thermal heat or electrical power, the requirements are required for installations covered by both the Renewable Heat Incentive and the Renewable Obligation Scheme and therefore covers all subsidies relating to biomass in the UK.

The **Renewables Obligation (RO)** has previously been the main subsidy for large electricity creating renewables in the UK. The scheme is only open for new applications up until March 2017 after which point any new schemes will be funded by the CfD's.

Under the RO, operators of certain renewable electricity generating plant are issued certificates for each MWh of energy generated. These are then traded or sold with a minimum price structure to electricity suppliers as the RO mandates that electricity suppliers had to produce a proportion of all electricity from renewable sources (including biomass). The required percentage is increased annually to incentivise further installations.

From April 2015, to qualify for a certificate all RO installations must also meet the minimum sustainability requirements as RHI installations.

The **Climate Change Levy (Fuel Use and Recycling Processes) Regulations (2011)** as allowed for under the **Finance Act (2007)** allows for a tax to encourage reduction in greenhouse gas emissions by charging against energy consumption. The tax applies to both domestic and commercial users although automatic exemptions are available for instances including low usage which typical residential homes will not qualify under. Biomass is excluded from the CCL as it is deemed to be carbon neutral.

The **Green Energy Act (2009)** defines 'green energy' in relation to micro-generation schemes as the generation of electricity or heat from renewable or low-carbon sources by the use of any equipment, the capacity of which to generate electricity or heat does not exceed the capacity of 5MWth. It also serves to provide promote the development, installation and usage of small scale renewables.

The **Planning and Energy Act (2008)** allows local authorities with planning obligations to set requirements for energy use and energy efficiency in local plans, this includes the stipulation of the reasonable inclusion of renewable energy sources, low carbon technology and to require minimum energy efficiency standards. Councils can use such powers to mandate the use of renewable energy such as biomass heating systems in new developments however in practice individual technologies are not typically specified.

Planning Policy Statements are used to set out Central Government policy on aspects of spatial planning at a local level. **The Supplement on Planning and Climate Change (PPS1)** introduced in 2007 provides guidance to Councils on how planning can limit emissions and stabilise climate change. The PPS1 has to be taken into consideration and incorporated into Regional Spatial Strategies. Schemes requiring planning permission also need to embed a low-carbon element to their plans and the PPS can be used in the decision making process.

The emissions from biomass boilers are regulated by the **Clean Air Act (1993)** which defines that boilers that combust more than 45.5kg/hour require installation of a dust or grit arrestor (usually known as a cyclone device) and that the flue height must be calculated to ensure sufficient dispersion. If a boiler is to be installed within a Smoke Control Area, then the boiler must be an exempt appliance under the Clean Air Act. If a boiler is to be installed within an Air Quality Management Area then the Local Authority will be required to assess the impacts of the biomass boiler emissions using the LAQM TG09 which provides a screening tool for biomass boilers. Additionally, biomass boilers under 300kW are required to meet the BS EN 303/5 standard which defines emission limits for different sized boilers.

3.4.2 Woody Biomass as waste

The **Waste Framework Directive (WFD) (2008/98/EC)** provides the framework for the collection, transport and disposal of waste in the EU. The Directive stipulates that any forestry material used in the production of energy through processes is not considered waste as long as they do not harm the environment or endanger human health.

Certain types of biomass considered as part of this pilot are covered extensively in the **Waste Incineration Directive (WID) (2000/76/EC)** as this covers all thermal treatment of waste. This includes direct combustion, pyrolysis and gasification however only wood waste which has been treated with preservatives or coatings containing halogenated organic compounds or heavy metals is considered within the document. Owing to the difficulties in identifying contamination of waste wood, the directive includes provision for wastes from Transfer Stations and other processes which would result in a mixture of waste would be classified as treated and are covered by the WID. The directive requires operators of plant which utilise such waste wood to meet stringent criteria around the handling of the waste, monitoring of emissions and the equipment required to abate hazardous materials being released to the air or water.

Within the UK, the **Environmental Permitting (England & Wales) Regulations 2010** does not classify felled timber as a waste product in certain circumstances such as where the final use of the product is fuel for an appliance. This is only true for waste virgin wood which has arisen from processes such as tree maintenance. All other waste woods that may have been accrued in different ways such as timber mill off cuts or shavings are considered to be waste and environmental permits must be held by the organisation which is storing or processing the timber. As this case study focused on the use of wood chip in small boilers (>300kW), these fuel sources are unlikely to be attractive due to the sensitive nature of such machines. This type of timber could however be of interest if the primary fuel source were to be derived through pyrolysis or gasification as the quality of the fuel type is of less concern.

As the use of fuel derived through timber based pyrolysis or gasification is only now beginning to be brought into mainstream use (although in limited quantity and scale), the UK government has not yet expressly stipulated its approach to permitting. It has been advised however in a regulatory position statement (**Environment Agency, 2012**) from the Environment Agency that the treatment of 150kg of this material per day is allowable without any specific environmental permit.

3.4.3 Future implementation in the UK

With estimates showing that biomass demand in the UK could increase 10 fold between 2010 and 2020 (Panoutsou, et al., 2011), current supply chains are likely to be overextended and cost implications will drive the search for alternative sources. At the same time, a review of the availability of biomass in the UK has found that there is estimated to be more than 492,000 tonnes (oven dried weight) of arboricultural arisings produced each year (Forestry Contracting Association, 2003), demonstrating a huge potential source of biofuel.

With the introduction of the sustainability criteria under the RO and RHI, the regulatory framework appears to be moving in the direction of reducing dependence on timber sources with high levels of embodied carbon. This will have the impact of decreasing the attractiveness of foreign sources of wood fuel and should see demand for local supply chains increase.

Fluctuating natural gas and oil prices will impact both positively and negatively on the implementation of closed loop biomass supply chains in the future. The current comparatively low fossil fuel costs serve to make biomass a less attractive option for heating fuel despite the inherent carbon reduction benefits. This has decreased the incentive for building operators to install biomass heating systems, despite the RHI providing a generous subsidy. Decreasing demand may lead to decreasing commercial prices of wood chip and pellets and will therefore impact on the economic viability of a supply chain when comparing to virgin sources.

Closed loop supply chains are likely to be of most interest to bodies that have both large demand and also requirements to maintain significant areas of green space. This is certainly likely to include Local Authorities but other public institutions such as Local Health Trusts, and Local Housing Authorities. It may be that collaborations would also be of interest, bringing together organisations with significant tree maintenance requirements with large biomass users. A list of the potential collaborators is shown in table below.

Table 6: Public and private bodies in the UK that would be likely find closed loop supply chains economically attractive

Supply Side	Demand Side
Network Rail	Local Authorities
Highways Agency	Police Authorities
Canals & river trust	Fire Authorities
Forestry Commission	Health Services
English Heritage	Housing Associations
Water Companies	District Heat Operators
Ministry of Defence	
National Parks	
National Grid	

The single largest barrier to implementing closed loop supply chains in the UK is from the distance between the source of the waste wood and the end user. As such larger Councils in the UK may find that they have to undertake a mapping exercise to understand the areas of demand around which clusters of waste wood can be drawn from.

The experiences detailed within the pilot description show that the different processing delivery methods offer advantages that should be considered by any organisation wishing to implement such a supply chain. As with the case of Stoke-On-Trent City Council, it may be advantageous for an organisation to utilise a third party to undertake the processing to reduce the immediate risk. Once the viability has been proven the capacity could then be brought in house to increase the income or cost avoidance potential.

Further investigation needs to be made to understand the impact that recovering waste wood from arboreal arisings can have on associated biomass streams. For example, a study of tree maintenance contractors in Herefordshire in the UK identified that a significant quantity of waste timber was either being sold or given away to other parties to be used in the biomass stream (see figure 15). An assessment needs to be undertaken to determine the impact that diverting these sources would have on the overall biomass market although this may not significantly impact directly on the viability of the supply chain.

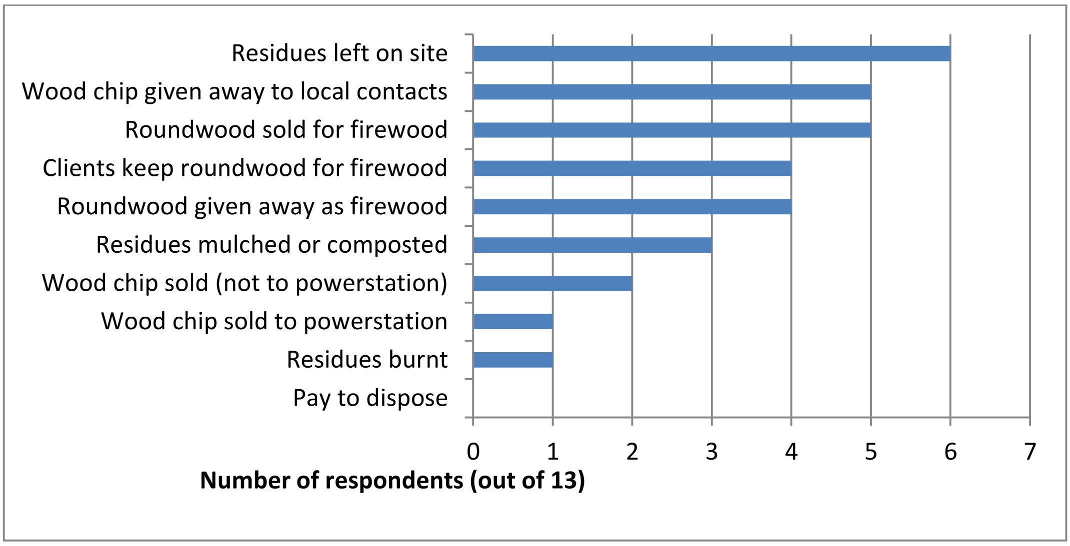

Figure 13: Methods of disposal of wood waste by tree maintenance contractors in Herefordshire (note that respondents could choose more than one)

3.5 Economic Assessment

As the project changed direction during implementation, the economic assessment of the pilot was undertaken using the three different processing scenarios put forward in the pilot description:

- Scenario 1: A purpose built wood fuel hub with the capacity to process 1,000 tonnes of wood waste per year
- Scenario 2: A pilot hub utilising an existing building with the capacity to process 100 tonnes of wood waste per year
- Scenario 3: As implemented, the processing of 100 tonnes of wood waste per year by a third party.

All assessments assume an exchange rate of 1 GBP to 1.39 Euro.

3.5.1 Wood Fuel Hub processing 1,000 tonnes

The cost to construct and operate the wood fuel hub with a capability of producing 1,000 tonnes of wood chip is shown in table 11. This assumes that the site would not already have a suitable building in situ or any hard standing which could be utilised. Two options around the equipment required for processing are considered, with both the cost of purchase and of hiring shown. Assumptions were required around the frequency that this equipment would be required for hire and were made after consultation with local biomass providers.

It has been assumed that one full time member of staff would be required but that additional skilled operators could be brought on as required. Other costs have been estimated to include business tax, insurance and the maintenance cost of buildings.

Table 7: Overview of costs relating to the construction and operation of a medium sized wood fuel hub

Construction including pole barn, 500m2 hard standing, utilities connections and blocks for material separation	**€102,16**
Equipment including **purchase** of loader, screener, chipper, delivery unit	**€271,050**
Equipment including **Hire** of loader screener, chipper, delivery unit[3]	**€54,210/y**
Staffing comprising one full time site manager	**€41,700/y**
Other costs including business rates, management costs, utilities, maintenance, insurance etc.	**€13,900/y**

This table shows the five year profile of operation including the initial capital costs. The analysis does not include any costs in relation to the borrowing that may be required to implement the project. In addition, no allowance has been made for the requirement to replace equipment should it be purchased at the outset. Indexation has been applied to staff and 'other costs' to represent growth.

As the waste is provided as 'green' it will naturally decrease in weight during processing and will not produce an equivalent quantity of wood fuel. As such the figure representing cost per MWh utilises an averaging factor of 0.6 (Francescato, et al., 2008) to represent the mass to fuel ratio that would be expected for a fuel that has a moisture content of 50% prior to processing and 30% on delivery. Based on the CV of the expected waste wood a representative value of 3.2MWh/Tonne is then used to determine acutal MWh produced per year from 1,000 tonnes of waste wood.

Table 8. Projection of costs over a five year period including summary of cost per MWh produced (all figures €)

	Year 1	Year 2	Year 3	Year 4	Year 5
Construction	102,165	0	0	0	0
Equipment (purchased)[4]	271,050	4,865	4,865	4,865	4,865
Equipment (hired)	54,210	54,905	55,600	56,295	56,990
Staffing	41,700	42,534	43,385	44,252	45,137
Other costs	13,900	13,900	13,900	13,900	13,900
Total Cost (equipment purchased)	428,815	61,299	62,150	63,017	63,902
Cumulative		490,114	552,264	615,281	679,183
€/MWh cumulative	**223.34**	**127.63**	**95.88**	**80.11**	**70.75**
Total Cost (equipment hired)	211,975	111,339	112,885	114,447	116,027
Cumulative		323,314	436,199	550,646	666,674
€/MWh cumulative	**110.40**	**84.20**	**75.73**	**71.70**	**69.45**

The assessment shows that the cumulative cost difference between buying and hiring the equipment is only around €10,000 by year five largely due to the cost to maintain the equipment. Wood chippers are typically high maintenance as they expend blades and belts fre-

[3] Assuming 6 days hire of screener and chipper and 12 days of loading, delivering per annum
[4] An estimate for annual equipment maintenance has been included from year 2

quently and the blades also need to be sharpened routinely. Therefore it may only be advantageous to buy the equipment if the frequency of use were to exceed that allowed for – 6 chipping days and 12 for deliveries.

The wood chip produced is initially expensive to manufacture at more than €200 per MWh if the equipment is purchased outright but decreases to around €70/MWh with both options by the fifth year of operation.

3.5.2 Pilot wood fuel hub processing 100 tonnes

The cost to construct and operate a smaller pilot wood fuel hub with a capacity to process 100 tonnes of wood chip is shown in table 13. Construction costs are significantly lower as the assumption is made that the building on site could be adapted for use. It is assumed that limited hard standing on site would need to be expanded by 500m^2. As the same equipment would be required, regardless of quantity produced the price to purchase remains the same. The maintenance of this equipment is however considered to be around half that of the medium sized wood fuel hub as it would not be utilised as often. As chipping would be likely to happen only twice a year the staffing costs are decreased by 75%.

Table 9: Overview of costs and income relating to the construction and operation of a pilot wood fuel hub

Construction of 500m2 hard standing, utilities connections, modification of existing building and blocks for material separation	€46,565
Equipment including **purchase** of loader, screener, chipper, delivery unit	€271,050
Equipment including **Hire** of screener, chipper, delivery unit[5]	€20,850
Staffing comprising one part time site operator	€11,120
Other costs including business rates, management costs, utilities, maintenance, insurance etc.	€11,120

Table 10: Project of costs vs income over a five year period for the pilot hub

	Year 1	Year 2	Year 3	Year 4	Year 5
Construction	46,565	0	0	0	0
Equipment (purchased)	271,050	4,865	4,865	4,865	4,865
Equipment (hired)	20,850	21,545	22,240	22,935	23,630
Staffing	11,120	11,342	11,569	11,801	12,037
Other costs	11,120	11,120	11,120	11,120	11,120
Income vs expenditure (purchased)	339,855	27,327	27,554	27,786	28,022
Cumulative		367,182	394,737	422,522	450,544
€/MWh produced	**1,770.08**	**956.20**	**685.31**	**550.16**	**469.32**
Income vs expenditure (hired)	89,655	44,007	44,929	45,856	46,787
Cumulative		133,662	178,592	224,447	271,234
€/MWh produced	**466.95**	**348.08**	**310.05**	**292.25**	**282.54**

[5] Assuming two chipping days and six deliveries per year

Despite lower operating costs, the five year profile shown in Table 14 demonstrates clearly that the pilot hub is not economically viable. The potential income available from the relatively small quantity of wood chip does not outweigh the requirements for equipment and staffing. It may be that the frequency of chipping could be reduced to a single instance however the pole barn/shed would need to be larger and the management of timber and wood chip to ensure that fuel is available for delivery would be more difficult. Costs relating to rental of vehicles for loading and delivery could also be decreased however this would not be significant enough to make the option viable.

3.5.3 As implemented – Processing contracted to Third Party

The wood fuel processing contract was split into two component parts; the sale of waste wood to the processor and the purchase of wood heat delivered to the boiler. The installation of a heat meter on the biomass boiler flow and return pipework ensures that the processor is incentivised to provide wood chip of the highest quality. The cost and income agreed is shown in table 15 with the indexing as per the contract for the full 4 year term. The costs around staffing to coordinate the collection are considered to be negligible as this could be organised by the Officer within the Council instructing the tree maintenance works to be completed.

Table 11: Costs agreed for both sales of wood waste and purchase of wood chip over the course of the contract

	Year 1	Year 2	Year 3	Year 4
Sale of wood waste (tonne)	€38.92	€40.31	43.09	€45.18
Purchase of wood chip (MWh)	€66.72	€70.89	€75.06	€75.06

The contract was tendered with the assumptions that 100 tonnes of wood waste would be provided to the contractor and that 190 MWh would be taken back as wood fuel. This was determined to be the actual annual requirement for the wood fuel boiler in a year with weather matching that of the 20 year average.

Table 12: Assessment of the overall cost of the third party processing contract

	Year 1	Year 2	Year 3	Year 4	Year 5[6]
Sale of 100 tonnes of waste wood	3,892	4,031	4,309	4,517.5	4,726
Purchase of 190 MWh of wood chip	-12,676.8	-13,469.1	-14,261.4	-14,261.4	-15,053.7
Income vs expenditure	-8,784.8	-9,438.1	-9,952.4	-9,743.9	-10,327.7
Cumulative		-18,222.9	-19,390.5	-19,696.3	-20,071.6
€/MWh cost to Council	**45.75**	**47.46**	**48.92**	**49.37**	**50.26**

The analysis, shown in table 16, shows that the supply chain results in considerable expense to the City Council of around €20,000 over five years. When comparing this to the fuel delivered however an average cost for each MWh of heat €48.35 is achieved throughout the five year duration.

[6] Although the contract is for 4 years, indexation based on the price trend of the contract has been applied to show a cost for year 5 to allow fair comparison between scenarios

It should be noted that the contract allows for the sale of more wood waste than the 100 tonnes required by the boiler at St James with any excess serving to enter into the processors normal fuel streams. As such the financial viability of the supply chain could increase considerably, with a break-even level of approximately 325 tonnes of waste wood each year.

3.5.4 Summary of economic assessment

The economic assessment of the first five years of the supply chain shows that the implemented third party processing scenario represents the most economically advantageous option. As table 17 shows, the third party scenario will see fuel delivered for an average of €48/MWh for the course of the contract, considerably lower than the other options. The large wood fuel hub capable of processing 1,000 tonnes of wood waste would provide fuel which is on parity with commerically available prices, but would be almost 40% more expensive than that produced by the third party. Fuel provided by a pilot hub is clearly not at all viable with costs greater than €280/MWh.

Table 13: Comparison of the most advantageous five year economic profiles

	€/MWh over five years
Commercial price[7]	69.47
Wood Fuel Hub	69.45
Pilot Hub	282.54
Third Party Processing	48.35

The costs of several of the options could be varied based on the system chosen. The price demonstrated by the third party contract is dependent on only 100 tonnes of wood waste being provided each year, considered to be at the lower end of the estimates. Should more than 350 tonnes be made available this figure could actually represent revenue rather than a cost. The large wood fuel hub itself could see its costs reduced as the actual requirements for equipment could be lower than projected however the demand for the estimated 600MWh of fuel created in this scenario is also largely dependent on significantly increasing demand in the City.

Although the long term preference is for the processing to take place at a hub operated by the City Council, it is clear that the economic viability of such a move will be difficult to prove. Undoubtedly demand in the City will need to grow significantly from its current point and as such additional boilers are being considered in City Council buildings. It is clear however that private sector users will also be required to prove the viability, and a review of these boilers is currently being sought. In addition to this, the possibility of setting up a wood fuel hub that would be able to valorise several different forms of wood waste is being investigated. This would include the sale of wood chip, wood pellets, logs and horticultural grade wood products to the public.

[7] Price secured through 2014/15 contract with MWF (€66.75/MWh) including projected index (RPI @ 2%). This contract has since been superseded with the current arrangement

3.6 Ecologic assessment (Life Cycle Analysis)

This section summarises the life cycle assessments undertaken for each of the three supply chain delivery scenarios detailed in the pilot report. The assessments have been undertaken utilising UK Solid and Gaseous Biomass Carbon Calculator (B2C2) made available by the UK Office of Gas and Electricity Markets (OFGEM)[8]. The B2C2 is the primary tool used by biomass suppliers in the UK to assess the GHG emissions which result from production, transport and combustion of solid and gaseous biomass fuels. This tool is used to calculate the carbon intensity of biomass supply chains to demonstrate that they meet the sustainability criteria required under the RHI and RO as discussed in section 3.2.1.

3.6.1 Included processes and assumptions

The analysis included a comprehensive assessment of all of the individual processes involved in the supply chain as detailed in table 18. Included within this table are the general assumptions that have been required at each stage to provide a representative figure.

Table 14: Stages of biomass production assessed and assumptions

Stage	Assumptions
Harvesting – emissions resulting from felling and roadside processing	Felled wood has a moisture content of 50% 35MJ/t required to fell wood (EUCAR, CONCAWE, JRC/IES, 2008)
Feedstock transport – Delivery of waste wood to processing hub	8km in Scenario 1&2 (estimated) 47km in Scenario 3 (actual)
Drying – Seasoning of green timber	Naturally dried to 30%
Biomass Conversion – Chipping to G30 standard	Diesel chipper utilised
Storage – Storage prior to delivery	No emissions resulting from storage
Feedstock Transport – Delivery of wood fuel to boiler(s)	8km in Scenario 1&2 (estimated) 47km in Scenario 3 (actual)
Combustion	Combustion plant is 70% efficient

In addition, it is assumed that there is no difference in the embodied carbon between implementation scenarios 1 and 2 as both require the delivery of wood waste to a central location and have similar processing requirements. In practice there could be high carbon emissions associated with the pilot wood fuel hub resulting from less production each time equipment is required. Deliveries to multiple boilers at the same time would also not be possible.

Excluded from the analysis is the carbon that would be required to construct the hub, the emodied carbon associated with manufacturing the vehicles and the secondary emissions such as commuting.

[8] Accessible at https://www.ofgem.gov.uk/publications-and-updates/uk-solid-and-gaseous-biomass-carbon-calculator

3.6.2 Comparison of delivery scenarios

A summary of the life cycle assessments is shown in figure 16 along with the standard figures for wood chip drawn from virgin timber as taken from the Department for Energy and Climate Change GHG reporting guidelines (AEA, 2012). The results show that both the designated wood fuel hub and the third party processing service provide a reduction in embodied CO2e when compared to the virgin timber average from standard biomass processors. This is primarily the result of the shorter distances between wood source, processing hub and the end user.

The comparison between the wood fuel supply chain delivery options shows a marked difference with the CO_2e intensity of the third party solution being almost twice as much. This is the result of the processing contractor being located 48km away from the City Centre and the emissions resulting from the transport. This could be mitigated in future by reducing the number of journeys, through increasing the quantity that can be collected each time or choosing a supplier with a hub located closer to the source of the materials.

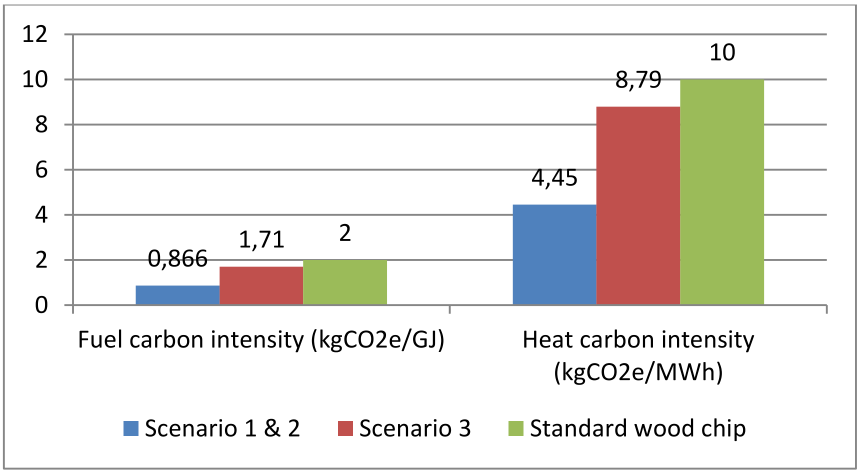

Figure 14: Comparison of life cycle emissions of the supply chain scenarios against standard factors

3.6.3 Comparison with fossil fuels

To allow for a fair comparison of the carbon intensity of the fuel from the supply chain with other non-renewable sources, the heating system at St James House Enterprise Centre was used to model the emissions. This allows for the inherent losses that would be incurred through the different systems to be accounted for across the range of fuels available.

Figure 17 shows the emissions that would occur assuming that 190MWh is the total heating requirement as actual heat into the building. General assumptions of heating system seasonal efficiencies have been included to allow for the conversion of fuel to heat. These have been assumed as grid electricity 100%, natural Gas 90%, gas oil 80%, coal 70% and Wood chip 70%.

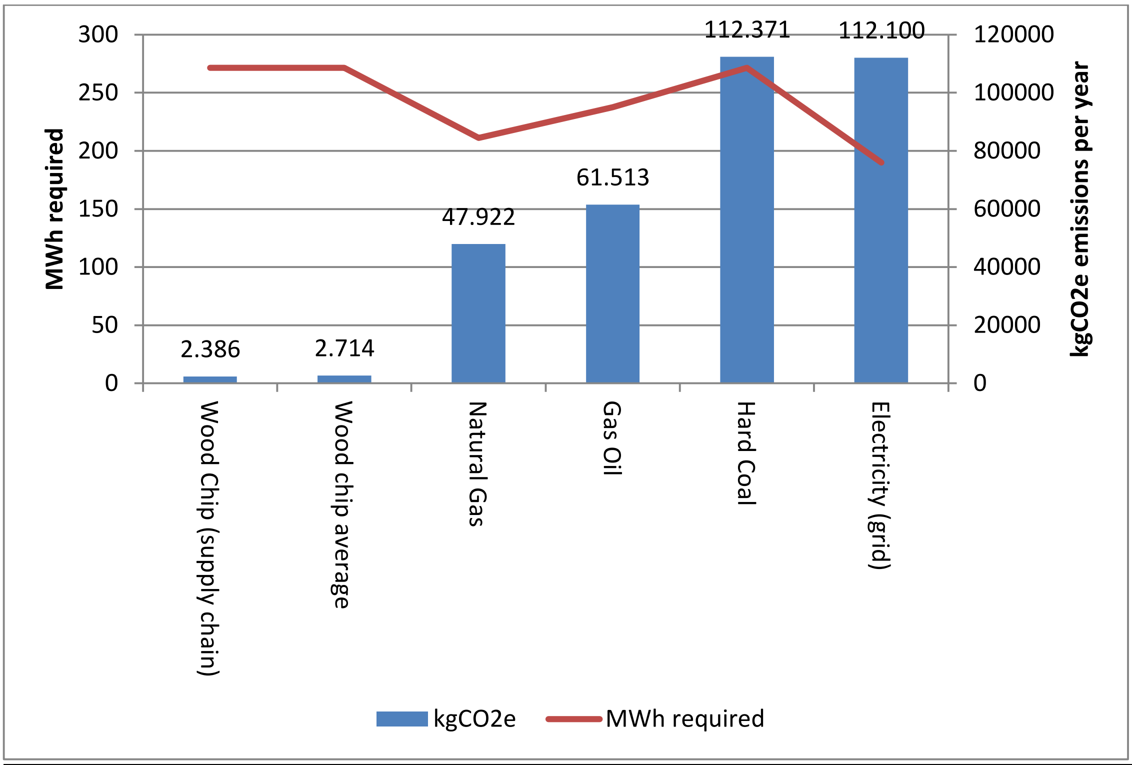

Figure 15: Comparison of emissions from heating fuel at St James House

3.6.4 Life cycle summary

In conclusion, it is clearly more advantageous from a carbon perspective to utilise wood chip that has been processed at a dedicated wood fuel hub within the City. It must be noted however that this assessment did not seek to identify the emissions associated with building the wood fuel hub; therefore it may not stand up in principle. The comparison shows that wood chip from the supply chain emits 12% less CO2 than average wood chip values but marginally more than the wood fuel hub scenario.

As St James House the model shows a 97% reduction in emissions in comparison to the electric heating system which was in place prior to the project.

3.7 Conclusion and regional strategy recommendations

A closed loop supply chain is now in place resulting in local wood waste being recovered from the Council's tree maintenance work which is then subsequently being processed into wood fuel by a third party. The supply chain commenced operation in the first quarter of 2015 and although delivery back to the boiler has not yet commenced, an anlaysis of the economic sustainability of the process is possible.

The available wood waste chosen for the closed loop supply chain represents the highest quality fuel available for the lowest cost to the Council. Contamination should be minimised in comparison to other available streams and screening prior to processing will ensure a high quality wood chip. There are limitations on the volume of wood available; however there are additional streams which could be brought online in the future, although this may come at a cost.

Wood chip was selected as the preferred medium rather than wood pellet as the treatment process required offered no significant benefits to the supply chain. Ruling out pyrolysis as a conversion technology due to the unavailability of the technology at small scale resulted in a higher quality of waste wood being required. Ultimately, a wood chip biomass boiler was installed at St James House Enterprise Centre in October 2013 replacing an aged and poorly performing electric heating system. The system has generated an initial demand of more than 60 tonnes of wood chip per annum.

The difficulties experienced in identifying a location for a wood fuel hub to provide the processing capacity for the supply chain shows how the implementation of such an undertaking should not be underestimated. The primary issue was found to be access, with the size of the heavy vehicles required ruling out many of the possible sites. With no sites being available for the siting of a medium sized hub capable of processing 1,000 tonnes or a smaller pilot hub, the processing capacity was contracted out to a local biomass supplier who would collect the wood waste and return it to the boiler as fuel grade wood chip.

Economically, a comparison between the different supply chain approaches showed that the solution as implemented represents the best value for money over a five year period although the fuel produced has slightly higher carbon content. Fuel is expected to be provided at an average cost of €48/MWh over the first five years with an estimated carbon content of 8.8kg/MWh. The level of risk to the Council is also minimised, as the purchase of equipment and building of the hub have been avoided, as well as a mechanism being put in place to provide avenues to mitigate variations to supply.

In terms of carbon, the supply chain as implemented results in slightly higher emissions than a wood fuel depot would have as the distances between source and the processing location is considerable. In comparison with the average for commercially available wood chip, the supply chain offers slightly lower CO_2e emissions although the wood fuel hub would have compared more favourably.

The Council intends to bring the processing capability back within its control, however it will first need to demonstrate that the operating costs can be reduced and that demand can be increased to make it economically viable. Should the processing be brought back in-house, it would be possible to decrease the size and quality requirements and therefore could lead to considerable increases in the quantity of wood waste available.

Ultimately, the woody biomass supply chain in Stoke-on-Trent has identified a new and until now underutilised source of low carbon energy. As local biomass supply chains are beginning to come under strain as demand increases, such sources of biomass will become increasingly more attractive to utilise. Many local authorities will be in a position to set up similar supply chains although larger counties may find that clusters of demand need to be identified to reduce transport costs. It may be that links between two or more groups may prove attractive as organisations that produce large quantities of wood waste could work with operators of biomass plants to produce an economic benefit to all parties. Alternatively, the recovery of waste wood directly into the commercial biomass stream as has been implemented in this case could prove to be the most risk averse and straight forward method of increasing the valorisation of what would otherwise potentially be waste.

4 Closed loop systems of biomass valorization by local authorities-Saarland strategy development for a sustainable landscape material valorisation in the UNESCO Biosphere Reserve Bliesgau

4.1 Case study description

The project aims at the development of a valorisation strategy for landscape material and greenery cuttings in the UNESCO Biosphere Reserve Bliesgau, located in the Southern part of the Federal State Saarland, Germany. The Biosphere Reserve underlies designated restrictions regarding landscaping and nature conservation. In particular, defined areas need to conserve their ecological functions described in the objectives of the UNESCO Biosphere Reserve Bliesgau, e.g. semi-natural grassland formations, orchards lanes. Consequently, an extensive landscaping by extensive agriculture or nature conservation activities are mandatory.

The purpose of the research is to evaluate sound, regional sustainable closed loop solutions for the acceleration of bioenergy from landscaping materials and greenery cuttings within the specific requirements of the UNESCO. The overall aim is that the investigated scenarios allow better ecological and socio-economical outcomes for the region than the current system. However, the potential use of biomass for a regional bioenergy supply is restricted not only by management (amounts and collection), but also by quality and technical aspects. Later, the study moves the focus on related regional biomasses. E.g. horse straw and manure as co-input for energy conversion.

ARBOR Objectives

AG "Biosphäre": Development and applied implementation of a sustainable model of use for the scopes "municipal green waste" und "landscape preservation materials from extensive agriculture" within the model region

- Coordinated material flow management for greenery cuttings
- Development and establishment of valorisation plants for grass-like green waste
- Handle potentials of extensive areas/land

4.2 Benchmarking

The biosphere reserve Bliesgau covers a surface area of 36,150 ha. 38 % (11,000 ha) is forest, 26 % (9800 ha) is used as grasslands and 16 % (5900 ha) is used as arable land (SAARFORST, 2012). Additionally, 1,100 ha of this area belongs to the core zone and thereby are completely not in use and reserved for natural development. Another 7000 ha belongs to the buffer zone. The aim of these areas is to preserve cultivated landscape from human utilization and work as a buffer to the core zone. Therefore the cultivation of the grasslands, which were former used as fodder and as litter in livestock farming, must continue. Finally, 22 % of the whole area (30 % of the forest and agricultural land) are protected conservation areas.

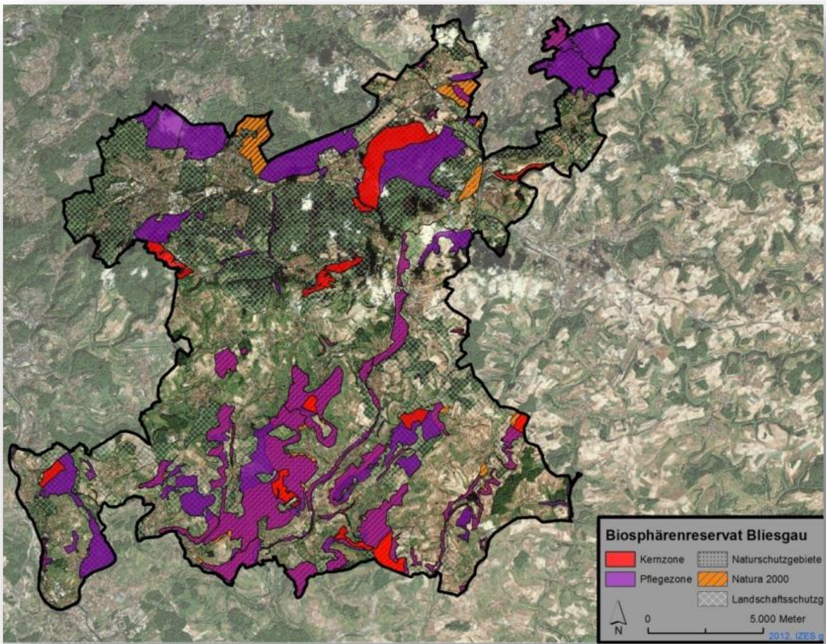

Figure 16: Boundaries of Biosphere reserve Bliesgau [red: core zone; violet: buffer zone; orange: Natura 2000]

4.3 Potential

4.3.1 Landscape material from nature conservation areas

According to the national agriculture subsidies databank, in the biosphere reserve Bliesgau only 7700 ha or 78 % of the grasslands are managed (InVeKos)[9]. Additionally, the grass yield in the region is consistently low or pour, with only 4 t grass (dry matter) per ha of production.

In the buffer zone there are 1900 ha of grasslands and 1400 ha of them are currently cultivated. The yield is less than the normal as only 2 t / ha can be achieved due to a reduced harvest. While the normal grasslands are cut twice (or even three times) a year, the grassland in the buffer zone is mown only once a year. Especially in nature conservation areas, the harvest time is limited. In accordance with the regional lease agreements, the meadows may only be cut once or twice per year and the earliest date for cutting is the 24th June (concerning two cuts it is 24th June and 15th August).

The grasslands of the biosphere reserve have a total potential of 32,200 t grass per year, which is partially already used as cattle feed. The region holds approximately 10.000 livestock units. They have a fodder use of grass and silage of 28,200 t per year. As a result, Accordingly the grass yield and use left a gap of 4,000 t per year.

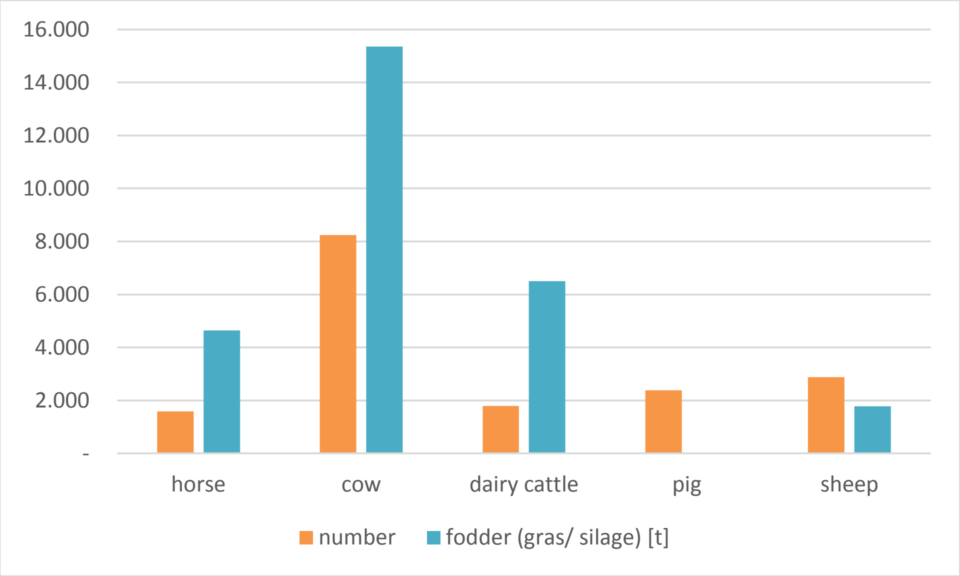

Figure 17: Numbers and fodder use of cattle

[9] InVeKos: Integriertes Verwaltungs- und Kontrollsystem

4.3.2 Greenery Cuttings from private and public garden and park areas

The greenery cuttings from private and public gardens and park areas are collected by the local municipalities. This region has 17 municipal collection points.

Every year 10,000 – 13,000 t of greenery cuttings and landscape material are collected and disposed. The delivered material is divided into a wooden and an herbaceous fraction, being nearly one third of it wooden based. Therefore, 3,500 t of wooden biomass and nearly 8,500 t of herbaceous biomass accrue in the region. 20% of the whole material, mainly from the wooden part, is already used for energy production and 80 % is composted. Furthermore, nearly 1,500 t of wooden and 8,500 t of herbaceous material is currently not in use.

4.3.3 Residues from agriculture (e.g. manure)

Approximately 10,000 livestock units live in the biosphere reserve. These animals produce about 54,000 t of liquid and 15,000 t of solid manure per year. While cow manure is essentially used as fertilizer on agricultural land, horse manure (mainly solid manure; about 2,600 t) is stored on open windrows.

4.3.4 Wood residues

In the biosphere reserve, 19 % of the woodland area is conserved and 81 % is cultivated. Additionally, these woodland produces residues which can be used to produce energy. In fact, currently nearly 33,000 m^3 wood could be harvested for this purpose. In rural areas, where houses still have wood-burners, half of the wood energy is already in use.

4.3.5 Energetic processes

The above mentioned biomass materials differ in structure and characteristic. Because of that, not every biomass fits to the same energetic process. In general, three main processes exist to use biomass for energy. These are the thermochemical conversion (combustion, carbonization, gasification and pyrolysis), the physical-chemical conversion (compression, transesterification) and the biochemical conversion (alcoholic fermentation, anaerobic digestion, aerobic degradation). Combustion, as an example of thermochemical conversion, and anaerobic digestion (biogas), in the field of biochemical conversion, are fully established in the market.

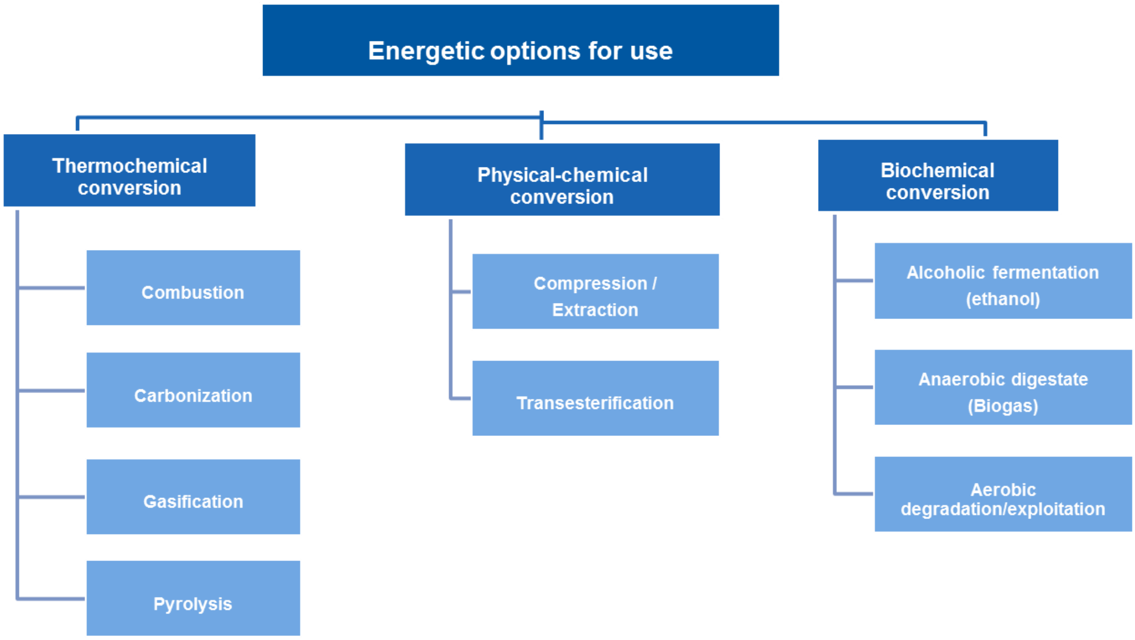

Figure 18: Options for energetic use of biomass

These technologies need different types of biomass for stable operations. For an ideal energetic use, fuel and process must be coordinate. Therefore, in general the characteristics of the fuels must be known.

The table shows the input material and the suitability to two energy conversation technologies, i.e. combustion and digestion. Furthermore, key factors, moisture content, ash content and gas yield are described and rated.

Table 15: Evaluation of input material and conversation technology

	Combustion	Digestion
Type of Biomass		
Landscape material lignin-rich herbal biomass	+	+-
Greenery cutting – Fine fraction (herbaceous)	-	+-
Greenery cutting – Coarse fraction (wooden)	+	-
Agricultural residues - liquid manure + part of solid manure (cow)	--	++
- solid manure (horse)	-+	++
Wood residues	++	--
Key factors		
Moisture content	High: -- Low: ++	High: ++ Low: -
Ash content	High: -- Low: ++	
Gas yield		High: ++ Low: --

4.3.6 Regional biofuels

Against this background some regional materials were collected and dried. Afterwards, they were tested for their attributes at Staffordshire University (UK). As the focus of the analysis was on grass from nature conservation areas, three different types of grassland and two types of greenery cutting (fine fraction and coarse fraction) were tested. The following table shows the tested materials.

Table 16: Material for fuel tests

ID	Material	Place	Description	Photo
01	hay -1	Reinheim - Hölle am Hochwald	semi-dry grassland (Fieder-Zwenke; Brachypodium pinnatum)	
02	hay -2	Rubenheim Hannock	location relatively rich in nutrients	
03	hay -3	Zentral Loheplateau, Reinheim - Auf der Höhe	dry grassland	
04	Greenery cutting - fine fraction	Deponie Hölschberg	Fine fraction: material after separation by sieving (used for compost)	
05	Greenery cutting - coarse fraction	Deponie Hölschberg	Coarse fraction: material after separation by sieving (used for burning)	

Results of the analysis shown in the figure below reflect a moisture content of 10 % for all materials, except from the coarse fraction of the greenery cutting that lies near 18 %. Moreover, the ash content is also below 10 % in most of the cases and only the fine fraction shows values over 25 %. The heating value ranges between 15 and 19 MJ/kg.

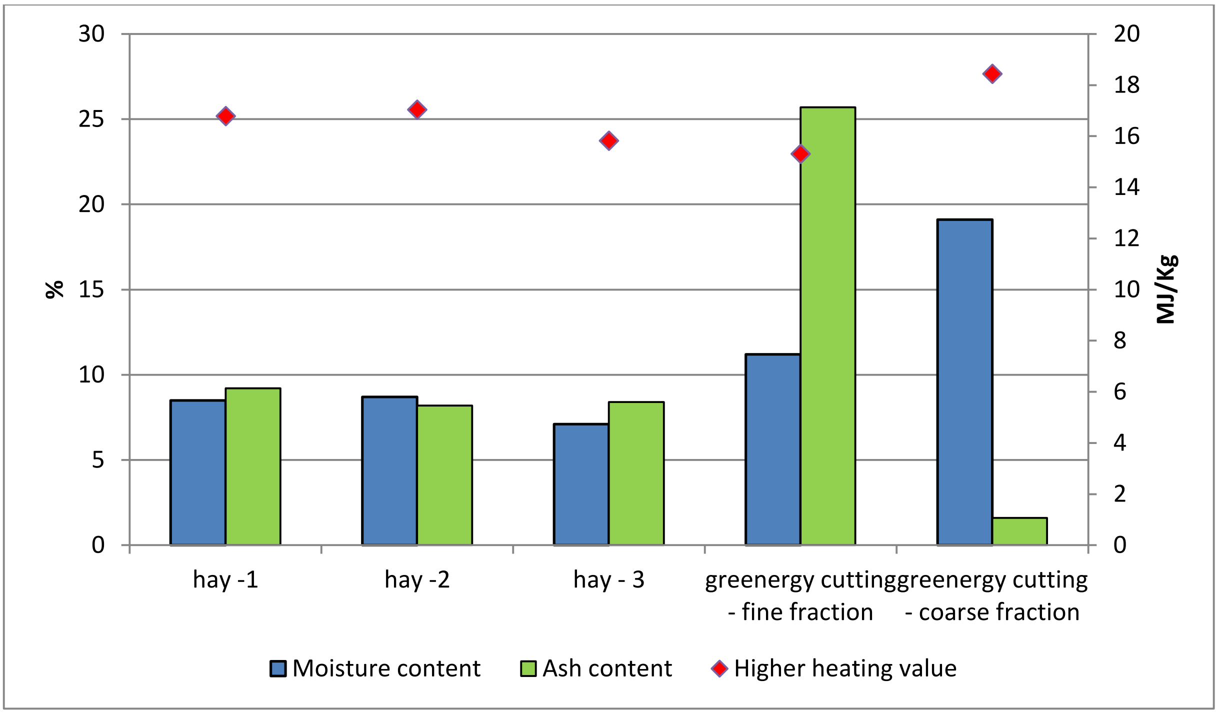

Figure 19: Moisture and ash content and heating value of the tested biofuels

4.4 ARBOR scenarios

On the background of the existing potential and the local circumstances, five scenarios arise. In discussion with regional stakeholder, such as representatives from the conservation sector[10], the agricultural sector[11] and the governmental sector[12], the scenarios were coordinated and refined.

Due to the different materials arising (waste, greenery cutting, agricultural residues) and the low amount of them, the scenarios give an overview of the possible options for an energetic valorization. These are dry and wet fermentation as well as combustion. Later, the state of the art is also modeled in order to compare all the systems.

The procedures shown below were analyzed in this case study.

[10] Manager of the administration union of the biosphere reserve (Interview 08.02.2012)
[11] Chairman of the farmer's association (Interview 06.03.2012)
[12] Head of Department Environment, education and building of the rural administrative district Saarpfalz-Kreis (Interview 06.03.2012)

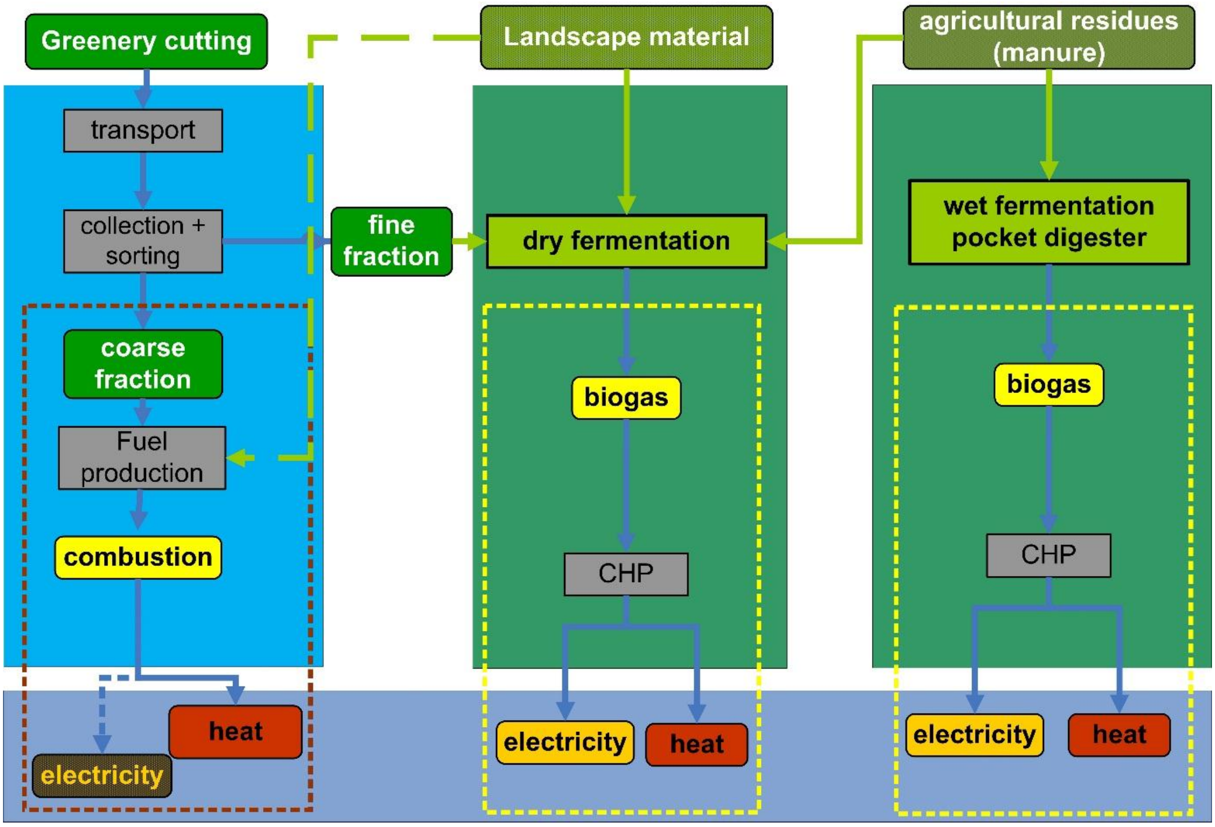

Figure 20: Analyzed processes

The following scenarios were ultimately determined for municipal greenery cuttings and landscaping conservation material utilization in the biosphere reserve:

- **Biosphere_0: Status Quo**
  Material use as fodder or as litter in livestock farming.
- **Biosphere_1: Dry Fermentation**
  Dry fermentation process with input mix of landscaping material, municipal green and garden waste and horse straw.
- **Biosphere_2: Dry Fermentation small scale**
  Dry fermentation process with input mix of landscaping material and greenery cutting.
- **Biosphere_3: Combustion**
  Burning of biomass of landscaping materials and greenery cuttings
  3a) wooden biomass
  3b) Hay and straw burner
- **Excursus**: **Biosphere_4: Pocket digester**
  Pocket Digester based on exclusively manure input.

4.5 Legal assessment

While the normal grasslands were cut twice (or even three times) a year, the grassland in the buffer zone is mown only once. Especially in nature conservation areas the harvest time is limited by nature conservation legislation. In accordance with the regional lease agreements, the meadows may only be cut once or twice per year. Moreover the earliest date for cutting is the 24th June (concerning two cuts it is 24th June and 15th August). Additionally to receive the feed in tariff for energy production from landscaping material from nature conservation areas, there is a legal limitation for mowing the areas maximum twice a year (Renewable Energy Act (EEG) 2012, plants in first operation from 2012-2014). This higher fee was provided because of the lack of activating these materials. In general landscaping material is under the waste legislation. The latest EEG 2014 pays this material off with the organic waste fee for anaerobic digestion and stopped the extra category for landscaping materials from nature conservation areas. Requirements on mowing are not described but at least 90 % of organic waste have to be proceeded with an additional post rotting process. The caloric minimum value (11 MJ/kg, ca. 3 kWh/kg) for energetic recycling instead of material use is not any longer applicable.

4.6 Economical assessment

An economic analysis was performed for the defined scenarios, with a special focus on the treatment facilities. All assumptions and the detailed cost estimates are based on experience of IZES gGmbH, which were verified by plant manufacturers and operators. All cost estimates relate to newly constructed plants.

4.6.1 Status Quo

Nature conservation areas

Landscape material from nature conservation areas is harvested and handled identically to hay or grass from grasslands. The big difference between the harvested materials are the harvesting time and, consequently, the quality of the material.

The harvesting process is subdivided into the following steps:

Mowing → Turning (1-2x) → Swathing → (bale pressing) → Transporting

The cost for the whole value chain is between 30.50 and 44.50 € per ton.

Table 17: Harvest cost of landscape material from Nature conservation areas

Step	Procedure	Average-Costs [€/t]
1	Mow	7.60
2	Turn (twice)	7.60
3	Swath	4.40
4	a) Bale pressing	17.4 - 24.9
	b) Loader wagon	10.9 - 16.3
Total	**with 4a**	**37 – 44.5**
	with 4b	**30.5 – 35.9**

In general, the material is used as fodder or litter for animal husbandries. Additionally, it is traded at the market, being the market price for hay between 85.00 and 150.00 €[13].

Greenery cutting

While the landscape material comes from agricultural land or nature conservation areas, the greenery cutting proceeds from the competence of the municipalities. This green waste needs to be treated, and therefore, the material is shredded and then sieved to 10 and 60 mm. The undersize (less than10 mm) is directly composted or post-rotted, since large parts of the inert fraction (soil, sand, etc.) are here located, solving later problems in biogas plant related to the abrasion. Furthermore, the fine fraction (10 to 60 mm) is dominated by grass and herbaceous material. The coarse fraction (over 60 mm) consists mainly of wooden material.

The costs related to the collecting, shredding and sieving of the fine fraction are between 16 and 20 € per ton.

Table 18: Handling cost of greenery cutting

Step	Procedure	Average-Costs [€/t]
1	Collect	5.00
2	Shred	6.00-10.00
3	Sieve	5.00-6.00
Total		**16.00 – 21.00**

The fine fraction, at the moment, is not handled in the market and it is considered a waste product. Also, the bigger parts are composted (see strategy “organic waste - Saarland”). The wooden materials, on the contrary, are traded at the market. E.g. landscape material can be acquired for 20 € per ton, material from greenery cutting is sold for 45 – 84 € per ton (dry).

Agricultural residues

The focus concerning agricultural residues relies on manure utilization. Cattle and horse manure is currently used as fertilizer on fields, mainly on the own agricultural land. The fertilizer value, concerning the nutrient content, is about 7.93 € per ton of fresh matter.

Table 19: Nutrient value of manure

Nutrient	Amount [%]	Nutrient value (price) [€/kg]	Fertilization value [€/ t fresh matter]
N	0.25	1.22	3.05
P_2O_5	0.20	0.98	1.96
K_2O	0.40	0.73	2.92
Total			**7.93**

[13] Proplanta (2014): Aktuelle Strohpeise und Heupreise 2014 – KW02 (http://www.proplanta.de/Markt-und-Preis/Agrarmarkt-Berichte/Strohpreise-Heupreise-2014-KW01_notierungen1389122115.html)

Therefore the total amount of liquid manure in the biosphere reserve contains 135 t N, 108 t P_2O_5 and 216 t K_2O.

In the region, there is a potential market for manure. Indeed, depending on the place, manure can be considered a valuable or a waste product. In the agricultural system of the biosphere reserve, for example, the manure is traded as a valued product.

4.6.2 Dry Fermentation

Against the background of the discussion that bigger plants are more efficient than smaller ones, the first scenario compares the use of different amount of materials. As described, suitable materials for fermentation are essentially landscape material from nature conservation areas, horse manure and the fine fraction or better herbaceous material from greenery cutting. In total 40,000 t of grass and greenery cutting material accrues in the biosphere reserve. Therefore, the scenario “Biosphere_1a” calculates a dry fermentation plant with 40.000 t of input material.

However, part of this material is already used for fodder or litter. As mentioned above, approximately 4,000 t of grass and 8,500 t of greenery cuttings, as well as more than 2,600 t horse manure, are produced and not used in the region. Therefore, the second scenario “Biosphere_1b” analyzes a dry fermentation process with 20,000 t of input material.

Landscape material, greenery cutting and horse manure serve as input material for a dry fermentation plant. In this case, fermentation plants are constructed as solid state fermentation or as plug-flow-fermenter, which have the advantage of being able to process difficult substrates with a high total solids content. Therefore, landscape material can be used in these kind of plants.

The fermentation process produces biogas, which can be used in combined heat and power units (CHP) or, alternatively, upgrade the gas into biomethane. The following calculation focuses on a CHP application. Moreover, digestate would be available to be used as compost or as fertilizer.

Table 20: Economical feasibility study on herbaceous greeneries

Dry Fermentation	20,000 t/a Input material	40,000 t/a Input material
Investment	8,300,000 €	17,800,000 €
Investment payments	-717,862 €	-1,520,141 €
Operating costs	-1,451,170 €	-3,089,339 €
Revenues	978,098 €	1,949,825 €
EEG (subsidies for electricty	*556,141 €*	*1,057,377 €*
heat	*78,624 €*	*152,448 €*
compost	*93,333 €*	*240,000 €*
Profitability	-1,190,933 €	-2,659,655 €

Assumption: The treatment of greeneries (collection, shredding, sieving) were taken into account. The preserving of landscape material (mowing, turning, swathing) was also taken into account.

The dry fermentation costs account for 60 – 65 €/t. Consequently, the fermentation of municipal green waste and landscape material appears to be, at the moment and from an economic point of view, not feasible.

4.6.3 Dry Fermentation – Small scale

The dry fermentation is not reasonable at the moment in the region under study and, in addition, the input material mainly accrues decentralized and in small bundles. Therefore, an option in the biosphere reserve could be small scale decentralized biogas plants (Pocket digester), which would be beneficiated by special programs promoted by the feed-in-tariff EEG for installations with a capacity lower than 75 kW.

Firstly, agricultural biogas plant based exclusively on manure were analyzed. Producers from small scale biogas plants were investigated and data according to the technology, input material and profitability was collected. Regarding to the economical assessment, a regional farm was used as an example.

At the moment, small scale dry fermentation systems are quite rare at the market, being the installed capacity usually around 100 kWel. The system consists of a substrate receipt, an agitator bin, a tank with inoculum culture, a fermenter, a screw-press separator, a gas storage and a CHP unit. A plant with an installed capacity of 120 kWel needs every seven days between 20 and 22 t of fresh materials as input. If mainly grass or landscape material from nature conservation areas is applied, about 3,000 t of material per year is needed.

A cost analysis, in this case, is not possible to perform due to the low number of installations and its related specific cost. There is only one producer that advises a plant with an installed capacity of 90 kW.

4.6.4 Combustion

Dried material with a high lignin content such as hay, straw and wood are suitable for combustion.

In general, combustion plants should focus only on one input material. Although the combustion process is nearly the same for all fuels, the burning temperature, the supply of incoming air or the melting points differs. Therefore, a combustion facility should be exactly adjusted to the biofuel.

An economic assessment has been carried out for a 500 kW wood combustion plant based on greenery cutting materials. In this region, combustion plants are mainly in operation during wintertime, having about 2,000 full load hours and an input of 500 t of wooden material with a heat output of about 1.000 to 1.500 kWh.

Table 21:Economical feasibility study, thermal recycling of wooden greenery cuttings in 500 kW$_{th}$ boilers

500 kW combustion	Min	Max
Investment	560,000 €	610.000 €
Investment	- 39.438 €	- 43,780 €
Operating costs	- 56,760 €	- 73,350 €
Revenues (heat)	€	€
Profitability	- 96,198 €	- 117,130 €
€/kWhth	-0.087 €/kWh	-0.106 €/kWh

The heat price is between 8.7 and 10.6 ct/kWh. As comparison, the price for natural gas is around 6.5 ct/kWh and for oil 8 ct /kWh.

Straw and dried grass can be used as a biofuel in a combustion process too. However, hay and straw have, in contrast to wood, a higher volume of ash and a higher emission factor for different substances. Indeed, emissions of chlorine and sulfur could cause corrosions and attack the combustion. Also, the lower ash melting point of straw and hay originates slagging. Therefore, these combustion plants need specialized heating constructions and emission filters.

Furthermore, according to the new German emission law (1.BImSchV), hay and straw burners (for consumer market) require extra tests which include measurements of dioxins and furans. However, at the moment it is not clear how to generate a one year dioxin and furan test and, therefore, every plant requires an individual authorization. Later, the number of straw and hay burners in Germany is low, making difficult to assess and compare economic parameters. In this case, the assessment is a case-by-case decision.

4.6.5 Pocket digester

Due to the situation explained above, a small scale biogas plant is of particular interest in Germany. The pocket digester process is a wet fermentation process based on cow manure. Here, the biogas produced is used in a CHP unit to produce heat and electricity. As an advantage of the system, the amount of produced heat and electricity can be used directly onsite. E.g. in the winter period the produced heat is mainly used for heating the system itself.

In particular, biogas plants between 11 and 33 kW of installed capacity are very interesting for the regional farmers where the necessary input material can be produced from 100 up to 300 cows. In this region, farmers would be in conditions to operate as they own about 100 to 150 cows on an average.

Table 22: Economical feasibility study on pocket digester

Pocket Digester		10 kW	20 kW
Investment		90,000 €	
Investment payments		-4,514 €	
Operating costs		-102,670 €	
Revenues		354,265 €	
	EEG (subsidies for electricty)	*348,129 €*	
	heat	*6,136 €*	
Profitability		247,081 €	

Assumption: The heat is used for the watering place of the cows and for hot water. Until now these things a heated by electricity.

The above table shows that the farm could generate a profit with this installation. Against the background, that this farm can use all the heat and electricity directly on-site, the economic assessment is positive.

4.7 Conclusion and recommended strategy

Regular meetings of the ARBOR Saarland Task Forces “Organic Waste” [2011-2015], socio-economic assessments for all ARBOR scenarios as well as scientific review at the ARBOR Transnational Advisory Board Meeting [04/2013] guarantee the strategic fit of the outcomes.

The vision was to valorise the material and energy efficiency for landscaping material from nature conservation areas and to shift the landscaping order into a regional resource supply service. The derived scope of action comprises: Landscape cultivation management plan; Technology change towards challenging biofuels; Regional product chains and marketing (high quality fertilizer, wooden fuels, biogas to power and heat).The derived measures for future implementation are recommended as following: Need for on-going political patronage to combine climate change and nature conservation; Need for exchange with other nature conservation reserves; Examination of the potential of extensive landscaping (as a nature conservation measure) to serve as a source for bioenergy supply; Need for landscaping collection and recycling hubs; Need for market demand on material use as e.g. fodder or litter in livestock farming; Need for testing of different qualities of landscape materials for combustion purposes; Introduction of innovative bioenergy concepts for the nature conservation area: dry fermentation process (input mix of landscaping material, municipal greenery cuttings and horse straw; manure pocket digesters)

5 Closed loop systems of biomass valorization by local authorities- Saarland strategy development for a sustainable sewage sludge valorisation

5.1 Case study description

This study is a component of an implementation-oriented overall strategy for the sustainable use and valorization of biogene residues from municipalities for the model region of Saarland, in the framework of the INTERREG IV B research project ARBOR (Accelerating Renewable Energies by valorization of Biogenic Organic Raw Materials).

The study includes the assessment and evaluation of the current situation as well as applied research to develop a sustainable sewage sludge strategy for the project region Saarland by recognizing already developed approaches and the delivering a consistent derivation of concrete recommendations for scope of actions and measures.

Specifically, it is intended to formulate a long-term sustainable strategy for the efficient recycling of sewage sludge, incurred in Saarland's public waste water treatment plants, on the basis of ecological and economic assessed recycling scenarios. Furthermore, it is aimed at the conceptual level to develop specific technical and political-organizational measures as well as to introduce adapted implementation processes.

A comparison of the German Federal States shows, that the highest quantitative sludge loads incurred corresponding to the number of inhabitants in the states of North Rhine-Westphalia, Bavaria and Baden-Württemberg (see figure below). In Saarland approximately 19,000 Mg DS was produced in the year 2010, accounting for only 1% of the total amount of sewage sludge from public treatment plants in total Germany (Benjamin, et al., 2013). Despite these seemingly minor amounts, a sustainable and resource-efficient handling of the sewage sludge is important. Noteworthy also is the low proportion of agriculturally recycled sludge in the largest surface states of Bavaria and Baden-Württemberg. These provinces have been advocating for several years - at the level of the Federal Council- for a complete phase-out of agricultural sewage sludge applications (UVM, 2002). In Baden-Württemberg the drinking water is sourced from surface water (Lake Constance), so that the release of pollutants from agricultural sewage sludge should be avoided and minimized.

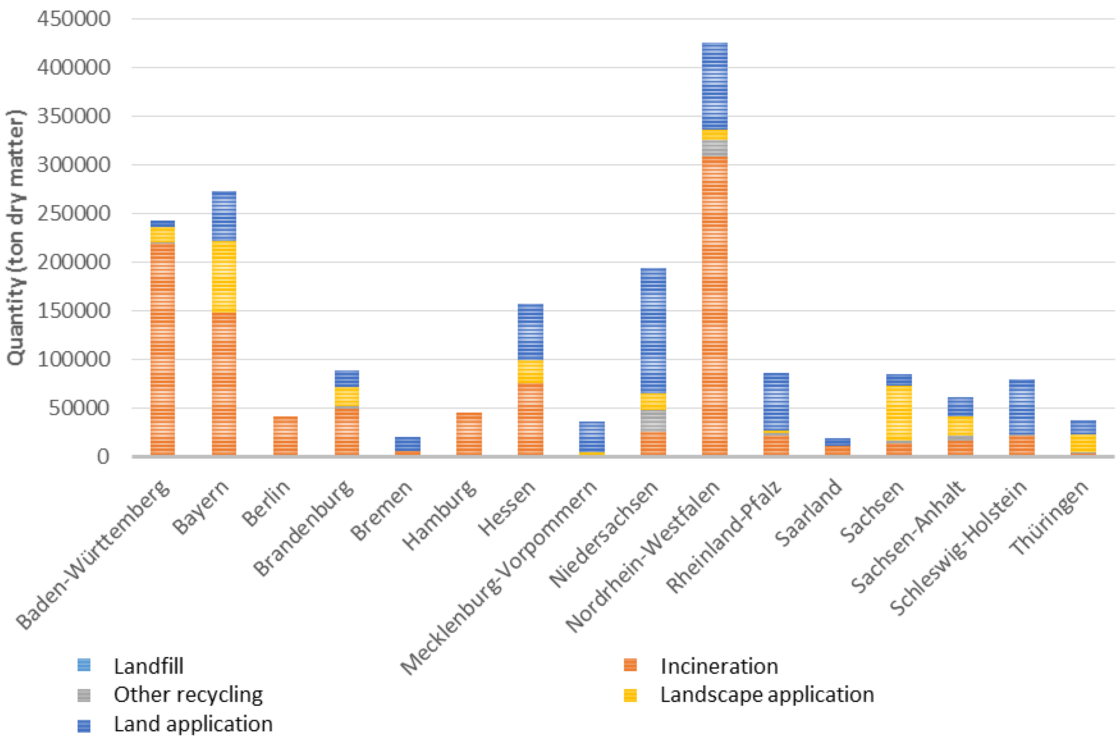

Figure 21 Country-specific distribution of recycling methods of sewage sludge from municipal wastewater treatment plants in 2010 (Benjamin, et al., 2013)

This corresponds to the current discussions, dealt at German federal level, addressing the fundamental question, if sewage sludge application on agricultural land should be continued and how to rank this with other recycling routes. Here the discussion is controversial, as the valuable sewage sludge fertilization effect (C, N, P, K) assessed with the risks of adding potential polluting ingredients, as partly elusive substances (e.g. endocrine disrupters) on agricultural soils and its discharge in waters, is not finally discussed yet. Regarding the closing of natural material cycles, current sewage sludge incineration routes for energy recovery show the disadvantage of low material resource efficiency, that valuable rare materials contained in the sludge will be lost irrevocably, as e.g. critical minerals as phosphorus (IZES, 2011).

5.2 Research context

The study was conducted in close cooperation with the Waste Disposal Association Saar (EVS), department Wastewater and Sewage Sludge, the Saarland Ministry of Environment and Consumer Protection and the Ministry of Economy, Employment, Energy and Traffic as well as the IZES gGmbH. The data on the amount, quality, origin and applied recovery routes of the current Saarland sewage sludge recycling were provided -for the most part- on real data by the EVS. Furthermore, data were gathered by the official population statistics of the Saarland Authority for Statistic Data. For conducting the Life Cycle Assessment (LCA) on all scenarios, information and data were gathered from the Swiss database for Life Cycle Inventories (ecoinvent 2014), complemented by the LCA studies and corresponding literature in the field of sewage sludge of the IFEU Heidelberg and the Fachhochschule ZHAW Zurich. Additionally information, e.g. on prices and costs, were provided by technology providers.

The ARBOR scenarios are spread into two time horizons. The status quo scenario bases on the actual sludge data, derived by the EVS from the reference year 2010, whereas the future utilization scenarios have been calculated for 2020. Technology data have been evaluated according to their availability and innovation character and are discussed under the premise of comparability.

5.3 Plant portfolio and sludge volume – Overview

The basis of all assumptions is the current stock of waste water treatment plants in Saarland, accounting for 140 plants and the resulting sewage sludge volumes. In Saarland almost 98% of the inhabitants are connected to the municipal mechanical-biological waste water treatment plants. The waste water of not connected households are steered indirectly after pre-cleaning in small decentralized wastewater treatment plants without ventilation (mechanical pre-cleaning) to the municipal waste water canalization. The waste water from isolated property, which is not connected to a public canalization, are disposed by individual systems (MEET, 2011) and are not considered in the following context.

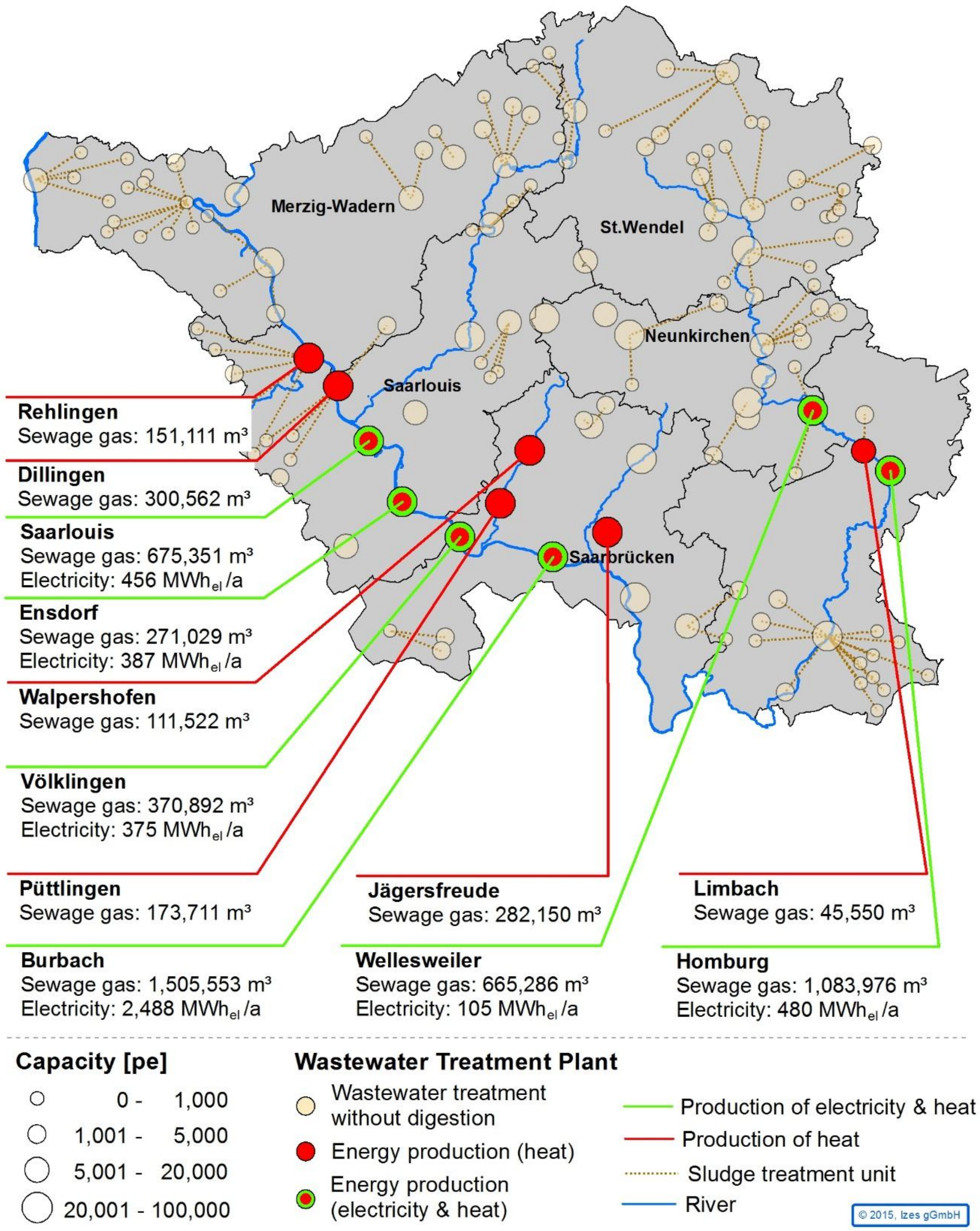

Figure 22 Locations and Design capacity of existing public sewage treatment plants and pumping stations in Saarland in 2012 (own representation, updated after (EVS, 2011a))

This figure shows the currently running municipal sewage treatment plants of the EVS. The figure displays the running waste water treatment plants and capacities in relation to the population equivalent and the annexation of the decentralized systems, including the three leachate treatment plants at the landfilling sites, to the central wastewater treatment plants. Highlighted plants (red and red-green dots) are the waste water treatment plants with anaerobic sludge treatment, supplemented by an indication of the amount of sewage gas and electricity production.

5.4 Development of the sludge quantities

In Saarland a differentiated population development is expected in the coming years. To display the future population development to the ARBOR reference period 2020, the population growth from 2001 to 2011 has been projected for each community from 2010 to 2020 in the figure below.

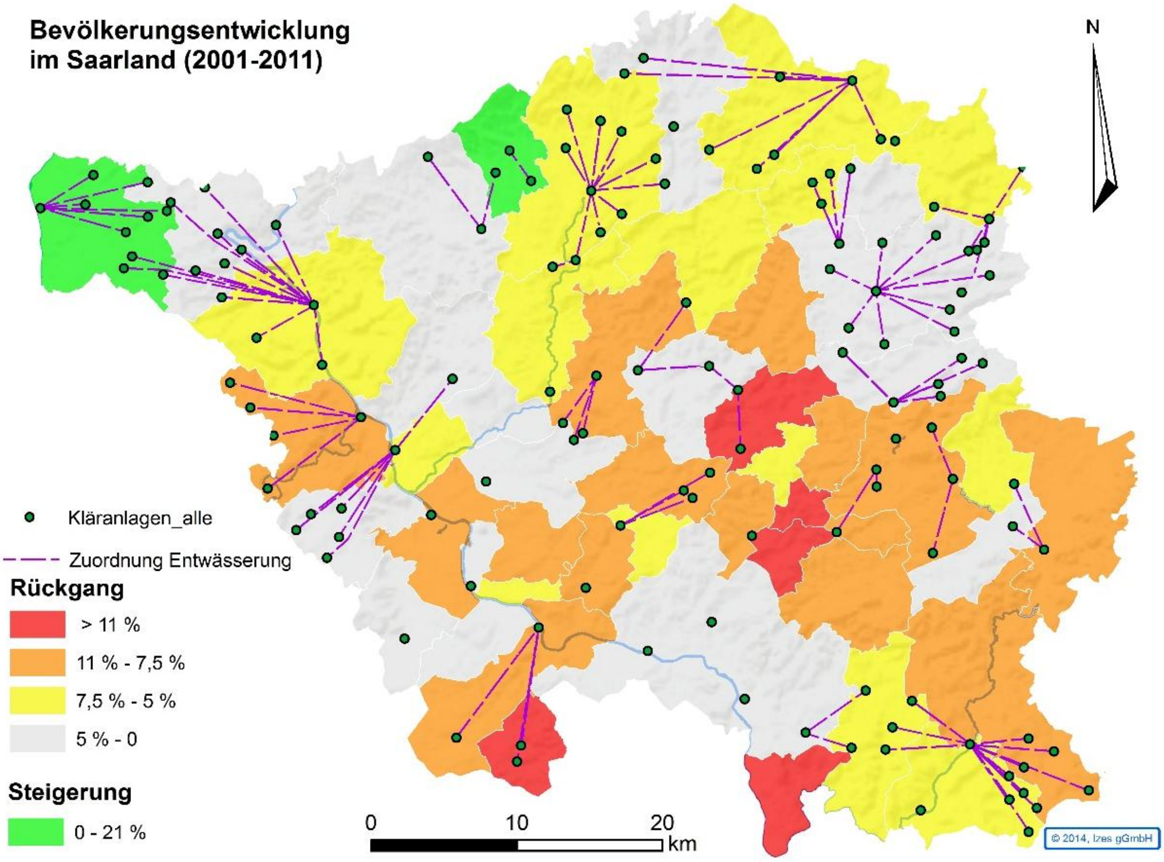

Figure 23 Demographics in the Saarland in the years 2001 to 2011

The development illustrates a fundamental decline in the population in many regions in Saarland, in particular the communities Kleinblittersdorf, Großrosseln, Illingen, Friedrichsthal and Sulzbach have experienced in the last decade, a population shrinkage of over 11%. In contrast, other larger municipalities, such as the Capital City of Saarbrücken and the city St. Wendel, record only a low population decrease. However, the municipalities Weisskirchen and in particular Perl, caused by the frontier to Luxembourg, have recorded an increase in population. The population growth was in the first accounting period an orientation point for determining expected future sewage sludge amounts in Saarland. This accounted development, however, does not correspond with the experiences of the EVS.

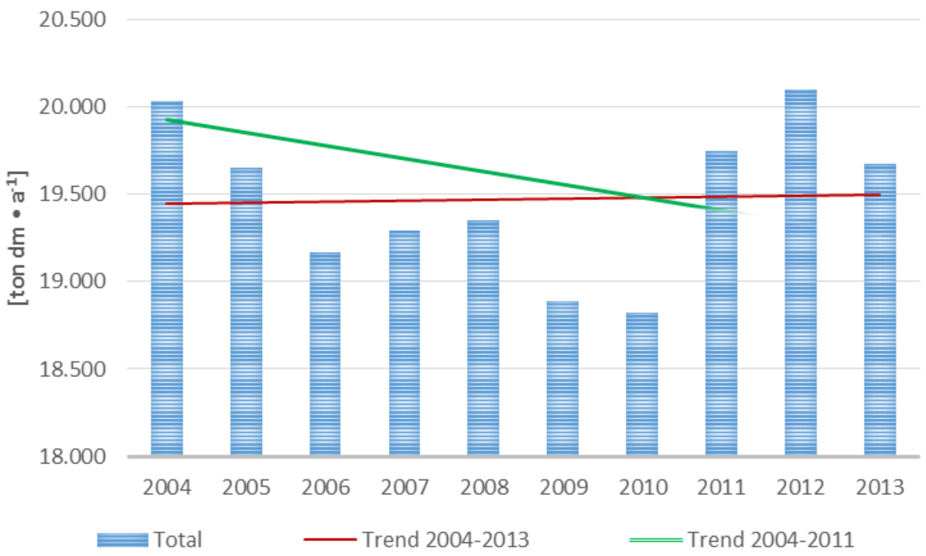

Figure 24 Development of sewage sludge amount 2004 - 2013 (EVS, 2004-2013)

In the years 2004 to 2011, the sludge amounts show rather a decline according to the population growth (see. figure ahead). However, if the observation period of the sewage sludge volumes is extended to 2013, a slight upward trend can be seen. According to the EVS statement, an overall increase in sludge quantity is recorded in the period between 2001 to 2011. This leads to the conclusion that the population growth can not be the sole indicator for determining the anticipated future sewage sludge quantity. Other factors such as the rainwater amounts have a significantly higher influence on the amount of sewage sludge (EVS, 2015). In coordination with the EVS, a sewage sludge volume of approximately 20,000 Mg DS will set for the ARBOR scenario baseline year 2020.

5.5 Scenarios

Together with the Regional Task Force Sewage Sludge (Working Group) four Recycling Scenarios have been worked out in relation to the status quo (Scenario 0). These four scenarios are mainly focusing on thermal sludge treatment procedures (incineration and thermal conversion). At the start of the study, the phase out for agricultural application was not fully considered, but the recovery of phosphorus has already been taken into consideration. In the final scenario definitions, the agricultural appliances and phosphorus recovery have been associated with the future scenarios in the form of additive modules. During the project lifetime, however, in agreement with the EVS, the agricultural application has been surrendered, since this recovery path will be phase out according to the stricter regulations on heavy metals and synthetic polymer contents in soils by the German Fertilizer Ordinance (DüMV, 2012). From enforcement of this stricter regulations (1.1.2015) the majority of the Saarland sewage sludge is no longer legally coherent to meet these criteria (see figure 5).

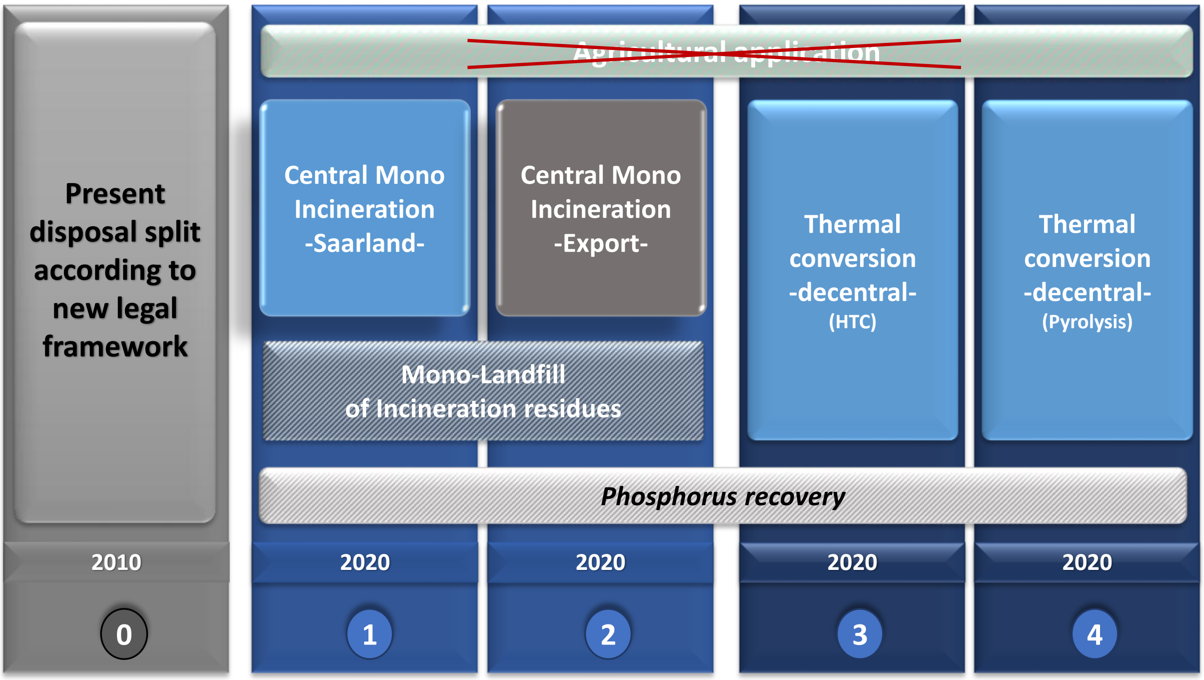

Figure 25 Sewage Sludge Recycling Scenarios

The following sections describe the status quo and the four scenarios incl. the module "Phosphorus recovery". Due to the current development of the legal situation on the agricultural use of sewage sludge and the economic assessment of the EVS on the relevance of the future agricultural sewage sludge volumes, the consideration of the module "agricultural use" is waived.

5.5.1 Scenario 0 Status Quo

In scenario 0 - Status Quo the actual sludge volume was accounted in the base year of 2010. In the average of the last year, the amount of sewage sludge was -with slight variations - approximately by 19,000 Mg DS / a (IZES, 2011). In 2010, about 18, 743 Mg DS or approximately 18.4 kg DS / Inhabitant * a have been recycled through the following routes: (see figure below):

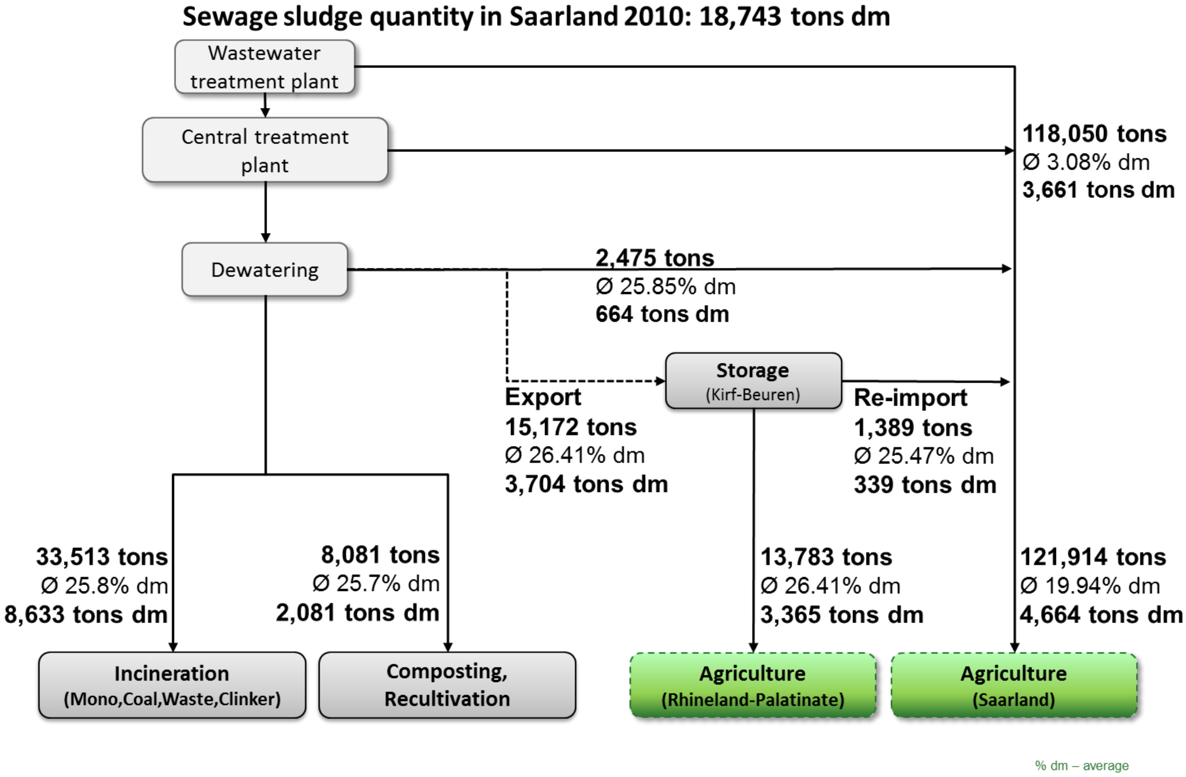

Figure 26 Sewage sludge utilization in Scenario 0 - Status Quo in 2010

Under consideration of the (changed) legal situation, the sewage sludge application on agricultural lands, as just described above, is no longer feasible (Saarland sludge composition). Legal background are the upcoming future Waste Sewage Sludge Ordinance, the amended Fertilizer Ordinance (already in force since 1.1.2015, transition period), with the result that sewage sludge, which no longer complies with the legal thresholds, is therefore no longer allowed to be spread on agricultural lands.

Based on the important framework condition, that in the future no more sewage sludge can be recycled on agricultural lands or as landscaping material, the total amount of sewage sludge from approximately 20,000 Mg DS is assessed in thermal recycling scenarios (see figure below).

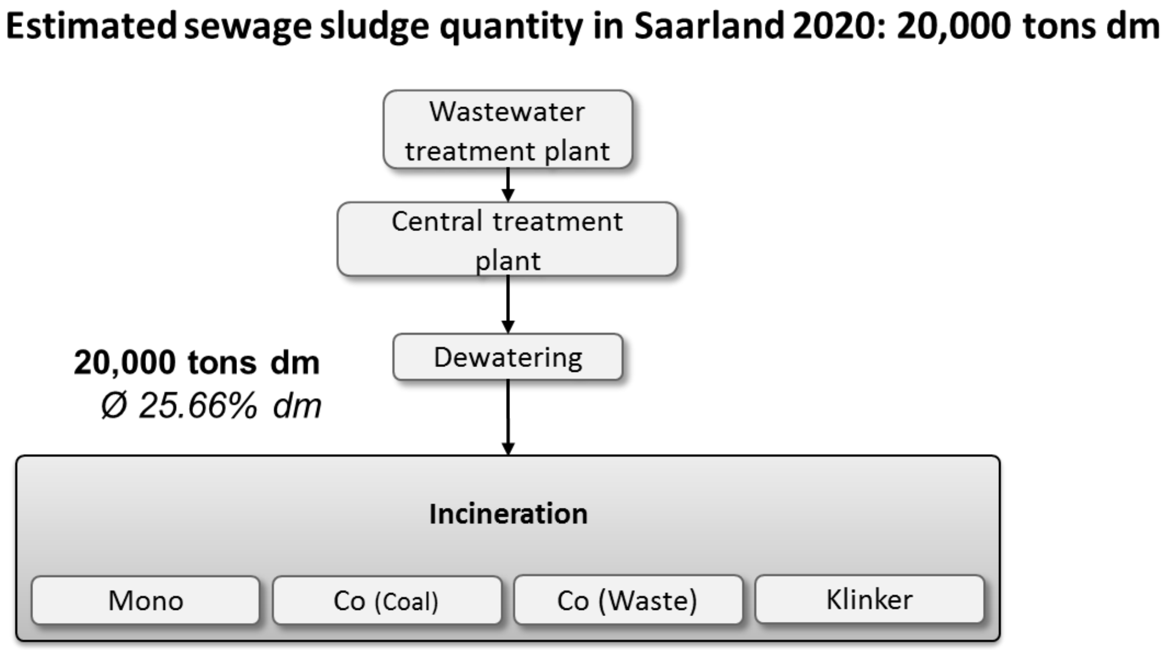

Figure 27: Sewage sludge utilization in Scenario 0 - Status Quo 2020 - taking into account the existing legal framework-

Remaining high-quality sewage sludge, in line with the legal limits and feasible for agriculture or landscaping purposes, are in terms of quantities and of low relevance neglected in the scenarios.

The figure above portrays, that the determined sewage sludge distribution is based on the plant related amounts of dry substance contents from the year 2010 and refers to 2020 with an assumed sludge volume of approximately 20,000 Mg DS. In addition, the amounts extrapolated to the sites are reduced by the input amount for the pyrolysis plant in Homburg. By a pure redistribution of formerly agriculturally recycled materials to the thermally utilizied sludge, a low dry matter content of 16.49% would be the result. Therefore the need for drainage of these masses is obvious. To simplify the assumptions, the average dry matter content of the thermally utilized sludge from the previous amount distribution is set here by 25.66%.

5.5.2 Scenario 1 & 2: Central thermal treatment

In addition to the continuation of the current situation of the recycling routes, but reflecting the amended legal situation (Scenario 0-2020), the ARBOR recycling scenarios have been worked out in the Working Group Sewage Sludge. In scenario 1 and 2, a central thermal utilization is defined as main recycling process. As thermal treatment a central sewage sludge mono-incineration plant is assumed (see figure below).

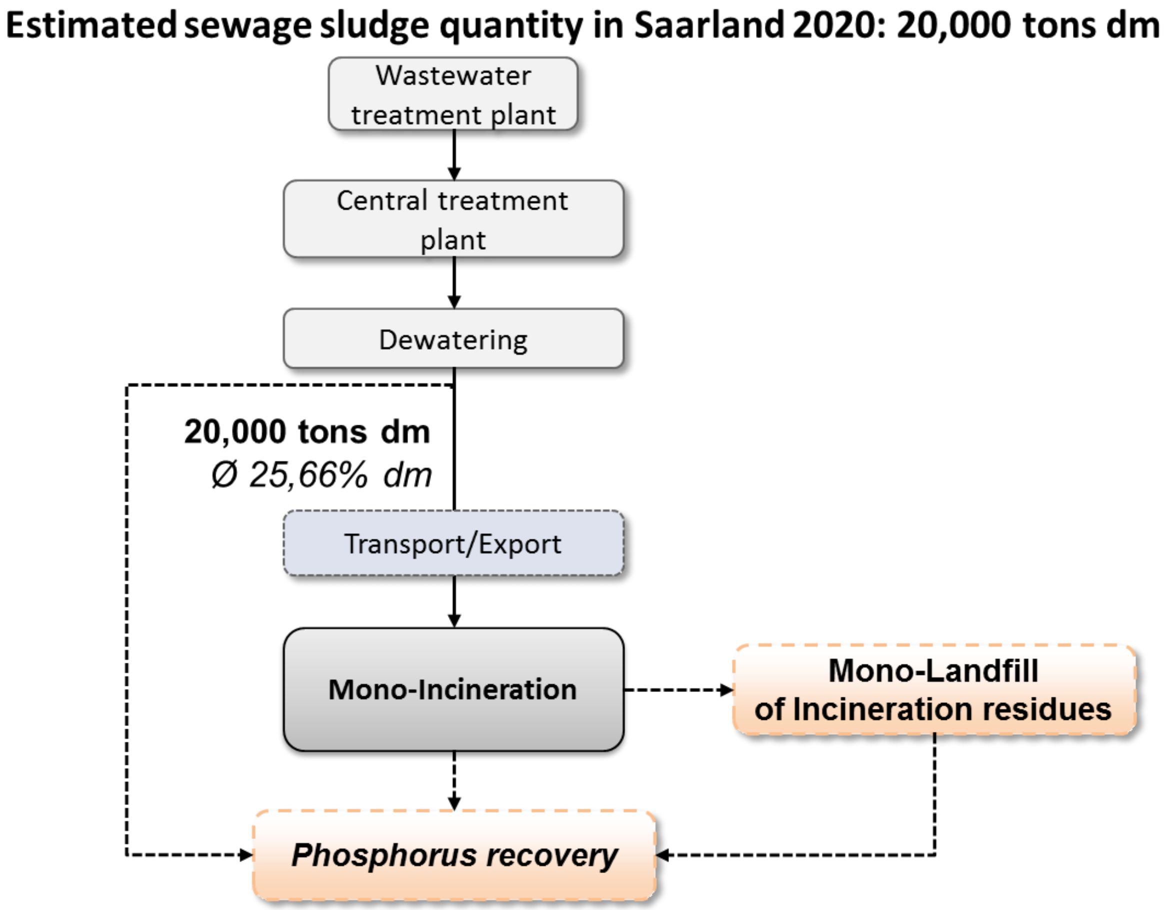

Figure 28: Sewage sludge utilization in scenario 1 & 2 – 2020

In scenario 1, the expected amount of sludge is supplied (approximately 20,000 Mg DS) to a central thermal treatment plant within the Saarland territory. In the context of the assessment, a fictitious site for the mono incineration needs to be chosen, so the transport expenses can be determined for delivery. In consultation with the Working Group Sewage Sludge, the waste incineration plant Neunkirchen has been fixed as a possible co-location for a mono sludge incineration.

In Scenario 2, the same assumptions are given, but the site of the thermal treatment is situated outside of Saarland. Also in this scenario, the definition of a fictitious location for the accounting is necessary. The Working Group Sewage Sludge has introduced the site of Mainz-Mombach, as there is a current approval procedure running. This assumption thus serves only to determine the transport costs and the determination of the technology assessment.

5.5.2.1 Scenario 3& 4: Decentral thermal treatment

The scenarios 3 and 4 represent two decentralized thermal recycling options. By analogy with the previous scenarios the module "phosphorus recovery" is also integrated.

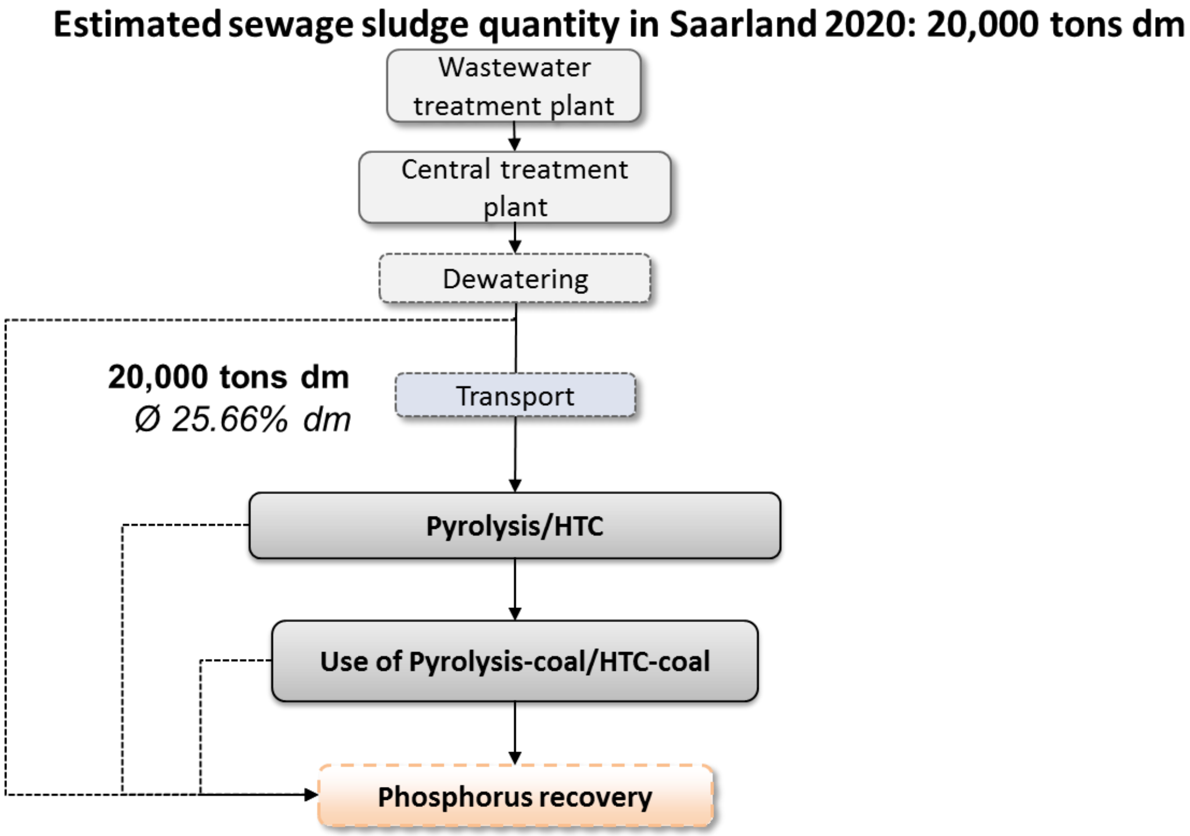

Figure 29: Sewage sludge recycling scenario 3- 2020

In these scenarios the decentralized thermal treatment technologies are Pyrolysis and Hydrothermal Carbonization (HTC). The dewatered sludge is transported, depending on plant size to two or three plant locations. The end products of the two conversion technologies are supplied to the respective application routes. The integration of the phosphorus recovery is analogue with scenario 1, however, only the phosphorus recovery from the sewage sludge is here considered.

In scenario 3, the Hydrothermal Carbonization (HTC) is located at two sites. The end product, the HTC biochar is used as supplementary fuel in coal-fired power plant.

In scenario 4, the pyrolysis conversion technology is designed for three locations. The by-product pyrolysis biochar can be used as a floor substrate or as an additive in the production of bottom substrates. The phosphorus recovery is not assessed, since the nutrients contained in the sludge of the pyrolysis biochar, is brought back into the nutrient cycle (biochar as soil substrate).

Based on the respective plant capacity size, two or three conversion sites are assumed. By choosing the appropriate locations, all central waste water treatment plants in Saarland have initially been contemplated. Considering an optimized sludge logistics (GIS based analyses on shortest transport performance), the three central waste water plants as Saarbrücken Burbach, Rehlingen as well as the site of Neunkirchen Sinnerthal have been identified as part of a GIS-based analysis. In the Working Group Sewage Sludge, these sites have been classified, however, for various reasons to be unsuitable. The Working Group Sewage Sludge has set the respective closest facilities as Völklingen, Merzig, and Wellesweiler.

5.6 Location and Technology Description

For a better understanding and assessment of the evaluation of sludge recovery scenarios with regard to their greenhouse gas emissions and their host-effectiveness, a description of the recycling sites and the technologies employed is required in advance. The location of the sites and the type of treatment provide the basis for determining the transport, which results from the product of the transport distance and the transporting of the fresh mass. In the Status Quo (Scenario 0), the recovery sites are specified, whereas the locations for clarifier sludge treatment are determined in advance from certain points in the scenarios 1 to 4. FIG. The following describes the current and future derived locations for the single scenarios briefly. Based on the locations to be supplied, the necessary transport services are subsequently shown. Furthermore, the utilization of technologies used on the basis of the essential features and assumptions described briefly next to the location of treatment sites.

5.6.1 Transport services in the scenarios

Scenario 0: Status Quo 2010 & 2020

The sludge transports 2010, as shown in the figure below, has been expired (EVS, 2012a). The exact quantitative distribution of the sludge can be seen in Section 3.2. The following illustration is intended to give an overview of the transport capacity within the sewage sludge utilization in the scenario 0. The graph on the left shows the agricultural use of sewage, the average represents the recovery path of thermal treatment and the left graph shows the landscape sites (composting, recultivation). There the derivation of the cumulated transport performance is portrayed in scenario 0 - Status Quo, 2010 by a total of around 15.4 million tons-kilometers (tkm). Considering the quantitative proportion in 2010 the expected transport capacity of approximately 18.8 million tkm for 2020 is portrayed in scenario 0 a. According to the statement by the EVS in the sludge working group the distribution of sewage sludge in the field of thermal and landscape architectural recovery has quantitatively shifted westwards, whereas the delivery sites have remained.

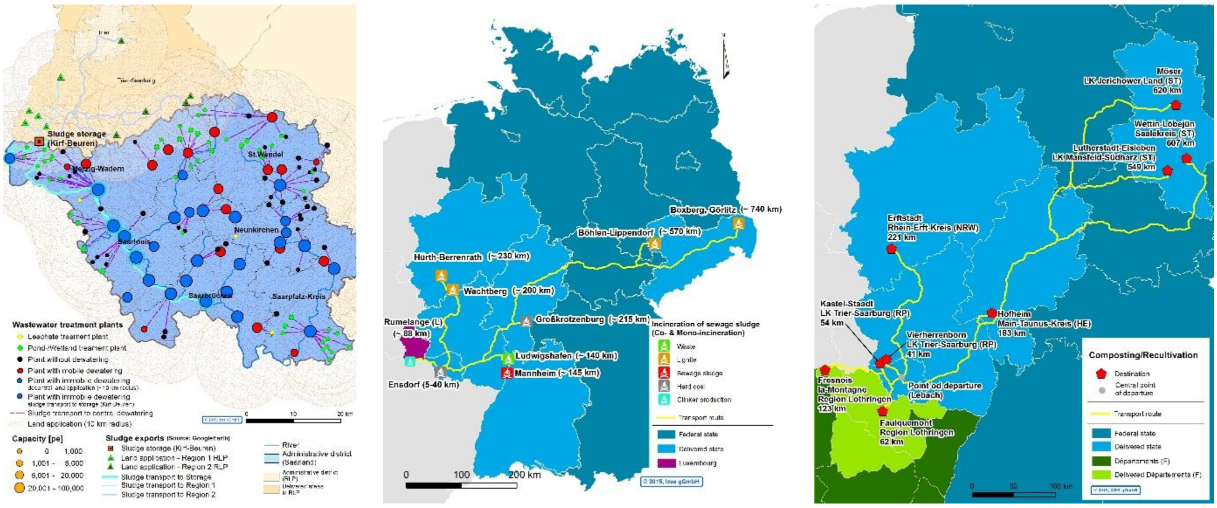

Figure 30: Sewage sludge logistic in scenario 0 – Status Quo 2010/2020

Scenario 1 & 2: Central thermal treatment in 2020

In the scenarios 1 and 2, the central thermal treatment is analyzed. In scenario 1, this central thermal treatment is investigated within the territory of Saarland, in scenario 2 the site is located outside Saarland.

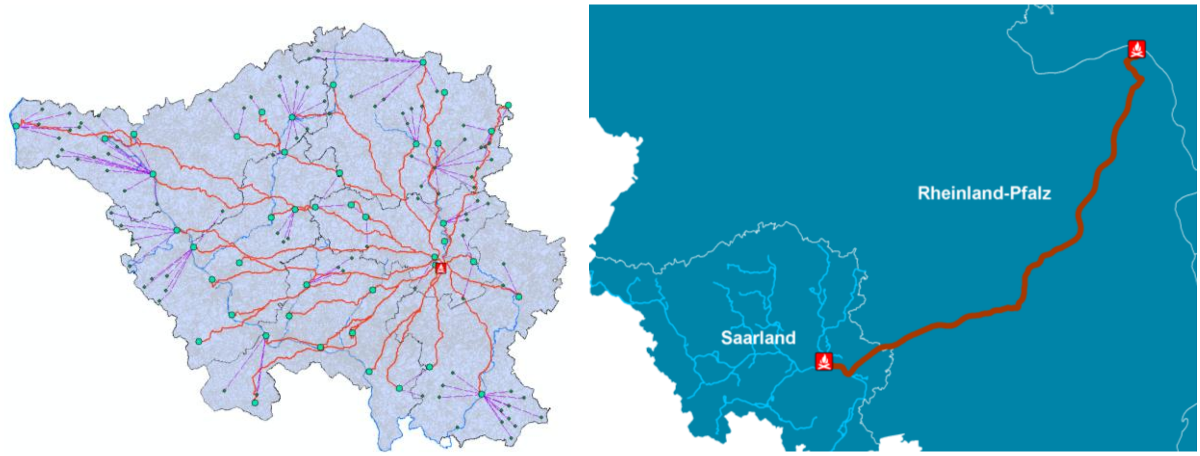

Figure 31: Sewage sludge logistic in scenario 1-2 – Status Quo 2020

In this study, no final site selection & decision is required, however, for the assessment of expected future impacts, both ecologically and economically, the determination of a treatment location is needed. Within Saarland, the site of the waste incineration plant Neunkirchen has been chosen. For the thermal treatment outside Saarland, the site in Mainz is considered and incorporated into this consideration. These locations are merely exemplary and are not subject to specific planning.

The resulting transport routes of the two locations are shown in the figure above and the derived transport services are summarized below.

Table 23: Transport service in scenario 1 & 2 – central thermal treatment 2020

	Transport Service [tkm]
Scenario 1	**1.745.802**
Scenario 2	**10.925.355**

In the phosphorus recovery module, a temporary storage of the sewage sludge incineration ash needs to be accounted next to the phosphorus recovery. One possible location for this temporary storage of the ash is the existing coal storage in Neunkirchen. Therefore, the transport service in the table, the transport performance in scenario 1 transport from incineration site Neunkirchen to landfill site Neunkirchen (approximately 14,500 tkm) and in Scenario 2, the return transport of ash from Mainz to Neunkirchen (approximately 1 million tkm) must be added.

Scenario 3 & 4: Decentralized thermal treatment in 2020

With the two scenarios 3 and 4, the decentralized thermal sewage sludge treatment in Saarland is considered. Scenario 3 refers to Hydrothermal Carbonization (HTC), Scenario 4 reflects the pyrolysis. The two treatment methods are described in the following section. In principle both procedures are modular and expandable, enabling them to be adapted to the required size. While in scenario 3 two locations are planned, in scenario 4 three sites are considered (see figure below).

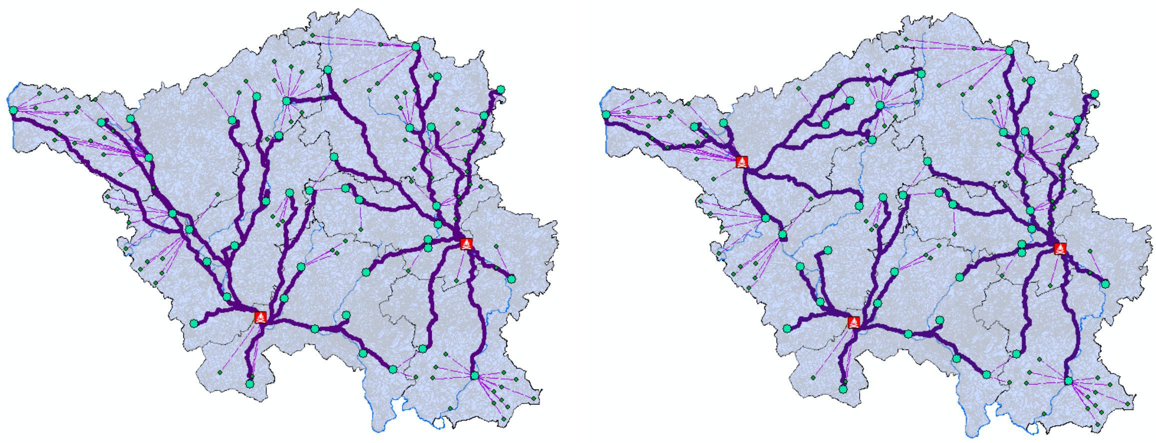

Figure 32: Sewage sludge logistics in scenario 3 & 4 – 2020

The possible conversion plants in scenario 3 shall be located on the sites of the central waste water treatment plants Völklingen and Wellesweiler. In scenario 4, as third site, the central waste water treatment plant in the city Merzig is added. The determination of the locations is based primarily on the expected transport costs, which turns out to be economically feasible at these three sites.

Table 24: Transport service in scenario 3 & 4 – decentral thermal treatment 2020

	Transport Service [tkm]

Scenario 3	**1.077.919**
Scenario 4	**871.901**

The results from these two locations & transport services are listed in this table. As in scenarios 1 and 2, the concrete site definition is set for reasons of better accounting and not binding. Actually further plant locations could be added or a plant could also be relocated. In the context of the site selection and determination of the transport services, it has been examined, that the number and location of these sites - in terms of the ecological assessment - have a relatively small impact.

5.6.2 Technologies applied in the scenarios

To map the reported scenarios, different sewage sludge treatment technologies are choosen.

Scenario 0 - Status Quo

The technologies in Scenario 0 - Status Quo are based on the technologies currently installed as agriculture, landscaping and thermal recycling routes. Wherein the agricultural application uses the wet and humid sludge as an organic fertilizer. The use of sewage sludge in landscaping intends a recovery in composting and recultivation measures of old landfills or by former surface mining areas. The thermal utilization comprises the combustion of sewage sludge in the mono-incineration or in co-incineration (coal and brown coal-fired power plants) -as well as waste incineration plants, but also in the clinker production.

Scenario 1 & 2 - Central thermal treatment

In both scenarios a central mono incineration plant is accounted. Since there is no existing mono-incineration plant running, in both cases, a circulating fluidized bed is provided as the combustion technology. At this point of the study, only key assumptions are explained briefly, which were taken from the planning of the mono sludge incineration plant in Mainz. Condition for the combustion of the sewage sludge in the circulating fluidized bed is a dried sludge with a dry substance content of about 42.3% DS, ie, the dewatered sludge has to be dried with an average dry matter content of 25.6% DS in advance. The following figure shows the energy balance of the plant.

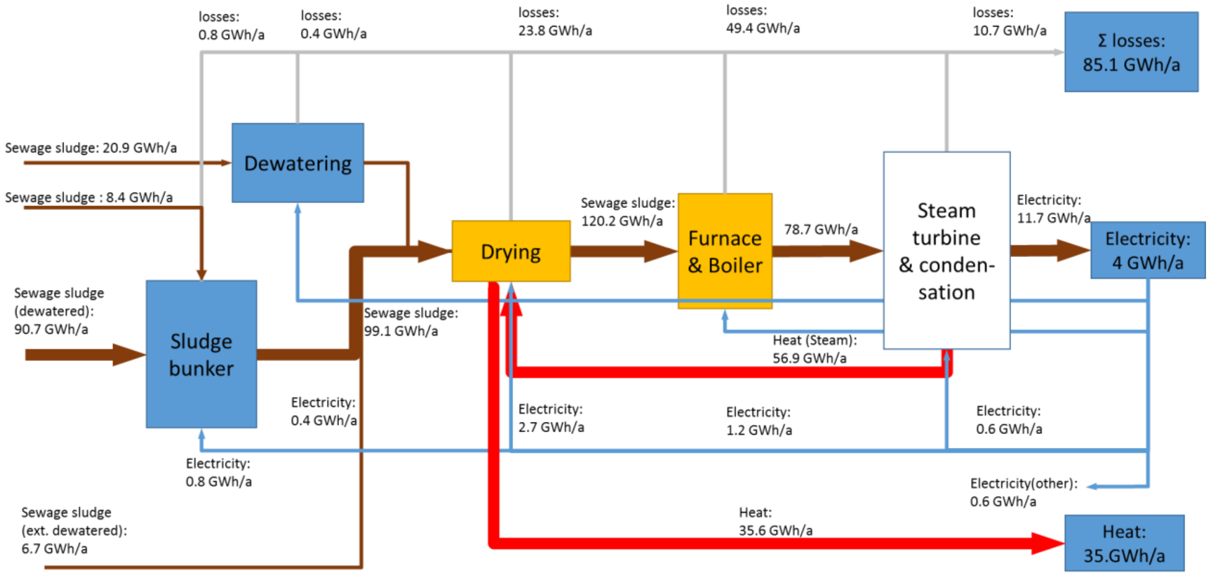

Figure 33: Energy flow diagram of the sludge incineration plant in Mainz (own representation by (Ifeu, 2014))

The plant has a net efficiency of 4.8% (gross efficiency: 12.8%), included the self-power proportion needed for all components. Regarding the heating generation, the upstream dryer is primary supplied with self produced heat, which results to a net efficiency of 39% (gross efficiency: 62.4%) (Ifeu, 2014). Here, it is assumed, that the sludge drying is just on-side of the mono- incineration plant. If, as in scenario 2 is assessed, a mono incineration plant is located outside Saarland, it must be determined, at what distance a drying remains ecologically and economically effective. Apart from this, a complete heat use is accounted in the calculation. The waste water of the plant (including exhaust vapors) is fed to a waste water treatment plant. The ash from incineration (approximately 43% DS sewage inputs) will be temporarily deposited in an interim storage facility in the view of the future phosphorus recovery from the ashes.

Scenario 3 & 4 - Decentralized thermal treatment

As already mentioned scenario 3 assesses the HTC process. The necessary information and the accounting data are taken from a peripheral study on hydrothermal carbonization of Applied Sciences in Zurich in co-operation with the plant manufacturer AVA-CO2. Below the framework data of the process are listed (ZHAW, 2013):

- process runs in the aqueous milieu/ (absence of oxygen)
- Pressure: 20 - 35 bar; Temperature: 180 - 230 ° C
- input material: rotten sewage sludge with 21,3% DS
- coal output approximately 80% DS sludge input; DS content of the HTC-coal: 70%
- calorific value of the HTC-coal 14 MJ / kg
- electric energy demand: 18 kWh_{el}
- thermal energy demand: 571 MJ

In scenario 4, the pyrolysis is accounted as conversion technology. The following information is considered:

- temperature: 600 ° C - 800 ° C (1,400 ° C)
- input Material: rotten sewage sludge with 70% DS
- heat from the combustion of the pyrolysis gas is used for drying the sewage sludge

For the exact process description, data from the system manufacturer Pyreg® (PYREG, 2015) are the basis.

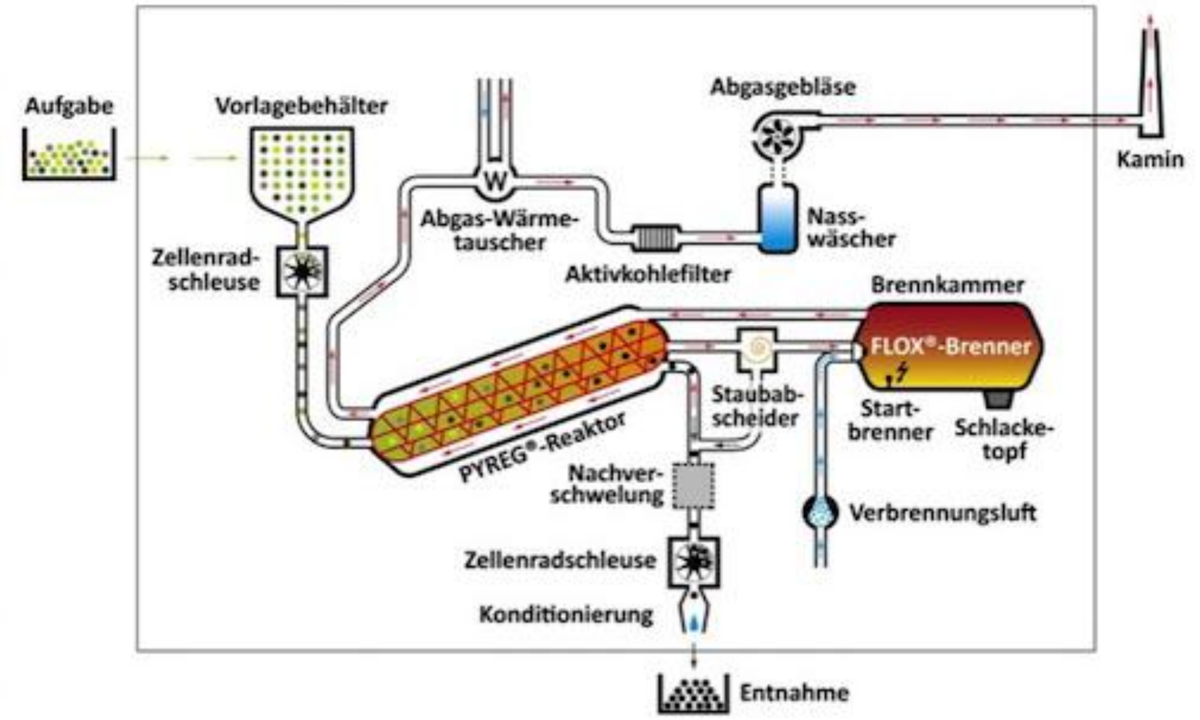

Figure 34: Pyrolysis-Process of the company Pyreg® (Pyreg, 2015)

The process of the company Pyreg® works on the principle of a staged combustion. Sewage sludge is not completely burned in the pyrolysis reactor, but first degassed and then ashed in a post-carbonization. The pyrolysis gas is burned in the so-called FLOX burner. The end product remains a completely sanitized and phosphorus-containing pyrolysis coal. According to (PYREG, 2015) the produced coal is the main advantage of the pyrolysis. In the coal, the nutrient substances and the heavy metals are enriched, also the amount of TOC (total organic carbon) is lowered below 1%. Another result is, that the high polluted sludge can be landfilled, the less polluted sludge can be applied on soils. One energy related disadvantage shows the pyrolysis process: the produced thermal energy is insufficient to dry sludge from 90% DS to the requested 20% DS.

5.7 Life Cycle Assessment of sewage sludge utilization scenarios in terms of greenhouse gas emissions

This chapter portrays the ecological impacts of the previously introduces scenarios. The environmental impact assessment focus on greenhouse gas emissions. All the relevant emissions, which contribute to global warming are determined and calculated in the common unit "$CO2_{eq}$". The emissions are related to the disposal of sewage sludge quantities per year (here 20,000 Mg DS). The emission loads in the scenarios caused by the sludge treatment or disposal also are partially offset by a positive benefit from sewage sludge application or treatment. This benefit is calculated as so-called “carbon credits” within the recovery scenarios. To give an example, the incineration of sewage sludge generates green energy, which offsets fossil fuels. Also fertilizing effects, achieved by the nutrient content in the sewage sludge, are eligible for agricultural applications as mineral fertilizers, cause the substitutional character (“carbon credits”) in the environment assessment calculation. Under all scenarios the following substitution effects have been taken into account:

Table 25: Advantage sewage sludge uses and the substitution of primary resources

Advantage sewage sludge uses	Substitutional converted products
Fertilizing effect (N,P,K) agricultural application	Mineral fertilizer (N,P,K)
Application in recultivation (Composting, recultivation)	No substitution (offset relation only on secondary resources)
Energy production as fuel (EBS)	Generally brown coal is the reference primary resource (baseline lower caloric value)

If these CO_2 impacts are assessed with the CO_2 credits, the following results are obtained for all ARBOR scenarios (see figure below). The four scenarios are compared with the status quo as well as with a future status quo, considering the legally fixed phase-out of sewage sludge appliances on agriculture and landscaping land. In this first assessment, the results of phosphorus recovery is not included.

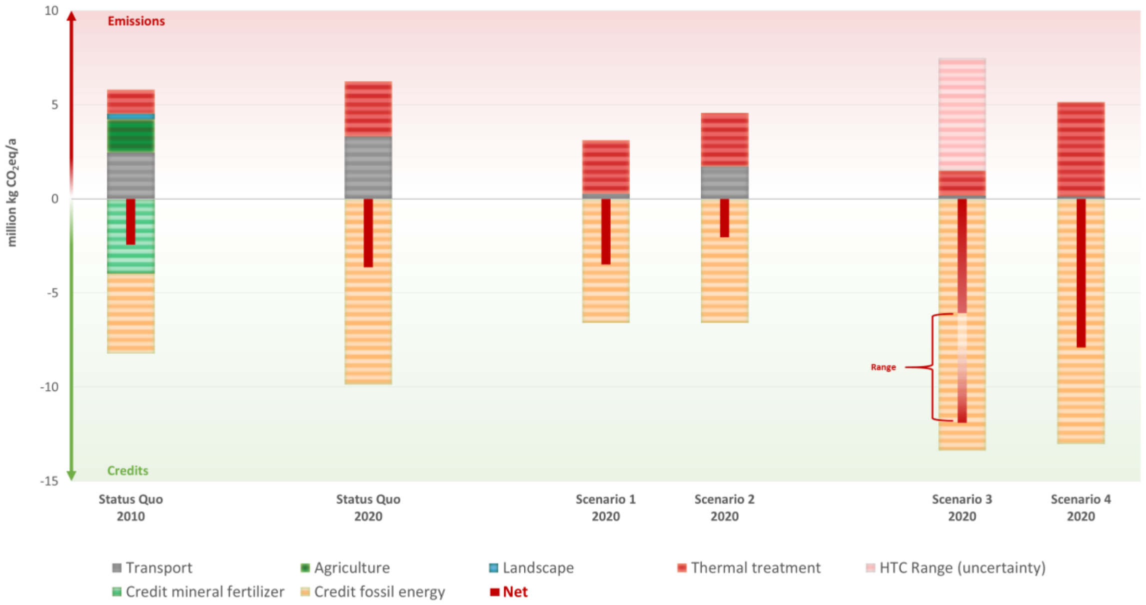

Figure 35: Impact assessment sewage sludge use

This figure shows upward aligned the air pollution resulting from the sludge transport of the specific scenarios, whereby the thermal treatment is reflected in the status quo (all existing sewage sludge incineration technologies), scenarios 1 and 2 refers to the mono- incineration and scenario 3 and 4 portrays the conversion technologies. Down the emission reductions are removed as a result of imputed substitution- effects. The positive carbon credits are reductions and are included e.g. for the substitution of mineral fertilizers in the use of sewage sludge in agriculture (only status quo 2010) and from fossil fuels, used as fuel in the thermal utilization of sewage sludge. The overall result is shown in the form of 'net-pillar' (red).

In the two scenarios Status Quo 2010 and 2020 high loads occur predominantly by the transport of the sludge to the thermal treatment plants and composting facilities as well as locations for recultivations. Nevertheless, it is important to emphasize, that savings in CO2 emissions of 2.4 million kg CO_{2eq} / a are already credited in the status quo scenario. This can be justified by the high fossil fuel substitution effects. The high transport service is the negative factor. In case of a solely Saarland recycling option, it would result in significant increase in GHG savings. Through the current legal development, a further increase in CO_2 savings of approximately 1,200 Mg CO2eq / a (net saving) by 2010 to 2020 is realistic. In terms of re-source efficiency, such approach should only be regarded as a transitional solution.

Scenario 1 describes the utilization of sewage sludge in a central mono-incineration within Saarland. The effects are distinguished in particular by the small transport loads. Considering the local Saarland utilization path, the impacts of transporting are hardly worth to mention op-posed to the status quo. Net there are approximately 200,000 kg of CO_2 savings less than in the status quo in 2020, means 3.5 million kg CO2eq. The lower transport service in scenario 1 is offset by the higher energy related substitution effects in the status quo scenario. In status quo 2010 and 2020 the sewage sludge is thermal recycled in the clinker production, resulting in significantly high savings effects (material efficiency).

In comparison of scenario 2 to scenario 1, an increased impact is exposed because of the sludge exports from Saarland. Therefore, the thermal recovery of total Saarland sewage sludge outside the Saarland results in a CO_{2eq} savings of approximately 2 million kg CO2eq / a.

Scenario 3 has the best performance with 6.0 million kg CO_{2eq} / a. On the one hand, the few sludge transports become noticeable here, on the other hand significant emission credits through the substitution of brown coal in scenario 3 as a result of the production of HTC-biochar are counted. However, the accounting of HTC technology is still subject to some uncertainty, as the energy consumption for the dewatering, drying of coal sludge and the problem of waste water arising. In total 6 million kg CO2eq can be expected to be reduced.

In scenario 4 the highest emission savings of 7.9 m kg $CO_{2eq.}$ demonstrate the decentralized thermal conversion technology pyrolysis. The emission loads are within the range of the uncertainty variation of the HTC-process and slightly higher than those of the mono-incineration, due to the process management and the significantly higher demands on the flue gas cleaning in the mono-incineration. Nevertheless, the pyrolysis is on top ranking because of its high substitution credits. For reasons of the comparability, credits for brown coal substitution has been credited, although the pyrolysis carbon is rather used as soil bottom substrate. This soil improving aspect states another positive argument as the phosphorus recovery could be dispensed.

The sewage sludge treatment was assessed with two sites (scenario 3) and three locations (scenario 4). Both scenarios represent the decentralized considerations. The transportation load in these two scenarios and the savings due to lower transport distances and due to the increased decentralization are negligible.

From an ecological perspective the issues sludge drying, nitrous oxide emissions in the fluidized bed incineration of sewage sludge, the comparison between HTC and pyrolysis processes are finally discussed in the summary and recommendation chapter.

Phosphorus recovery

The impact assessment of the recognized phosphorus recovery process is summarized in the figure below.

To highlight and compare the outcomes of the two processes, the methods have been applied to the scenario 1. To classify the results the reference status quo is additionally portrayed. The evaluation of the Seaborne process involves some uncertainties. Material and energy consumption are known, however, to account for the material supply can due to insufficient data basis only be roughly estimated. This rough estimate is incorporated in the range bar "strain P-recovery (area - SB)" in scenario 1 (light blue).

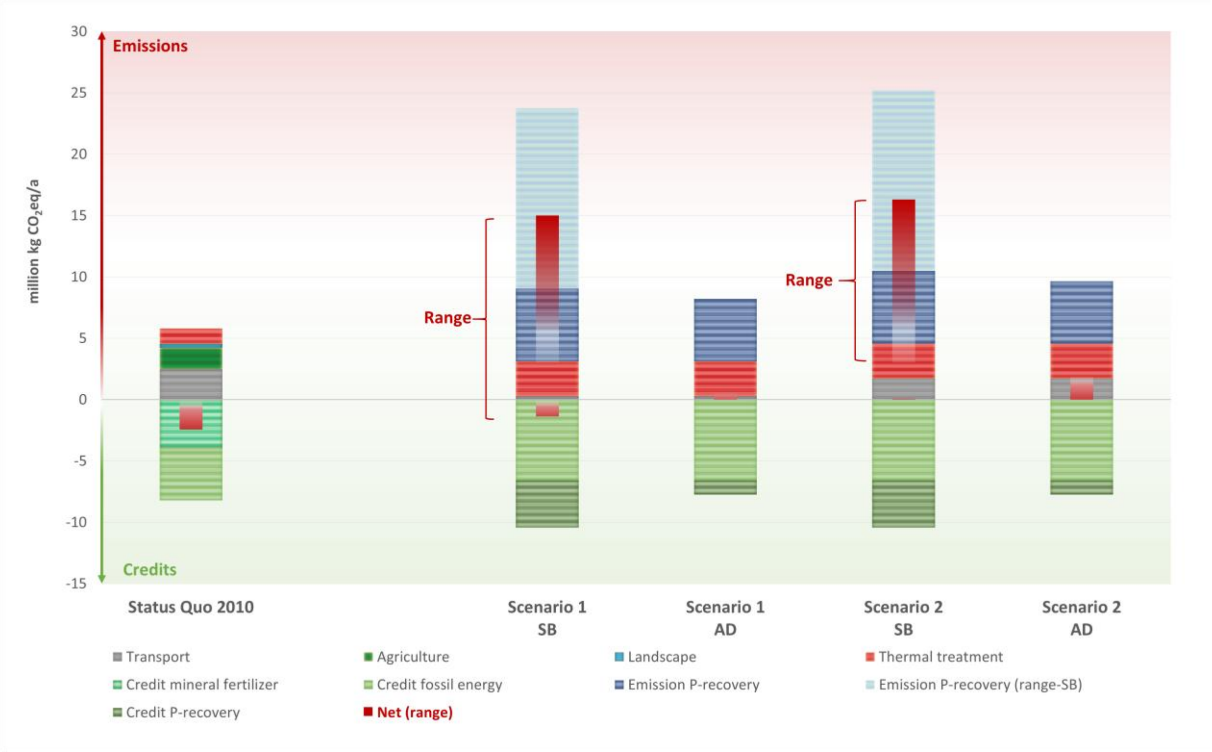

Figure 36: Assessing the impacts of phosphorus recovery process Seaborne (SB) and Ash Dec (AD) in Scenario 1 & 2

A phosphorus recovery is from an environmental perspective, if only the greenhouse gas emissions are taken into account, not an advantage, rather relevant from the viewpoint of resource scarcity. Scenarios 1 & 2 bear emission savings without the impact of phosphorus recovery. Through the still enormous energy and material consumption of the two procedures, no major positive effects can be achieved by balancing the substitution effects. The credit for the substitution of chemical fertilizer is too low to compensate for the impact category greenhouse gas emissions by the load. As already mentioned, other impact categories such as resource scarcity should be assessed for phosphorus extraction.

5.8 Economic assessment of sewage sludge utilization scenarios in terms of their cost-effectiveness

In cooperation with the responsible public waste disposal entity, the Disposal Association Saar (EVS), the cost data of status quo 2010 was gathered. The sludge disposal in Saarland is under the EU procurement directive. This regulation regulates the spectrum of choice about the recycling route of sewage sludge. The figure below compares the actual cost of disposal by the EVS with the average cost data by literature.

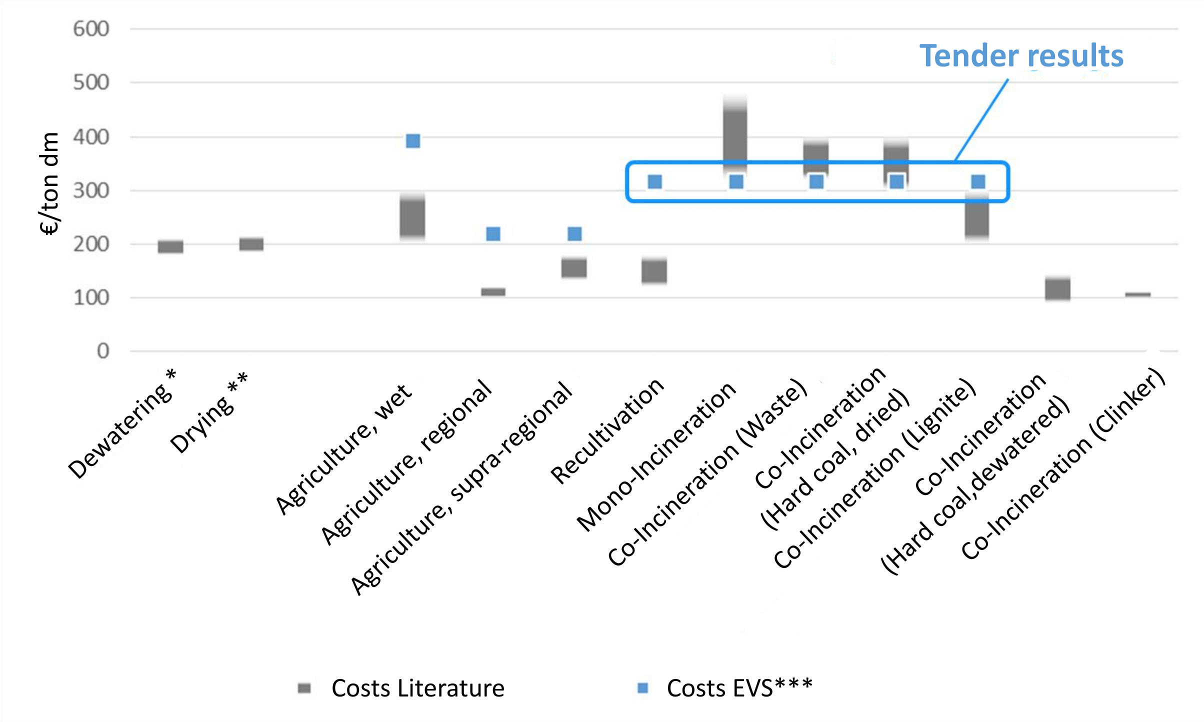

*Figure 37: Disposal costs of EVS compared to average literature values (Schumacher, et al., 2009) * (Pinnekamp, et al., 2006), ** (Jacobs, et al., 2013), *** (EVS, 2015)*

The cost of the EVS for agricultural exploitation (both wet and liquid) are significantly higher than the costs by literature values. The cost of the EVS for the dispose-supply in thermal recycling and recultivation measures are derived because of the public tenders for the disposal of sewage sludge amounts. Here the costs are up to the recultivation and incineration in brown coal fired power plant in the lower range of the average disposal costs.

The economic assessment of the different disposal scenarios are primarily based on the real data of the respective technology providers (eg AVA-CO2, PYREG GmbH, Outotec GmbH), which have been verified or supplemented by various literature values. As part of the profitability calculation the following basic parameters have been defined:

- costs in € or € / year gross♣
- capital costs: interest rate 3%; credit by communities: currently 2%
- depreciation periods in accordance with depreciation tables
- power price: 0,2 € / kWh,
- gas price 0.06 € / kWh (prices for industrial users)

- insurance: 1% of investment costs,
- maintenance / repair: approximately 3% of investment costs,
- staff costs by public service of the federal states (TV-L),
- administrative expenses: 10% of staff costs

Any income, e.g. from sludge sales or of a potentially marketable end products such as bio-char by HTC coal / pyrolysis were not considered as part of the assessment. The figure below compares the disposal costs of the sewage sludge utilization scenarios:

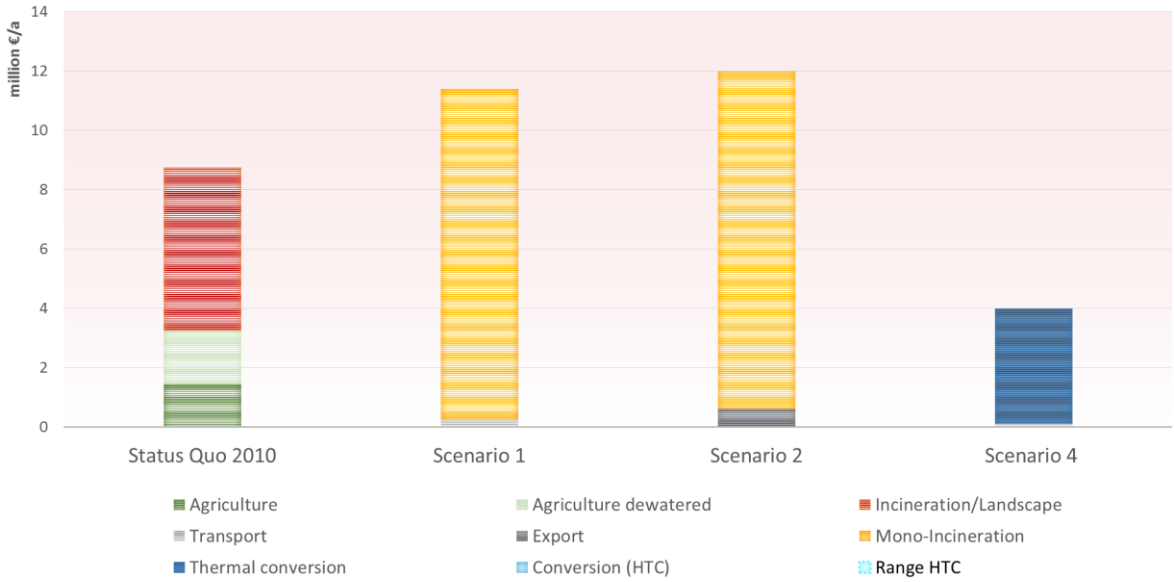

Figure 38: Annual disposal costs for sewage sludge scenarios

For status quo scenario, the cost of the disposal of sewage sludge are approximately € 8.7 million. In case, that the future disposal of the entire sewage sludge will be steered into a mono-incineration, the annual disposal costs will increase to around € 12 million; a mono-incineration plant outside Saarland will even top the costs to approximately € 13.5 million. In scenarios 3 and 4, the disposal costs are on average around € 4 million. In scenario 3, the costs are between € 2.4 million and € 5.8 million due to the already mentioned uncertainties in the process assessment.

To determine the cost development in the scenarios, all the technologies used and their cost data are briefly described. In scenario status quo, the public tender results for the accounting period have been used. The recovery of wet sludge in the agricultural application shows economic costs in the amount of approximately € 393 / Mg DS. The costs incurred for processing the dewatered sludge for agricultural application is approx. € 219 / Mg DS. The remaining materials are used for thermal recycling and recultivation in landscaping with costs of 318 € / Mg-DS (EVS, 2014).

For the economic assessment of the scenarios 1 & 2, literature data have been applied (see table below):

Table 26: Cost compilation sludge mono-incineration after (Schumacher, et al., 2009)

Annual performance sewage sludge	***120.000 Mg FM / a***
Investment	29.062.500 €
Capital Service	2.948.699 €
Operating Costs	13.100.099 €
Revenues	-2.311.492 €
Economic Feasibility	11.425.814 €
Spec. Treatment Costs	95 € / Mg FM
Spec. Treatment Costs	**381 € / Mg TS**

In the further stage of the assessment, the interim results have been discussed with real data of manufacturers. This has resulted in specific treatment costs for mono-incineration of sewage sludge around 585 € / Mg TS (see. table below). The cost accounting of the mono-incineration in scenario 1 and 2 bases on these real cost data.

Table 27: Cost compilation sludge mono-incineration after (outotec, 2014)

Annual performance sewage sludge		***30.000 Mg TS / a***
Spec Treatment Costs	180 - 210 € / Mg TS	195 €/Mg TS
incl. Transport (Distance 100 km)		
Dewatering costs	375 - 405 € / Mg TS	390 €/Mg TS
Total		**585 €/Mg TS**

Since the costs vary depending on transport costs (included in the specific treatment costs), the following calculation is derived for the two scenarios as follows: In scenario 1 treatment costs of 180 € / Mg DS plus the average cost of drainage € 390 / Mg TS, resulting in a total cost of around 570 € / Mg DS; in scenario 2 € 600 / Mg DS have been accounted because of the export load.

In Scenario 3, the sewage sludge the HTC cost are accounted for treatment costs. The cost calculation bases on literature data by (Ifeu, 2012) and verified with the manufacturer AVA-CO2 (AVA-CO2, 2014) (see. table below).

Table 28: Cost compilation Hydrothermal Carbonization after (ifeu, ICU, 2012)

Annual performance sewage sludge	**10.000 Mg FM/a**	**35.000 Mg FM/a**	**60.000 Mg FM/a**
Investment	3.088.050 €	6.800.850 €	7.883.750 €
Capital Service	305.694 €/a	696.592 €/a	809.624 €/a
Operating Costs	412.576 €/a	1.209.818 €/a	1.914.773 €/a
Revenues	0 €/a	0 €/a	0 €/a
Economic Feasibility	718.270 €/a	1.906.410 €/a	2.724.397 €/a
Spec. Treatment costs	72 € / Mg FM	54 € / Mg FM	45 € / Mg FM
Spec. Treatment costs	**281 € / Mg TS**	**213 € / Mg TS**	**177 € / Mg TS**

It should be noted, that in these costs compilations two important cost items are not included. Costs for the treatment of the resulting waste water treatment are not integrated, as well as the cost for dewatering and drying the produced carbon HTC. A differentiated cost determination for dewatering or drying is after (AVA-CO2, 2014) difficult, due to the differently applied processes and the achieved dry matter contents (procedures for the AVA-CO2 processes: dewatering using chamber filter press up to 75% DS, drying by flash dryer to approximately 90% DS). In scenario 3, treatment costs are about 281 € / Mg DS. The accounting with the highest specific treatment cost is adequate because of the partial-accounting of the uncertainties, on the other hand, a comparable plant scale can be performed to pyrolysis.

Scenario 4 differs from scenario 3 by choosing the conversion technology. In scenario 4, the pyrolysis has been selected. In the context of a sustainable sewage sludge recycling strategy, the EVS has already build a pyrolysis plant at the treatment plant site in Homburg. The costs have been developed directly with the EVS on the basis of the planned system.

Table 29: Cost compilation Pyrolyses after (Pyreg GmbH, 2015)

Annual performance sewage sludge	**9.000 Mg FM / a**
Investment	3.607.000 €
Capital Service	291.084 €
Operating Costs	196.650 €
Revenues	0 €
Economic Feasibility	487.734 €
Spec. Treatment costs	54 € / Mg FM
Spec. Treatment costs	**194 € / Mg TS**

In addition to the scenarios the possibility of phosphorus recovery should be considered along. As an example, a method for the recovery of Phosphorus from sewage sludge incineration ash is researched and the determination of the specific costs are shown below.

Table 30: Cost compilation Phosphorus recovers after (Pinnekamp, 2007)

***Annual performance sewage sludge** by sewage sludge amount*	**15.000 Mg Ash / a** ~ 30.000 Mg DS sewage sludge / a
Investment	11.026.720 €
Capital Service	1.246.573 €
Operating Costs	3.604.834 €
Revenues	0 €
Economic Feasibility	4.851.407 €
Spec. Treatment costs	**ca. 323 € / Mg Ash**

The specific treatment costs are very high (324 € / Mg) for the combustion ash. If these treatment costs apportioned to 1 Mg sludge, the specific treatment costs are around € 140 / Mg DS sludge. For a market feasible cost calculation the phosphorus recovery costs needs to be lower than the manufacturing costs (market price). Thus costs amounting to approximately € 5.80 / kg P per kg derive for recovered Phosphor. In this budgeting the revenues for any sale of phosphorus are not yet calculated. Considering a product price of 0.5 € / kg P and a yield of phosphorus of 837 mg of p / a - in consideration of a full recovery of the potential recovery potential) a revenue of € 418 500 / a is to be expected (Pinnekamp, 2007). Herewith the manufacturing costs can be even up to 5.30 € / kg P, nevertheless a marketability for the recovery process is still not achievable under the current framework. An analysis of further recovery processes is at this point not essential. To portray the current cost situation of phosphorus recovery, the figure below shows the recovery from sewage sludge and from the ashes.

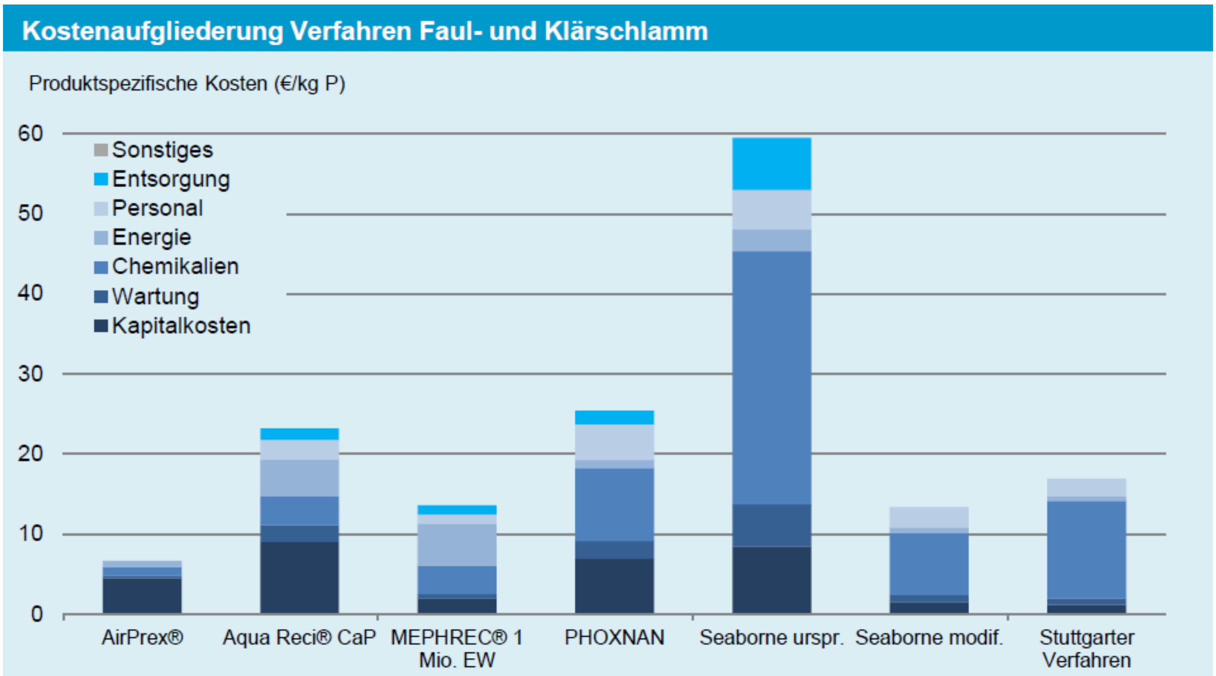

Figure 39: Cost compilation sewage sludge procedure (bi.iwr, 2014)

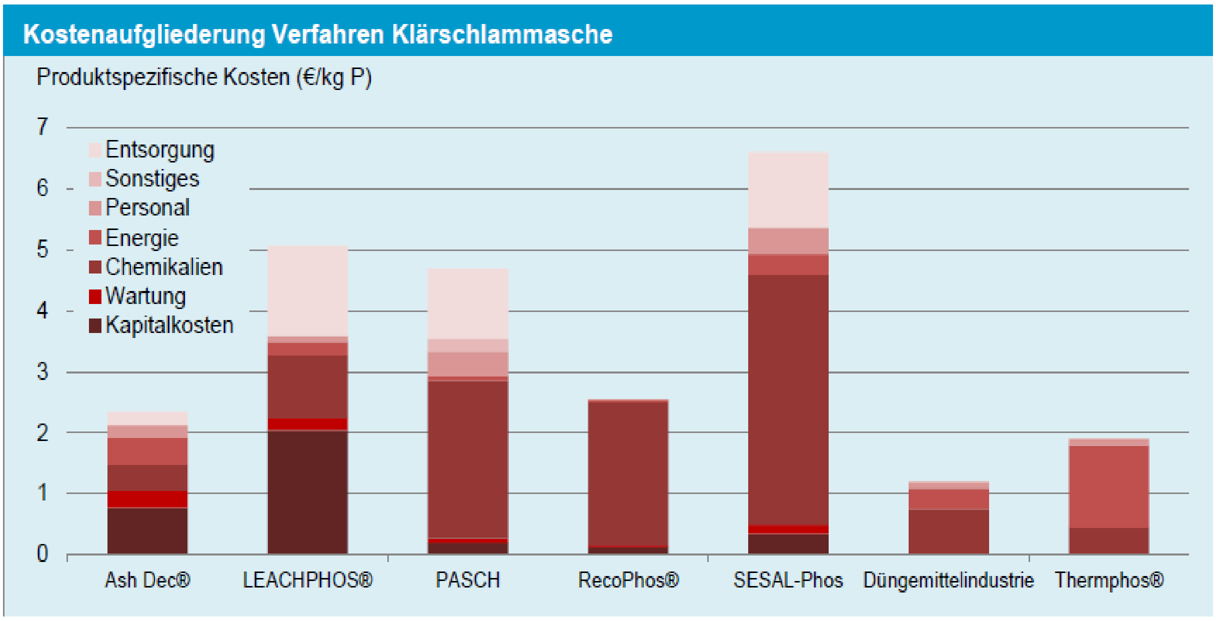

Figure 40: Cost compilation ash procedure (bi.iwr, 2014)

The economic assessment shows that there is currently no process on market proving an economic feasibility. The phosphorus recovery is yet to grant more time to develop. In the future, it is expected, that further shortages of phosphor resources will arise, and consequently, the price of phosphorus products will increases. Thus processes such as Ash DEC® or Seaborne can economically become feasible.

If a recovery of phosphor shall be implemented in the future, current resources need to be saved. Therefore, the mono incineration needs to be already planned with ash storage options. According to (Terrag GmbH, 2015) the costs of landfilling of 1 Mg ash is currently at approximately 30 - 35 €. In addition to these costs, however, the technical processes to extract the phosphor in future needs to be considered.

5.9 Conclusion and strategy recommendation

The current sewage sludge treatment is facing a transformation. The agricultural use is currently and in the future only possible to a limited extent, i.e. possible for very high quality sewage sludge. For this reason, the focus of this study was on the thermal sludge treatment. After an assessment of greenhouse gas emissions and the economic assessment by the Saarland Task Force Sewage Sludge (representatives of public legal Disposal Association Saar, department waste water and sewage sludge, the Ministry of Environment and Consumer Protection and the Ministry of the Economic, Employment, Energy and Transport; and the IZES gGmbH), a recommendation was derived for a current and future alignment of a sustainable sewage sludge treatment in Saarland. In addition, various aspects that were discussed during the project phase, mentioned briefly here.

<u>Agricultural application and co-firing</u>

First, it can be stated that a continuation of the agricultural recycling of the Saarland sewage sludge, as shown in the status quo, is phased out by fertilizing legislation in Germany. A distribution of sewage sludge as i.e. through the application on agricultural soils, recultivation areas, co-firing in power plants and waste incineration plants, appears in terms of the future shortage of resources also as not useful and should be largely avoided. A recovery in clinker production has been included in the assessment because of the status quo situation, but this was not a focus, so that possibly benefits of this recovery path have remained not evaluated. The consideration of this recycling option may seem appropriate-under certain circumstances, as the sludge is both energetically and materially valorized (resource efficiency). Here is need for further research. The mono-incineration of sewage sludge incineration appears to be the only remaining possible scenario of the previous recycling methods in the future. Therefore, a continuation on existing structures and procedures appears to be not effective. The scenarios therefore focus on thermal valorization of sludge treatment processes, which have either a central or a decentralized infrastructural design.

Mono-incineration:

The mono-incineration is the central variant of the assessment, which leads to very high investment costs. In addition, it is important to find a suitable site/location. In Saarland, there is only one optional location, which is necessary to examine it more detailed within a concrete planning context. As an alternative to the Saarland solution, there is the option to mono burn it outside Saarland, in the neighboring Federal State Rhineland-Palatinate. Both approaches require additional sludge input streams to secure the capacity utilization. Here a cooperation within the Greater Region (Rhineland-Palatinate, Luxembourg, France) would be desirable. As a result of sewage sludge mono-incineration, it is important to take into consideration a Phosphorus Recovery Strategy. At present, there is no solely recommendation from an environmental and economic point of view for any particular assessed treatment. Fact is, that at present, no process can be operated economically. Therefore, the combustion ash must be stored to a future recovery. Due to the huge investment costs and the uncertain outlook for the nutrient recovery of phosphorus from these ashes, no recommendation for this recycling alternative can be explicitly addressed.

Hydrothermal Carbonization and Pyrolysis

In two other scenarios, decentralized approaches have been considered. Both conversion routes, as hydrothermal conversion (HTC) and the pyrolysis show higher positive results in terms of environmental assessment and economic assessment than the mono- incineration. Both technologies are still in development, whereas the technology of pyrolysis can be categorized as low-tech, the HTC process more than high-tech. The pyrolysis process is also fraught with less uncertainties. While project lifetime, the EVS has realized a pyrolysis plant at the wastewater treatment plant in Homburg. The economic data for the assessment are related to this plant and can be considered as reliable data base. Compared to the Pyrolysis plant, the HTC plant is technically more complex. Additional HTC bears other outstanding issues, such as the waste water problem and the energy demand for coal sludge dewatering and drying, increased maintenance and operating expenses and staff skills for operational management. In HTC process, nutrients are bound in the sewage sludge as well as heavy metals in the coal. In Switzerland, there are current attempts to recover the nutrients especially phosphorus from the HTC-coal instead. Results were not available at the reporting date, an initial assessment according to the solution of nutrients, seem to be realistic. Furthermore the HTC coal can be used energetically as a substitute for fuel in coal power plants. The pyrolysis coal - according to the manufacturer statements- show properties allowing for direct application as soil substrate or in the manufacture of floor substrates. In this context, the heavy metal pollutants are widely eliminated, so that nutrient recovery procedures are not required. The HTC technology can- under optimal framework conditions also provide better economical and economic performances, but this technology is fraught with much more uncertainty. Further research on this needs to be done in future.

Sewage sludge drying

If the sludge is treated in an incineration, a pretreatment in form of drying needs to be done. Is the drying process implemented decentralized, i.e. to the central wastewater treatment plants, the subsequent transport costs are significantly reduced. Nevertheless, the high energy consumption of the drying process is significant. At the sewage treatment plants, the necessary energy is usually not produced, must be supplied by external sources. Is the drying process located at the Recycling facilities, the heat generated during combustion can be used to dry the sludge, further excess heat can be used externally (assumption of full heat use and the sites have an optimal infrastructure for heat networking). If this heat cannot be used in the practical context, the positive carbon credits will be reduced and can tend the potential savings to zero.

An alternative to sludge incineration represents the Hydrothermal Carbonization in scenario 3. With regard to the drying process, the HTC process shows a decisive advantage. The HTC sludge requires no upstream drying as a drying of the sludge is achieved (approximately 70% DS) through the HTC process. Depending on the use of HTC-coal, e.g. as co-firing in coal-fired power plants, an additional drying of 70% to 90% downstream is mandatory. In addition, the HTC-coal after (ZHAW, 2013) has also significantly improved drainage features and the heat required for this purpose may be provided by the waste heat from the HTC process. Beside these advantages, complex engineering technology must be applied.

Nitrous oxide emissions from sewage sludge incineration

In this study, the fluidized-bed process has been assumed to account for the sludge incineration. Depending on the combustion temperature and the type of process (one- / bicameral system), the N_2O emissions of fluidized bed combustion show a large fluctuation range between 60-180 mg / m³. Due to the high global warming potential of nitrous oxide is a change in the emissions significantly impacting the carbon credits of the scenarios. Based on this experience and the state of the art, the emissions have been adopted within the lower range.

Carbon credit allocation

The products generated (electricity, heat, biochar, phosphorus fertilizer) are accounted for positive carbon credits in the Life Cycle Assessment. When using (HTC) biochar in a brown coal power plant, it is expected to be credited for substitution for brown coal (high carbon credits). If the reference scenario changes, as e.g.to a modern natural gas power plant, the carbon credit will be reduced significantly. The consequence would be, that the HTC coal utilization offsets less favorable emissions.

Data quality

The technologies, which have been assessed in the scenarios show different levels of technical maturity and perfection. Accordingly the quality of data vary and a direct comparisons with each other needs to receive adequate consideration of these framework conditions. The data quality of established technologies (co-fired power plant, waste incineration, etc.) is relatively good, while the data of new innovative processes (HTC process, pyrolysis of sewage sludge, P-recovery) refer to first pilot plants or studies, influencing the data quality correspondingly.

6 Transferability to ARBOR regions

The following chapter portrays the findings of the ARBOR questionnaire on organic waste management and sewage sludge recycling by local authorities in the participating ARBOR regions. The leading author of the study, IZES gGmbH, had developed the questionnaires and delivered the document to the regional partners of the consortium. The partners bear the responsibility of the national data and further information gathering.

The resume of the information gathered is presented from here onwards. The German case studies information is not repeated in this chapter but fully presented in the chapters above. In the case some information is not portrayed for the partner regions, it may not have been available in the moment the questionnaire was answered or it was not stated by the corresponding partner.

6.1 Transferability on organic waste management

6.1.1 Collection of waste within the ARBOR regions.

6.1.1.1 Ordinances regarding to separate collection of organic waste

In the ARBOR regions to be compared with the German case studies, the only country which is obliged to collect biodegradable waste (organic waste) separately is the Netherlands. There, all municipalities are forced to make a separate collection since 1994.

The Flanders region has, as a difference, a mix concept for the management of organic waste. Although the separate collection of green waste is compulsory (VLAREMA), the regulation concerning the collection of organic waste is determined by each municipality. Moreover, the municipality chooses whether or not to separately collect organic waste, at which cost price, and at which time interval. In this therritory, green waste is defined as the compostable organic waste from the maintenance of gardens, parks, river banks, roadsides, nature reserves.

Within the sectoral execution plan, the Flemish cities and municipalities have chosen whether to be a region that collects organic waste from households (gft-regio) or a region that collects greenery cuttings (groenregio). As a consequence, 69% of the population lives in an area where the organic waste is separately collected (and the greenery cuttings are brought by the inhabitants to the municipal container site). On the contrary, 31% of the population lives in an area (usually in areas with a low inhabitant density or rural areas) where the greenery cuttings are separately collected. In these latter areas, there is potential to extend the separate collection of organic waste from households. The distribution of those areas in the Flemish region is showed in the following figure:

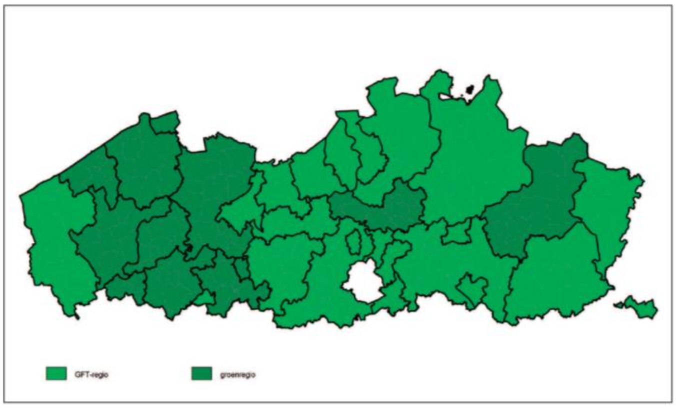

Figure 41: Partitioning of the different municipalities within Flanders into regions that collect organic waste (GFT-regio) and regions that collect greenery cuttings (groenregio)

Additionally, a municipality or part of it can be exempted of separate collection of organic waste if the Flemish Minister of Environment agrees and in case one of the following scenarios happen:

- Heavy contamination of the waste stream
- Unreasonable cost for collecting the organic waste
- Hygienic reasons, e.g. lack of space

On the other hand, neither the United Kingdom nor Luxemburg has a mandatory separate collection of organic waste (bio-waste). Luxembourg consist voluntary on both house-to-house and bring collecting system and it is guaranteed on the whole country territory. The 2012 data indicates that 72.2% of the population has the access to greenery cuttings house-to-house collecting system (organized in parallel to bring-system), while the rest has only the access to the bring-system (Source, AEV, 2014). In the United Kingdom, the separation of other materials is enforced by law but organic waste is not considered. The Household Waste Recycling Act (2003) mandates that there must be separate collection of at least two materials (i.e. general waste & plastic). The revised Waste Framework Directive (waste regs. 2011) provides for separate collection of glass, paper, plastics and metal.

6.1.1.2 Characteristics of separate collection systems for greenery cuttings apart from organic waste from households

As it was expressed above, greenery cuttings collection systems differ in the Flemish region from gft-regio to groenregio. The characteristics of the service in each region is shown in the following table:

Table 31: Characteristics of the organic waste collection system in the Flemish region

	System	Modalities	Frequency
Organic waste (gft-regio)	Pick-up system	Containers or compostable bags	Two weekly
Greenery cuttings (groenregio)	Pick-up system and collection sites		4 times per year
Greenery cuttings (gft-regio)	Collection sites		

In the United Kingdom, the collection authority can chose themselves how they wish to manage greenery cuttings. There is no legislation and such decisions are made upon economic assessment.

The characteristics of the service in Luxembourg consist on both house-to-house and bring collecting system and it is guaranteed on the whole country territory. The 2012 data indicates that 72.2% of the population has the access to greenery cuttings house-to-house collecting system (organized in parallel to bring-system), while the rest has only the access to the bring-system (Source, AEV, 2014). How the system is exactly organized depends on the municipalities, which are in charge of organizing that. The consortia of municipalities have central collecting sites for different waste types. There, the residents can bring and deposit their greenery cuttings. Regarding the house-to house collecting, in most of municipalities there are several days per year defined when the community collects this type of waste, while in the others the pick-up service is available on demand the whole year round.

Finally, in the Netherlands greenery cuttings and organic waste is collected once a week in special bins. It is also possible to bring large amounts of greenery cuttings to waste sorting stations (recycling centers).

6.1.1.3 Average transport distance from collection sites to processing locations

According with estimations, in Luxemburg the average transport distance from collection sites to processing locations is between 20 and 25 km. The same value in the Netherlands rises to up to 75 km.

6.1.1.4 Responsibility for organic waste collection and treatment

Within the ARBOR regions to be compared with the German case studies, the responsibilities for collection and treatment usually belong to each municipality. For example, Flemish municipalities chose how this is organized: pick-up system at the doorstep, pick-up system for a neighborhood, collection by means of street containers or collection at a municipal site. Additionally, in this area each municipality is also responsible to recycle or remove the waste which can be achieved in cooperation with other municipalities.

Furthermore, the Luxemburgish law states that the municipalities are responsible for organizing collection and valorization of the waste streams. However, once the waste is transported to the valorizing plant the further responsibility for the treatment is overtaken by the plant. All the municipalities are organized in different syndicates regrouping several municipalities, which are in charge of organizing collecting and valorization.

In the United Kingdom responsibilities are split between collection authorities and disposal authorities. Waste Disposal Authorities (provided for under the 1999 Environmental Protection Act) are typically provided by Local Unitary Authorities (tend to be large). Waste Collection Authorities are legally bound organizations which provide household collection services and are typically comprised of smaller local authorities.

Finally, municipalities form the Netherlands are also responsible for waste collection, but the treatment is done by commercial or semi-commercial organizations. For example, the AVU (Waste Removal Utrecht) has closed a contract with the VAR (Veluwe Waste Recycling) in

Wilp for the processing of organic waste. The process contemplates the fermentation and composting of the waste and the use of biogas to generate electricity. In the facility part of the energy is used in the own system and the surplus is delivered to the grid. The company has a contract that runs from January 1st 2009 to 2016 and can be extended by 2 years.

6.1.2 Amount of waste produced and potential use within the ARBOR regions

6.1.2.1 Average inhabitant density

The inhabitant density varies widely within the ARBOR regions. Flanders, the UK and Luxembourg have 474.0, 255.6 and 1*94.6* inhabitants/km^2 respectively.

Furthermore, the total size of the UK is 243,610 km^2 and the population is reaches 64,5100,000 inhabitants. In Luxemburg those values are 2,586.4 km^2 and 549,680 Inhabitants respectively.

The variation within the countries is also important, e.g. in Belgium there is a high variation between urban and rural areas. Moreover, the main cities of Luxemburg, Luxembourg City and Esch-sur Alzette, have a population of 107 242 and 32 600 inhabitants and a size of 51.7 km^{2}and 14.4 km^{2}respectively. This results in 2,073 and 2,272 inhabitants/ km^{2}respectively. This also means that for the residual area of 2550.3 km^{2}of Luxemburg the average density is 160 inhabitants/ km^2. In general in the northern part of the country the density is much lower.

Regarding to the Netherlands areas participating in the project, there is a density of 906 inhabitants/ km^2 in Utrecht and 407 inhabitants/ km^{2}in Gelderland.

Finally, the United Kingdom can be broken down by region as it follows:

- England: size: 130,395 km^2, Total inhabitants: 53,012,456 Population density is approximately 407 inhabitants/ km^2.
- Wales: size: 20,779 km^2, Total inhabitants: 3,063,456 Population density for is approximately 148 inhabitants/ km^2.
- Scotland: size: 78,387 km^2, Total inhabitants: 5,327,700 Population density is approximately 67.5 inhabitants/ km^2.
- Northern Ireland: size: 13,843 km^2, Total inhabitants: 1,847,257 Population density is approximately 133 inhabitants/ km^2.

6.1.2.2 Annual amount of collected organic household wastes and/or greenery cuttings

The annual amount of organic waste and/or greenery cuttings collected in the partner countries of ARBOR regions changes according to several factors. Usually the characterization is split between organic waste from households and greenery cuttings, but some specific and determining details regarding to the amount of wood collected is also reported.

The characterization of the waste collected in the UK is shown in the table below. However, in 2013 the total recycled ‘other organic waste’ (including green garden waste, mixed garden and food waste, wood for composing and compostable organic waste) was 3.57 Mtons. This suggests that only around 33% of the available organic waste enters the recycling stream.

Table 32: United Kingdom household waste composition. Period 2010/11

Type	Total	Percentage

Garden Waste	3.795 Mtons	16.5%
Food Waste	3.864 Mtons	16.8%
Wood	0.874 Mtons	3,8%
Other organic	0.575 Mtons	2,5%

In comparison, statistics form Flanders reported that in 2013 the total amount of organic waste and greenery cuttings collected from households were 268,403 ton/year and 439,498 ton/year of fresh matter respectively. Additionally, the wooden share was 26% (i.e. 112519 ton) of total collected greenery cuttings. Furthermore, a distinction is made in figures from 2010 for the collection in municipalities and industrial areas: 88,239 ton/year were collected from municipalities and 247,735 ton/year were collected from industries.

Flanders also reported the following amounts of waste per inhabitant that are collected (2013):

Table 33: Flanders household waste composition. Period 2013

Type	Total / inhabitant
Organic Waste	41.87 kg
Fine Garden Waste	51.01 kg
Wooden Cuttings	17.01 kg

The ARBOR region of Luxemburg reports that 29,573 tons of organic waste and 38,467 tons of greenery cuttings from households were collected in the year 2012 (AEV, 2014). Also, the total amount of g*reenery cuttings in the region* was 45,406 tons. From those values the total wooden greenery cuttings that is treated by composting plants was 13,962 ton and the wooden share was the 31% of total collected greenery cuttings. In Luxembourg statistics of household waste collections, the wooden fractions is not reported separately.

Finally, in the Netherlands 281,000 tons per year of organic waste are collected from the households of Utrecht. Furthermore, 102,000 tons of greenery cuttings are collected in the same region. In Gelderland, 111 kg per year per resident of organic waste are collected from households.

6.1.2.3 Export or import mass flows to/from other countries or regions

Regarding to mass flows between countries, the UK is a net importer of waste. It is estimated that more than 130 million tons were imported in 2012. However, no specific information is available on the import/export of organic wastes.

In Flanders, the largest part of the greenery cuttings is processed within the region. Only a small part is exported to the Netherlands for composting. The woody fraction mainly goes to the Walloon region. On the contrary, woody fraction of greenery cuttings is also imported from the Netherlands, with estimated amounts of 5000-10000 tons/year, for incineration in Flemish installations.

In addition to the amount stated above, more waste is imported by waste processing companies in the Netherlands. E.g., AVR waste processing company is importing waste from Italy, England, Belgium and Germany. However, it cannot be differentiated how much of the waste is organic waste.

Lastly, 775 tons of organic waste has been exported out of Luxemburg in the year 2012. This situation was due to the exceeded national capacities (Source Statec, 2015).

6.1.2.4 Amount of green cuttings and total surface under maintenance

The amount of hectares in the United Kingdom in the public ownership is 620,000 hectares. These figures include land controlled by national government, forestry commission and other national bodies. (Office of National Statistics, 2012).

In the Flemish region, on the other hand, there are no figures of the exact amount of wooden cuttings from the maintenance of roads and public domains. This amount is highly variable and is estimated to be a few thousand tons per year.

In the Netherlands, each municipality can create its own policy regarding the maintenance of trees. In general, the forest area is 3,464 km^2 and the nature area is 1,377 km^2, which is mostly under the control of municipalities. In general, the perennial fruit and other trees take 18,436 ha land, which produces approximately 280 kiloton wood waste per year (Koppejan et al., 2009)

6.1.3 Treatment methods used in the ARBOR regions

6.1.3.1 Recycling technologies used by the partner countries of the ARBOR project.

In the United Kingdom the organic waste (including household and herbal greenery cuttings) is treated through the following methods:

- Composting (including In-Vessel Composting): 5.850 Mtonnes
- Industrial Anaerobic Digestion (AD): 0.26 Mtonnes
- Commercial AD (including on-farm): 1.43 Mtonnes
- Mechanical Biological Treatment: 2.51 Mtonnes

Wooden greenery cuttings is primarily re-used for burning as either round wood for domestic or chip for large scale electricity generation. The national percentage for that material is not available.

The recycling methods for all greenery cuttings coming from Flemish households consist of material recycling technologies, such as mulching or composting. The treatment of greenery cuttings coming from industries is composting, mulching or energetic valorization (see table below). In total, 512,000 tons of greenery cuttings were composted in 2011. This produces annually about 260,000 tons of compost from greenery cuttings (2011). In theory 100% of the woody fraction of greenery cuttings is recycled through composting or direct re-use. Concerning the organic waste from households in Flanders, 83% of the waste is processed in composting installations, while the remaining 17% is processed in digesters. From the composting of organic waste about 110,000 tons of compost is produced annually.

Table 34: Flanders treatment of the collected greenery cuttings and organic waste (2010)

Treatment	Greenery cuttings from industries/municipalities	Organic waste from house-holds
Other pre-treatment	48 651	
Compost	220 202	83%
Re-use	840	
Recycle	1 255	
(Secondary) material**	296	
Sorting	50 227	
Landfill**	375	
Incineration**	14 123	
Digestion		17%
** Prohibited since 2011, Vlarema		

Biological treatments are also chosen in Luxemburg. The region treats the 100% of the collected organic waste from households through anaerobic digestion. Later, herbal greenery cuttings are mainly composted but a small fraction is also digested in biogas plants. The whole amount of wooden greenery cuttings is composted (100% of the 13,962 tons FM collected)

Finally, the Netherlands manages more than 50 percent of the organic waste via burning and the rest via aerobic and anaerobic digestion. Furthermore, organic household waste is fermented and then composted, using the electricity generated in the own system and delivering the surplus to the grid. Those last methods are used also for herbal greenery cuttings. In contrast, wooden greenery cuttings are burnt together with coal in already existing installations.

6.1.4 Legal and Policy Assessment within the ARBOR regions

6.1.4.1 Legal standards for organic waste treatment

In England and Wales, the Environmental Permitting (England and Wales) Regulations 2010 covers the licensing required for the storage, treatment, disposal and use of waste. For organic waste, there are several licensing exemptions:

Table 35: Licensing exemptions for organic waste in the UK

Exemption Number	Treatment Process	Applicable Volumes	Relevant Restrictions	Types of activities included
T23	Aerobic composting and associated prior treatment	Store or treat up to 80 tonnes of waste at any one time at the place of production and the resultant compost is to be used at that place; Store or treat up to 60 tonnes of waste not at the place of production and the resultant compost is used at a different place than where it is composted.	Restricted to no more than 10 tonnes of: - Paper or cardboard - Canteen or food wastes within the total volume.	A school composts kitchen and garden waste in its grounds; An allotment association composts their old plants and trimmings; A community composting group brings locally produced vegetable peelings and garden waste to a central point for composting, prior to use back in local gardens.
T2510	Anaerobic digestion (at premises not used for agriculture and burning of resultant biogas)	50m3 of waste at any time.	Minimum retention period of 28 days Biogas must be used to produce power in a sub 400kW appliance.	A business or organisation, such as a hotel, prison or hospital digesting their own food waste producing digestate for use on the gardens and biogas to generate electricity.
T26	Treatment of food waste in a wormery	6 tonnes annually of paper, cardboard or food waste.	Vermicompost must be used to treat land.	Composting of food waste from an office canteen.

In contrast, authorities from the Flemish territory require that organic waste compost, greenery compost and the end products of the biological treatment of organic-biological waste have to be produced in a licensed installation for the biological treatment of organic-biological waste, and that holds an inspection certificate. General rules for the treatment of waste streams are described in VLAREMA. The principle is to use installations in agreement with the best available technique. Moreover, all waste streams in Flemish region which are separately collected, are not allowed for incineration. Exceptions are made when the waste is heavily contaminated such that recycling of the product is not justified or if the environmental-economic balance of recycling is negative as compared to incineration with energy recovery. For organic-biological waste, quality standards are being formulated to express the maximum degree of contamination that is allowed (cfr. UMBHA, strategy plan for household waste). Additionally, waste that is non-recyclable but combustible is not allowed for landfill. Therefore, in the Flemish region only waste that is non-recyclable and non-combustible can go to landfill, which results in the prohibition of the disposal of organic waste through this method (UMBHA, 2014).

In the same line with the criteria mentioned above, Luxemburgish law on "Waste management" ("Gestion des Déchets" from 21.03.2012) declares that organic waste needs to undergo composting or anaerobic digestion treatment and only if this is not possible, due to characteristics of the waste, it can be valorized in different way.

Latterly, in the Netherlands it is forbidden to dump green waste in a landfill. Household waste is incinerated and this contains also organic fractions from the people who do not separate their waste. The National Waste Management Plan 2 (LAP2) policy is set for organic waste (i.e. vegetable, fruit, and garden waste): the promotion of separate collection, followed by processing and recycling or recovery. The minimum standard for the treatment and processing of organic waste composting (recycling) or digestion (biogas as fuel), followed by aerobic drying / after-ripening (recycling of digestant). In this last region, an agreement among different stakeholders, such as government, NGOs and energy companies have been developed. According to this agreement, the biomass that competes with food is not allowed to use. Burning of some biomass is allowed, for instance, waste from forest maintenance, agricultural waste (e.g. grass and straw), waste from agro-food and wood industries, etc.

6.1.4.2 Legislative restrictions for the application of organic waste on agricultural land.

The use of the products of the organic waste treatments in agricultural land is usually restricted by the environmental permitting regulations. For example, in the United Kingdom the compost or digestate resulting from recycling processes such as AD or In-vessel composting is considered a waste product and only up to 50 tons can be spread per hectare each year.

The Flemish region does not allow the direct use of organic waste on the land. Only the endproduct of the biological treatment can be applied as fertilizer or soil conditioner. Compost from a licensed installation for the composting or digestion of vegetables, fruit and garden waste with a maximum 25% of organic-biological waste from industries or of organic waste from the maintenance of gardens, public parks and roadsides. can be used as fertilizer, if some conditions with respect to the chemical compositions are fulfilled.

In order to apply the compost as a fertilizer or soil conditioner, the dose has to be adjusted to the agricultural requirements and to the agricultural properties of the product without exceeding the concentrations as mentioned in the table below. The correct application is observed by the respective approval authority.

Table 36: Maximum metal concentration in compost in UK

Heavy METALS (1)	
PARAMETERS	DOSERING (g/ha/jaar) (2)
Arseen (As)	300
Cadmium (Cd)	12
Chroom (Cr)	500
Koper (Cu)	750
Kwik (Hg)	10
Lood (Pb)	600
Nikkel (Ni)	100
Zink (Zn)	1800

Furthermore, in the Flemish region when applying the compost and end products coming from the biological treatment of organic-biological waste streams for the construction of landscapes, infrastructures or other cultural-technical constructions, a multiple of the maximal allowed dose can be used, and is calculated based on the total life expectancy of the construction.

As well as in Belgium, in Luxemburg it is not allowed to apply organic waste directly on agricultural land. If it is digested or composted it has the status of organic fertilizer so of course it undergoes the N limits for spreading. Additionally, if organic waste is treated in biogas plants either the waste or digestate have to undergo the hygenization for at least 1h at 70°C. For example, two biogas plants in Luxemburg hygenise the organic waste before introducing it into digestion tanks, making that the final digestate does not need to undergo this procedure. A 3rd plant runs in thermophilic mode (55°) which guarantees only partial hygenization, but the product – thick fraction of the digestate is composted together with other biomass streams. This guarantees fulfillment of the hygenization conditions.

In the Netherland ARBOR region, the legislative restrictions are set in the Wet Milieubeheer (Environmental Protection Act) Chapter 10, The Landelijk Afvalbeheer Plan (National Waste Management Plan), de Meststoffenwet (Fertilizer Law), Wet Bodembescherming (Soil Protection Act). In some cases greenery cuttings can be used directly to fill a ditch, but then a special permit from the regional government is necessary.

6.1.4.3 Certification systems for quality assurance for treated organic waste products

The certification for quality of treated organic waste products in an issue assessed by all the authorities in the participating ARBOR regions. Indeed, The United Kingdom, Belgium, Luxemburg and the Netherlands use public or private authorities to guarantee the quality and safeness of those products.

In the United Kingdom there is a Biofertiliser Certification Scheme (BSC), which provides assurance to consumers, farmers, food producers and retailers that digestate produced from anaerobic digestion is safe for human, animal and plant health. Also, the Compost Certification Scheme is an independent assessment and certification to BSI PAS 100. This standard directs the minimum requirements for compost, including testing methods, upper limits for testing parameters and restrictions against inclusion of certain derivatives.

Later, the Flemish territory summits the biological treatment of organic-biological waste streams to a quality guarantee system, managed by OVAM. Also, the quality of the compost or digestate has to meet the VLAREMA standards when it is applied on agricultural land. Next to that, a users' certificate, delivered by OVAM, is necessary. This documents states certain conditions that the user needs to meet.

Regarding to this topic, in Luxemburg the two biggest producers of compost apply the RAL-Gütezeichen and the smaller ones have their compost analyzed by certified laboratories. Nevertheless, there is no information available regarding a digestate certification system.

The Netherlands, instead, has clearly identified quality assurance system for this organic waste products. Indeed, if the organic waste is mentioned on the Appendix Aa of the Meststoffenwet (Fertilizer Law) the material can be used as co-product for digesting and the digestate can be used as fertilizer on the land. Then, Chapter III of the Uitvoeringsbesluit Meststoffen (Fertilizer Implementing Decree) lists the agricultural and environmental requirements for the use of compost.

Furthermore, there are two recognized compost labels for the use of organic products in the garden. The organizations form the Netherlands that issue these certificates guarantee to the users of these compost no running undesirable risks. To ensure this safety, they have developed requirements for the composition and maximum allowable contamination level: Keurcompost and RAG certificate. Both green compost and organic waste can be certified. The origin has to be mentioned and certified companies are periodically audited by an external organization.

6.1.4.4 Use of timber from tree maintenance processes. Specific licences and limitations.

In general, timber arising from tree maintenance is considered to be a waste by all the authorities that belongs to the ARBOR regions and compared with the German case studies. Nevertheless, some distinctions can be made regarding to this issue, e.g. in the UK some exemptions are available for wood which is destined to be used as a fuel product.

The Flemish territory categorizes the waste timber from tree maintenance as biomass-waste and has some rules for the application that are rather complex. In general, branches with a diameter less than 10 cm cannot be incinerated, but have to be used as structure material for composting. Exceptions can be made in certain circumstances, e.g. when there is an approved maintenance plan. When using the waste timber for incineration, a licence has to be applied for in case the power is higher than 300 kW.

In Luxemburg some exceptions can be made as well. In this territory, part of the wooden fraction of greenery cuttings (e.g. collected by the municipalities) has the waste status and has to be treated from the legal perspective as such with all the necessary permits. Other wooden fractions coming from trees maintenance do not have automatically the status of waste and e.g. can be combusted without the additional permits for waste treatment. These wooden streams, since not considered as waste, are not included in the official Luxemburgish waste statistics.

In the Netherlands, this type of material is also considered a waste and the only limitation for the use in farming, forestry or for the production of energy is the implementation of processes or methods which do not harm the environment and do not bring human health at risk.

6.1.5 Economy related aspects within the ARBOR regions

6.1.5.1 Incentives for electricity and or heat generation from organic waste.

Within the ARBOR region the criteria and type of economic incentives for electricity and/or heat generated from organic waste is wide and there is no unique approach. For example, feed in tariff or heat incentives are used by most of the partners but only some of them focus the incentives in cogeneration projects.

The United Kingdom has no specific incentive for waste products. Indeed, neither the Renewable Heat Incentive nor the Feed in Tariff specifically incentivize waste products. Indeed, there is a tariff available for electricity generated by AD but the price paid is the same regardless of the fuel source.

A similar situation is found in in Luxemburg where all the waste collected is digested or composted but they do not receive any additional subsidies for electricity or heat generation from organic waste in particular. The system of subsidies is independent of the substrate (except for manure digestion, for which a special bonus has been created). However, the investment subsidies for the biogas plant include the condition that the biomass for digestion needs to be locally sourced.

On the other hand, the Flemish region has green electricity certificates that are attributed in case the electricity is produced from incineration of woody biomass. For heat from biomass there is a financial support system if the heat is produced by means of a CHP (so-called CHP-certificates), e.g. digestion of organic waste and biogas valorization through CHP. The value of one certificate is calculated based on the origin of the heat/electricity but does not depend on the efficiency or the sustainability of the production process. Additionally, for investments in installation that produce ‘green heat’ and with a capacity greater than 1MW, there is a ‘groene warmte call’, delivered by VEA (the Flemish Energy Agency) with a total budget of 1 million euro.

In the Netherlands, the SDE+ subsidizes the production of heat, power and gas from biomass. For the production of power through CHP (combined heat and power) the criteria for subsidy is the percentage heat used. The more heat is reused, the higher is the subsidy.

6.1.5.2 Fees for organic waste disposal for the private customer

The disposal cost for private costumers and the mode of charging the service differs within the ARBOR regions. Regarding to this issue the authorities chose to charge the service either per ton or use an overall municipal tax instead.

The areas which had chosen to use waste fee per tones are the UK and Flanders. In the first place, fees per ton for compost, compost in vessel and incineration are £28-42, £56-83 and £83-139 respectively. In Flanders, the cost for the processing of organic waste from households is 80 euro per ton and for greenery cuttings is 60 euro per ton.

On the other hand, citizens of Luxemburg and the Netherlands are usually charged through communal taxes. In Luxemburg, for example, those taxes are adjusted according to the chosen volume of the waste disposal container. There, they have a choice between several sizes of the container, depending on the average produced waste volume. Since each community has its own waste valorization concepts and costs, the prizes differ in different locations.

The ARBOR region in the Netherlands has a different tax in every municipality and it is part of an annual municipality tax. Often citizens can bring green cuttings from the garden for free to the waste sorting stations because the fee is included in the overall municipality tax. Citizens pay taxes for waste removal in general, which also includes the price for organic waste. Therefore, there is no separate price for organic waste disposal.

Additionally, in the Flanders region the total cost of 26 million and 31 million euro for organic waste from households and greenery cuttings respectively is reported. In this area, the cost for collecting the organic waste is 75 million euro for the pick-up system (collecting at the door) and 84 million for the bring-system (container park). For the pick-up system this is about 30 euro per inhabitant.

Furthermore, in this last region according to the decree for materials, the municipalities can shift this cost to the producer of the waste. This is the principle of “the polluter pays”.

6.1.5.3 Specific treatment costs per technology

In most of the countries that belongs to the ARBOR region there is no information available or it was not stated by the corresponding partners. Only the Flemish territory has specific cost per each technology. Those costs are:

- The cost for composting greenery cuttings is about 25 euro/ton.
- The cost for composting organic waste is about 65-75 euro/ton.
- The cost for digesting organic waste is about 78-80 euro/ton.
- The cost for processing roadside grass is about 20-60 euro/ton.

6.1.5.4 Market situation of composts/nutrients, digestate, bio-char from organic wastes

Within the ARBOR regions, there is a potential market for the products from the organic waste treatment such as composts/nutrients, digestate, bio-char. For example, a study of digestate in Scotland by the Waste Resource and Action Plan group found a general price of around €6 per ton in 2010.

Furthermore, in the Flanders region the price on the market for compost (from greenery cuttings or organic waste) varies and is on average 2-3 euro/m³ total product (FM and excl. transport). The marketing of the compost mainly goes to wholesale customers (47%), which are soil mixers, producers of potting soil and other, and the greening sector (34%). The following table shows the distribution or destination of the compost produced in Flanders.

Table 37: Marketing of the compost from greenery cuttings and household organic waste (2011) in Flanders

Marketing	Percentage of compost
Greening	34%
Soil mixers	23%

Potting soil	10%
Other wholesale customers	24%
export	4%
Agriculture	5%

As it can be appreciated in the table below, Luxemburgish prices for compost differ between the trading syndicates/companies. Later, the marketing situation in Luxemburg for the digestate produced has the characteristic that this product never appears on the "free market". In 2 out of the 3 biogas fermenters, the digestate is spread on the agricultural fields belonging to the members of the collective, which own these plants. In the 3rd fermenter (which is run in dry fermentation mode) the liquid fraction is recirculated to the fermenter while the solid fraction is composted together with the classic compost streams. Therefore this product appears as compost on the market.

Table 38: Compost prices in Luxemburg

Prix du compost

Type de produits	En vrac / en sachet	Tamisage [mm]	Prix / m^3 en € MINETT-Kompost [1]	SIDEC, Angelsberg	SIDEC, Fridhaff	Hesperange	SIGRE
Compost mûr	en vrac	0 - 10	37,0	12,5 [2,3]	12,5 [2,3]	-	
		0 - 15	-	-	-	-	5,10 [4]
		0 - 20	-	12,5 [2,3]	12,5 [2,3]	gratuit	-
		0 - 30	-	-	-	-	-
		0 - 40	-	12,5 [2,3]	12,5 [2,3]	-	-
	en sachet	0 - 10	123,3	-	-	-	-
		0 - 15	-	-	-	-	37,5
	en Big- Bag	0 - 10	-	12,5 [2,3]	12,5 [2,3]	-	-
		0 – 15					5,10
		0 - 20	-	12,5 [2,3]	12,5 [2,3]	-	-
Compost frais			pas d'indication	-	-	-	-
Mélange terre / compost	en vrac	-	37,0	-	-	-	-
Écorce d'arbre	en vrac	15 / 40	37,0				
		7 / 15	37,0	-	-	-	-
Écorce d'arbre (pin)		15 / 40	40,0				
		7 / 15	40,0				
Lëtzebuerger Blummebuedem (Flora vitalis)	en sachet (30 l)	-	137,5	-	-	-	-
			Prix / sachet ou Big-Bag en €				
Consigne sachet	-	-	-	-	-	-	0,25
Consigne Big-Bag	-	-	-	12,50	12,50	-	15,00
			Livraison de 1 à 6 m^3				
Livraison	en Big Bag	-	-	50 € + 2,5 €/m^3	50 € + 2,5 €/m^3	-	-

1) pour de plus grandes quantités les prix sont négociables
2) jusqu'à 6 m^3 gratuit; prix indiqué se réfère à des quantités entre 7 et 100 m^3; lors d'un achat de plus de 100 m^3 le prix est de 5 € / m^3
3) > 6 m^3 gratuit sur présentation d'un formulaire dûment rempli, certifiant les propres besoins du compost
4) prix: 7,5 € / Mg (=5,10 € / m^3) pour des quantités de moins de 10Mg, 4 € / Mg (=2,72 € / m^3) pour des quantités de plus de 10 Mg ; prix par m^3 calculé sur base du poids spécifique du compost (hypothèse: poids spécifique (valeur moyenne 2009) = 0,680 kg / l)

6.1.6 Best practices found within the ARBOR regions.

6.1.6.1 Examples of municipal organic waste based closed loop systems

United Kingdom

- Harper Adams University College – Anaerobic Digestion[14]

The anaerobic digestion (AD) Unit installed at Harper Adams takes both farm waste and food waste from both the college and the surrounding community and processes it into electricity through a CHP. This electricity is then used to power the university campus through a private-wire arrangement with only the excess being exported to the national electricity grid. In addition, a high quality natural fertilizer is produced which is used in place of inorganic fertilizers on local farm land.

- Fife Municipal AD Plant[15]

This dry AD plant is run by Fife Council (a waste disposal authority) and processes both food and garden waste into heat and electricity. The plant currently takes waste from around 120,000 homes (43,000 tons) but an expansion is planned up to 165,000 homes. The plant uses a CHP engine to produce around 1.4MW of electricity and also provides heat to around 230 homes and public buildings. The site is saving around 18,000 tons CO2e per year.

Flanders

- Dry anaerobic composting[16]

A good practice example of the treatment of municipal organic waste is IGEAN (intercommunal organisation) in Brecht. Household waste from vegetables, fruit and garden together with non-recyclable paper (called GFT+) are processed through dry anaerobic composting (DRANCO procedure). The composting process delivers compost of high quality, which is sold on the market, and biogas, which is used to produce green electricity. The produced electricity is used to run the DRANCO installation. The installation has a capacity of 65,000 tons per year and produce electricity for 3,200 families.

- Composting at home and recyclable gardening

  The Flemish government promotes this kind of closed-loop recycling. All organic waste should be processed in the garden.

[14] Harper Adams University College – Anaerobic Digestion (https://www.clarke-energy.com/2012/harper-adams-college-anaerobic-digester-chp-plant/)

[15] Fife Municipal AD Plant - http://www.resourceefficientscotland.com/sites/default/files/RES%20project_case%20study_AD%20at%20Fife%20Council.pdf

[16] Dry anaerobic composting- http://milieuenveiligheid.igean.be/vergistingsinstallatie%20gft_plus/3493/default.aspx?id=73

Luxemburg

- Syndicate Minette –Compost[17]

The syndicate collects organic waste and greenery cuttings from 16 communes in the south of Luxembourg. Next to that it runs a composting plant (capacity 20,000 t/a) and a biogas plant (capacity 25,000 t/a) operated in dry fermentation mode. The thick fraction of digestate is integrated into composting process, so that the final product is high quality compost, traded directly at the production site. The produced biogas is upgraded and injected into the country natural gas grid.

- Naturgas Kielen[18]

This biogas plant is run by the cooperative of 30 farmers and 5 communes. The plant co-digests organic waste of different origins (industrial and municipal) together with manure and energy crops (altogether 50,000 t/a). The produced biogas is upgraded and injected into the country natural gas grid. The digestate is used as organic fertilizer and spread on the field of the farmers belonging to the cooperative operating this plant.

- Bakona Sarl

The biogas plant digests locally sourced organic waste, agricultural residues, manure and greenery cutting (altogether 22,000 t/a) and injects the produced biogas into the country natural gas grid. The digestate is spread on the local fields.

Netherlands

- In Beetsterzwaag (the North of the Netherlands) a rehabilitation centre and a school are heated with a biomass plant which uses local collected wood.
- In Zeeland Ecoservice Europe and Greewinds producing bioenergy (biofuel, bioelectricity) from local agricultural and agro-food wastes and provide it to local industries.
- Inofase is also an example of closed loops, see the synergy park report.

[17] Syndicate Minette –Compost (http://www.minett-kompost.lu/de-DE/home)

[18] Naturgas Kielen - http://www.naturgaskielen.lu/beschreibung.html

6.2 Transferability on Sewage Sludge Recycling

6.2.1 Quantitative Targets & Qualitative Objectives within the ARBOR regions

6.2.1.1 Policies for the acceleration of the energetic and nutrient recycling from sewage sludge

Specific objectives, policies and targets are described for each ARBOR region below, to be compared with the German case studies. In this chapter, the main steering policies and legislations in regard to the management of materials and production of energy from sewage sludge is assessed.

Belgium:

In Flanders there is an ongoing transition towards circular economy in order to establish a solid basis for green bio-based economy. New technologies should allow to recycle waste streams as effective as possible. Currently, waste streams are ineffectively being used because of the imbalance between demand and supply and the contradictory policy at European and national level. While Europe is promoting biomass for energetic purposes, the Flemish policy aims at valorizing biomass as high as possible in the cascade, in which energy recuperation is subordinate to material development.

Policy concerning the management of materials

Actions to establish a circular economy are formulated in the Flemish program concerning the management of materials (*Vlaams Materialenprogramma*). The goal of the program is to solve actual conflicts in the current policy and to prevent similar conflicts in the future. The main idea is to apply an integrated approach of energy, water and materials, such that the actions should aim at:

- Contribution to the renewable energy through digestion of wet biomass waste streams from companies
- Simplification of the recovery of nutrients from waste streams (sludge, digestate, …) and the trade of recovered nutrients and organic carbon

As an action within the programme for management of materials, an action plan regarding the management of organic biological waste streams (*Uitvoeringsplan organisch-biologisch afval – UPOBA, 2014*) was developed. In this action plan, specific actions with respect to the recovery of nutrients are formulated:

- mapping of the demand for recovered nutrients
- setting quantitative targets for the recovery of nutrients from organic materials
- developing an action plan to improve the trade of recovered nutrients and organic carbon
- realizing demonstration projects
- stimulating and facilitating nutrient recovery by modifying restricting legislation
- performing research of alternative technologies for the recovery of nitrogen from the endproducts of digestion

In 2012, a Flemish nutrient platform for consultation (Vlaams Nutriëntenplatform) was initiated in order to use nutrients more efficiently, to improve the recycling of nutrients and transfer knowledge and technologies for nutrient recuperation. The platform consists of entrepreneurs, government and researchers that combine their strengths.

Closely related to the UPOBA, is the action plan concerning the management of sewage sludge (*Uitvoeringsplan Slib, 2002*), and is more extensive than the UPOBA which does not deal with certain types of sewage sludge. The slib action plan is the framework for the Flemish government to execute the policy concerning sludge. The plan aims at decreasing the amount of sludge that is being burned or that is brought to landfill. Although prevention and recycling are the leading principles, the plan also aims at improving the slib treating capacity. As part of the implementation of the European directive urban wastewater treatment (91/271/EEC) and because Flanders is identified as vulnerable region (Flemish Vlarem II regulation), the removal of nutrients (nitrogen and phosphorus) is obligatory for the waste water coming from communities with more than 10.000 inhabitants.

Policy concerning the production of renewable energy

Similar to the management of materials, Flanders developed an action plan for the production of renewable energy (*Actieplan Hernieuwbare Energie*). The main target of the plan is to improve the energy-efficiency and to stimulate energy systems based on renewable energy. It is aimed at maximally producing the energy in Flanders and to stimulate a transition towards green energy. In order to achieve the goals of the action plan, the energetic valorization of biomass is necessary.

Concerning the energetic recycling from sewage sludge, the action plan renewable energy stimulates the digestion of the sludge. The system of green certificates (groenstroomcertificaten) makes the energetic valorization of biomass waste streams financially interesting. In addition, it is becoming increasingly difficult to find marketing channels in agriculture to get rid of the sewage sludge. In winter, the sludge cannot be disposed on the land such that the sludge collecting basin is saturated and other possibilities for the disposal of sludge are necessary.

<u>The Netherlands</u>

There are some stimulation processes from the Dutch government. They think along with entrepreneurs who would like to invest in the techniques within initiatives like nturientplatform.nl. Green electricity (coming out of the digestion of sewage sludge) is subsidized by the government with the SDE+ subsidy.[19]

<u>Ireland</u>

At present there are no policies aimed at the acceleration of the energetic and nutrient recycling from sewage sludge. As the large majority of sewage sludge, both historically and most likely into the future, is used in the agricultural sector as fertilizers and soil conditioners, it is highly

[19] http://www.nutrientplatform.org/leden.html

unlikely that any other potential applications will be considered, especially considering the importance of the agricultural sector to the Irish economy. There are attempts to make awareness of energy from waste such as Waste Management in Ireland –Benchmarking Analysis and Policy Priorities: Update 2010, by Forfás & CBI Brief October 2010, going to Waste: Making the case for energy from waste .

Luxemburg

At the moment, there are no policies for the energetic and nutrient recycling from sewage sludge. However some sewage sludge treating installations profit from certain investment incentives for innovative installations. Such support, however, is not only restricted to sewage sludge and decided, to our knowledge, based on case to case basis by the administrating institutions.

6.2.2 Sewage Sludge Potential within the ARBOR regions

Table 39: Overview of sewage sludge potential in ARBOR partner regions

Region	Sewage Sludge	Amount	Unit	Dry matter content
UK	Sludge, liquid		tons/year	
	Sludge, dried	1.6 million[20]	tons/year 2013-2014	
	Sludge, dewatered (mech.)			
Flanders[21]	Sludge, liquid (total)	144 908	tons DM/year	3%
	Sludge, dried	34 251	tons DM/year	≤ 40%
	Sludge, dewatered (mech.)	92 138	tons DM/year	90%
Luxemburg	Sludge, liquid	No data		
	Sludge, dried	8733	tons DM/year	
	Sludge, dewatered (mech.)	No data		
Ireland	Sludge, liquid	na	tons/year	
	Sludge, dried[22]	64,546	tons/year	
	Sludge, dewatered (mech.)	na	tons/year	
The Netherlands	Sludge, liquid[23]	8.625.000	tons	4%
	Sludge, dewatered (mech.) [24] (ca. 25% dry matter)	1.500.000	tons	23%
	Sludge, dried [25] (> 35% dry matter)	862.500	tons	40%

20 Calculated from: Explanatory Variables and Volume Measures - Wastewater
21 data from 2011, OVAM
22 Tones of sewage sludge produced by the county based treatment plants in 2013.
23 Sewage sludge with average dry matter content of 4 %
24 Mechanical dewatered sludge (e.g. centrifuge, belt, filter press) with average DM content of 25%
25 Dried sludge (e.g. thermal, solar) with an average DM content up to 95 %

In Ireland, there is extra information available regarding to the destination of this product. Indeed, the sewage sludge produced via the local waste water treatment plants during 2013 (64,546 tons of dry solids), was mostly treated and then reused on agricultural land as a soil enhancer of fertilizer. Other destinations for the dry sewage sludge include composting, landfill and a very small portion to anaerobic digestion, application to energy crops and direct fuel reuse. The destinations of the produced sewage sludge is shown in the table below.

Table 40. Sewage sludge production and utilization in Ireland - Source: EPA Focus on Urban Waste Water Treatment in 2013[26]

	Agriculture	Composting	Landfill	Other	Total
Quantity (Tons dry solids)	51,996	9,340	2,866	344	64,546
% of Total Produced	80.6%	14.5%	4.4%	0.55	

6.2.2.1 Prognosis on potential development in accordance to demographic development and efficiency aspects in waste water treatment plants

In the Flemish region, the amount of sludge has increased with 35% between 2000 and 2008 and with 5% between 2008 and 2010 due to an increased connection of sewers towards the WWTP. In the future, it is expected that the sludge production will not increase at the same rate due to following measures:

- Optimization of the water treatment installation and pre-digestion process
- Improvements of the sewage network
- Separate collection of industrial waste water
- Separate collection of rain water
- Measures at the source to reduce the sludge production

The goal is to limit the sludge production to 68 g DM per inhabitant per day (in terms of BOD; 50g DM in terms of N-demand). No problems in sludge treatment are expected because the sludge treatment capacity in Flanders in sufficiently high and such that export of the sludge for treatment is not urged. Moreover, the export of sludge is only admitted for useful applications.

A high increase in the amount of sludge produced was also identified in Luxemburg, with an increase of 11% in the period 2011-2012. It is estimated that in the future the increasing trend will persist as the demographic prognosis for Luxemburg forecasts further population growth.

6.2.3 Current applied technology and management for sewage sludge within the ARBOR regions.

6.2.3.1 Treatment technologies/options and percentage of energetic or material recycling

The following table resumes some of the treatment technologies used within the ARBOR regions for treatment or energetic or material recycling of sewage sludge:

[26] http://www.epa.ie/pubs/reports/water/wastewater/30086%20Urban%20Waste%20Water%20Web.pdf

Table 41: Overview sewage sludge treatment routes in ARBOR partner regions

Region	Treatment technology	Fresh matter [ton/year]	Dry matter (%/total amount, Mg)
Netherlands[27]	Total	1.400.521,00	23,20%
	Re-cultivation (building materials, road pavements, installation of the re-use of minerals).	21.344,00	16,60%
	Co-combustion in lignite power plants (just coal)	347.409,00	16,50%
	Co-combustion in cement production plants	108.985,00	34,00%
	Co-combustion in waste incineration plants	922.783,00	24,50%
Flanders	Mono burning		65.500
	Co-combustion in cement production plants		32.000
	Co-combustion in waste incineration plants		15.000
	Digestion		15.000
Luxemburg	co-combustion in cement plant in Luxembourg		144 (1.7%)
	Combustion in Germany		1027 (11.8%)
	Agricultural application		4292 (49.4%)
	Composting		3221 (31.1%)

Table 42: Treatment technologies/options for sewage sludge in the ARBOR region

Complementing the information given above, in the Flemish region, the incineration of municipal sewage sludge is limited to 195,000 tdm from 2010 onwards as stated in the sludge action plan ("Slibplan 2002"). Of the sludge that is incinerated, about 40% is co-combusted and 60% is mono burned (fluidized bed). Since the incineration capacity is increased, the use of sludge as coverage for landfills is stopped (since 2006). In 2011, about 34% of the produced sewage sludge (MWWTP) was digested.

In addition, Luxemburgish solutions that contemplate the combustion of the material involve a drying or dewatering process. Similarly, the compost is dewatered and used almost in its totality in the region (2856 tons DM in Luxemburg and 356 tons DM transported to Germany). For agricultural application, the sludge is used in a liquid form or it is dewatered depending on the location of the plants and potential fields.

[27] 2012 statistics. http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=70156ned&D1=a&D2=a&D3=0,3,6,12&D4=l&HDR=T&STB=G2,G1,G3&VW=T.

Statistics from the United Kingdom reported that 80.3% of sludge was recycled to land, 18% was disposed of through thermal destruction and 0.7% went to landfill within the period 2010-11[28]. Furthermore, solutions for sludge treatment and energetic or material recycling were identified among the region. E.g. Thickening or dewatering, digestion, composting, thermal drying and incineration or combustion.

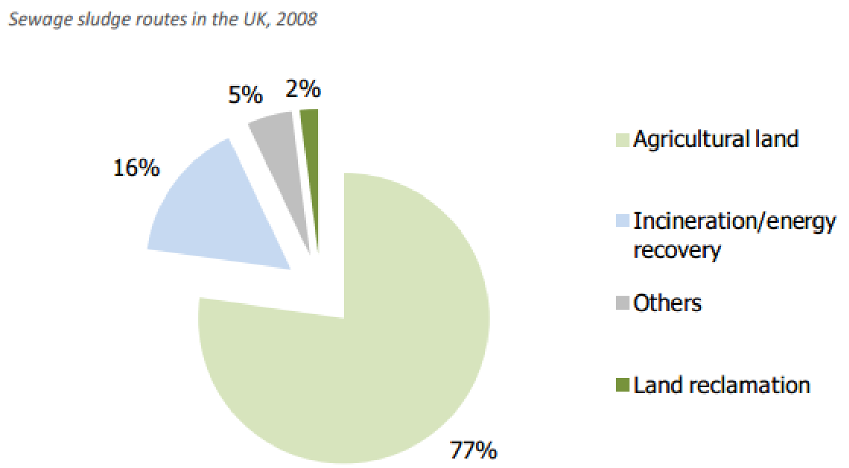

Figure 42: Sewage sludge routes. Source: Water UK (2010) Recycling of Biosolids to Agricultural Land.[29]

The following figures represent the current situation in the United Kingdom regarding energetic or material recycling of the sewage sludge[30]:

- Sewage sludge currently represents approximately 5% of total energy generation from biomass sources.
- In 2013, 761GWh were generated from sewage sludge digestion, which represents approx. 4% of total energy generated from biomass
- Some plants only use the sewage gas to generate heat but many use combined heat and power (CHP) systems, with the electricity generated being used on site or sold under the NFFO.
- The proportional importance of sewage sludge digestion as an electricity generation technique has fallen from 9% of bioenergy generation capacity in 2009 to 5% in mid-2014. The installed capacity increased by 30% between 2009 and 2012, but has fallen moderately since.
- 4MW Sewage gas plants are under development and 1.1MW are awaiting construction.

On the other hand, in Ireland there is no nutrient recovery of sewage sludge at a commercial scale, or commercial gasification pyrolysis of sewage sludge. The incinerator in Duleek county Meath has been operational since 2011, being run by Indaver, with some capacity for incineration of sewage sludge material.[31]

[28] http://www.water.org.uk/policy/environment/waste-and-wastewater/sludge
[29] https://dl.dropboxusercontent.com/u/299993612/Publications/Reports/Waste%20recycling/recycling-biosolids-to-agricultural-land--january-2010-final.pdf
[30] Renewable Energy (Industrial Report) - UK - December 2014
[31] www.indaver.ie

6.2.3.2 Centralized and decentralized collection, treatment/recycling technologies

In the Flemish territory, the water treatment plants are built as a function of the 11 river basins, which are Ijzer, Brugse polders, Gentse kanalen, Beneden Schelde, Leie, Boven Schelde, Dender, Dijle, Demer, Nete, Maas I and Maas II. Each river basin is further divided into treatment areas, which includes a treatment installation fed by different collectors. These collectors catch the waste water from the sewers of the neighbouring communities or parts of the community. To which installation the waste water is finally transported, depends on the topography of the landscape, since water flows from higher to lower located places.

In addition, the sludge action plan ("Slibplan 2002") stated that from 2010 on minimum 95 % of the incineration and co-combustion had to take place within Flanders. Since 2006 Flanders is self-regulating regarding (final) sludge treatment capacity and, as a consequence, there is no need for export anymore.

Later, under the Water Act 1989, ten water service companies were appointed to provide water supply and sewerage services in England and Wales. These act alongside a number of water supply companies that are not active in sewerage treatment and disposal. Furthermore, those companies are overseen, licensed and monitored by a number of regulatory bodies. The companies deliver water and/or sewerage services regionally (or locally). Their regional monopoly is based on boundaries fixed at privatization in 1989, but companies can apply to vary their appointments to cover a new area.[32]

The responsibility in the Netherlands for the transport of the waste water from the houses to the first sewage treatment system lies at the communes (decentral). Furthermore, the sewage treatment systems are in hands of the water boards (decentral).

Collection and treatment of waste water is decentralized in Ireland, with the local authorities (County councils in Ireland case) responsible for the collection, treatment and subsequent usage of waste water and sewage sludge materials. There are 32 major county and city councils which process waste water in Ireland, each with specific quantities, goals and operational considerations. These each serve their local area with regards to waste water collection and processing.

The region of Luxemburg count with 39 sewage treatment plants. They are mainly managed by 7 intercommunal sewage or waste treatment syndicates (SIDERO, SIVEC, SIDEST, SIDEN, STEP, SIACH, SIFRIDAWE). Moreover three municipalities (Hesperange, Luxemburg and Mondorf) administrate their sewage treatment plants on their own. Additionally there are also two International Associations for Sewage Treatment (in Rosport and Mompach) created with the German municipality of Trier. Each sewage plant owner organizes collection and management/treatment of the sewage sludge within its territory.

Only big sewage treatment plants have the mobile or stationary sludge dewatering installations. Therefore, in the smaller installations of Luxemburg usually the sludge is only statically pre-thickened and then delivered to the bigger waste water treatment plants belonging to the territory of the same syndicate/sewage treatment plant owner.

[32] *"UK wastewater industry structure.doc"*

6.2.3.3 Transport distances for the collection sites and applied technologies

Transportation cost is one of the main bottlenecks of the treatment of wet sewage sludge in the Flemish region. The different treatment plants can't be easily reached for all municipalities. Then, local dewatering of the sludge at or near the MWWTP might be a solution, since weight reduction means a large reduction of the transport costs. The transport distance is assumed to be less than 100 km.

In the United Kingdom, the transport of dewatered sludge for disposal generally takes place via road transport. An EA controlled waste license is required in order to transport sludge. The main disposal routes are agricultural land spreading, incineration, land filling, forestry and silviculture (the intensive production of forests), land reclamation and combustion technologies which generate energy (a potential substitute for coal or gas). (Ofwat 2010 report)

Regarding to this topic, in the Netherlands region there are around 350 sites which process waste water from houses. All those locations do produce sewage sludge and 30% of it is burned in the place Moerdijk (Noord-Brabant). Several of the waste water processing sites are now in a transition and they will produce electricity for their own. Moreover, they use a digester which works with thermal pressure hydrolysis. The digester will make gas, which can fuel gas-engines to produce the green electricity. Some of the waste water processing sites do not burn the gas, but (are intended to) deliver the gas on the gas network. Anyway, digestion of sewage sludge will cause less transport.

In Luxemburg transport distances are under 30 km but unfortunately there is no information regarding the transportation cost of exported material.

Ireland, on the other hand, has a small amount of applied technologies in operation at the moment, which makes data collection difficult.

6.2.3.4 Quality of sewage sludge, end-/by-products, substituted products and energy outcomes

In Flanders, the average removal efficiency for the biological oxygen demand (BOD), the chemical oxygen demand (COD), and the suspended solids (SS) are respectively 98 %, 90 % en 95 % (stable rate since 2008). The removal rate of phosphor and nitrogen has increased to respectively 84% and 80% (2013). This increase is due to an increase in the number of waste water treatment plants, that can remove the nitrogen.

Table 43. Average quality of sewage sludge (source: Aquafin 2008)

Organic matter	%	58
Organic nitrogen and ammoniak	% N	4,7
Phosphorus	% P2O5	5,6
Iron	% Fe	4,6
Zink	mg Zn/kg DM	1302
Copper	mg Cu/kg DM	306
Plumbum	mg Pb/kg DM	149
Chrome	mg Cr/kg DM	72
Nickle	mg Ni /kg DM	30

Cadmium	mg Cd/kg DM	4,3
Mercury	mg Hg / kg DM	0,9

Moreover the quality of the end products differs according to the destination of the material. The following aplications are considered in the Flemish region:

- Agricultural application**:** The quality of the treated sludge has to meet the VLAREA standards when it is applied on agricultural land. Next to that, a users' certificate, delivered by OVAM, is necessary. This documents states certain conditions that the user needs to meet.
- Incineration: Energy is also recovered from the sludge that has not been digested and from the digestate. 35% of the available sludge, which is a total of 31.154 tons (2013), is dried and is used for co-combustion in cement ovens to replace the fossil fuels. The dried sludge (90% dm) has an energetic value of at least 10 MJ/kg. Wet sludge has a caloric value of 2-3 GJ/ton, while dried sludge (90% ds) can have a caloric value of 9-10 GJ/ton.
- Digestion: Aquafin owns 17 digestion units for the MWWTP sludge with a total capacity of nearly 60 000 tons dry matter. Of those installations, 15 are equipped with gas engines. Together they produce 10.259.102 kWh green electricity (2013). Per ton dm MWWTP sludge, 280 Nm^3 or 6,440 MJ of biogas is produced. The energy demand for the digestion process ranges from 1,500 MJ (summer) to 2,600 MJ (winter) per ton dm.
- Composting: In order to be composted, the sludge has to contain at least 50% organic matter. Additionally, the sludge has to meet the VLAREA standards to be used as fertilizer or soil amendment and the composted sludge has to meet the Vlaco quality standards. After composting, the dry matter content increases with 50%.
- As the large majority of sewage sludge, both historically and most likely into the future, is used in the agricultural sector as fertilizers and soil conditioners, it is highly unlikely that any other potential applications will be considered in any significant quantity.

Other regions like Luxemburg had also specified quality of sewage sludge, end-/by-products. Indeed, average characteristics of the sewage sludge in terms of nutrient content are:

Table 44: Nutrient concentration for sewage sludge treatment in Luxemburg

Nutrient	Concentrations range in DM
K	0.09 – 0.31%
Mg	0.29 – 0.83%
Na	0.10 – 0.32 %
P	1.09 – 3.78 %
Total N	2.99 – 4.32 %

Maximum measured values for heavy metals in Luxemburg were taken from samples from 11 sewage treatment plants with 6 samplings/year.

Table 45: Heavy metals values in Luxembourg

Heavy metals	maximum measured values
Plumbum	92 mg/kgTS
Cadmium	3mg/kgTS
Chrome	71 mg/kgTS
Copper	457 mg/kgTS
Nickle	48 mg/kgTS
Mercury	2 mg/kgTS
Zink	2320 mg/kgTS

The Netherlands

- quality of sewage sludge (nutrient content; pollution)

For the use in the agriculture: See below. For the use into different kind of processors, like burners: unknown.

- quality of end-/by-products (nutrient content; pollution; electricity; heat; fuel),

When waste water processing sites do digest the sewage sludge, than the gas which come from the digesters contains different kinds of pollution like water, carbon dioxide, H_2S and siloxanes.

6.2.4 Deviation in Legal and Policy Assessment within the ARBOR regions

Relevant acts and ordinances from designated Arbor region, to be compared with German case studies is stated below, together with essential legal amendments in future expected with impact on the current situation of sewage sludge treatment.

United Kingdom

The Department for Environment, Food and Rural Affairs (DEFRA) sets the overall water and sewerage policy framework in England, including:

- standard setting
- drafting of legislation
- creating special permits (e.g. drought orders)

In addition, the European Union sets European water, wastewater and environmental standards. Ofwat is the economic regulator of the water and sewerage sectors, which includes:

- protecting the interests of consumers wherever appropriate by promoting competition
- making sure that water companies properly carry out their functions
- ensuring that water companies can finance their functions

The Environment Agency is the environmental regulator of the water and sewerage sector. It is the principal adviser to the government on the environment, and the leading public body protecting and improving the environment of England and Wales. [33]

<u>Luxemburg</u>

Two relatively new amendment were pronounced in Luxemburg:

- Règlement grand-ducal from 23.12.2014 deals with management of the sewage sludge.
- Règlement grand-ducal from 01.08.2014 deals with production of electricity from renewable energy sources.

6.2.4.1 Characterization and definition of sewage sludge/ treated sewage sludge

Among the partners in the ARBOR project, the definition of sewage sludge/ treated sewage sludge as waste material is given. E.g. Ireland clearly identify this material as a waste and, as such, there is specific environmental protection criteria associated with its use.

In Flanders, in addition, sludge is defined as waste according to VLAREMA, under chapter 19 'Waste from installations for the treatment of waste, off-site water treatment installations and the production of water for human consumption of for industrial application'. Then, if the sludge meets the requirements as specified in VLAREMA, the regulations of the Uitvoeringsplan Organisch-Biologisch Afval (action plan for organic-biological waste) are applicable.

In the Netherlands, sewage sludge is under the waste law, voices are raising to establish a certification for sewage sludge. Therefore it is not clear or unknown, if the sewage sludge will not be considered as waste anymore after that.[34]

6.2.4.2 Responsibility for waste water treatment and sewage sludge recycling

The responsibility for waste water treatment and sewage sludge recycling in the ARBOR regions relies on public and private authorities.

In Flanders, for example, municipal waste water is treated by Aquafin n.v, sewage sludge is incinerated by Aquafin n.v. (Bruges), Indaver (Beveren), E.ON Generation (Genk) and SLECO (Beveren). Aquafin n.v. owns 17 digestion units for the MWWTP sludge. Furthermore, in this region the municipalities are responsible for the construction and management of the sewage infrastructure and small-scale water treatment installations within their boundaries. Due to great efforts from those municipalities, the percentage of treated waste water has increased from 30% in 1991 to 64% in 2005. Aquafin is responsible for the construction and management

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[33] "Regulations and controls" section in Water UK (2010) Recycling of Biosolids to Agricultural Land
https://dl.dropboxusercontent.com/u/299993612/Publications/Reports/Waste%20recycling/recycling-biosolids-to-agricultural-land--january-2010-final.pdf

[34] http://www.infomil.nl/onderwerpen/integrale/handboek-eu/afval/zuiveringsslib/overzicht/
http://waterenenergie.stowa.nl/upload/publicatie2014/STOWA%202014%2035_Web%20LR2.pdf

of water treatment at a trans-municipality level (Vlaams Gewest). For this larger-scale applications, Aquafin designs, builds and exploits the sewage pipes, pumping stations and water treatment installations. [35]

The Netherlands territory which participates in the ARBOR project has the 'Ministry of Economic Affairs' and the 'Ministry of infrastructure and environment' dealing with different kinds of issues on behalf of the environment, fertilizers and durability of the economy. Nevertheless, it is not known who is directly responsible.[36]

Moreover, Irish local authorities (County councils in Ireland case) are responsible for the collection, treatment and subsequent usage of waste water and sewage sludge materials. There are 32 major county and city councils which process waste water in Ireland, each with specific quantities, goals and operational considerations. Amounts of sewage sludge produced by each local authority in 2013 are shown below:

Table 46: Amounts of sewage sludge produced by each local authority in 2013 in Ireland [37]

Water services authority	Tons dry solids/year
Carlow County Council	875
Cavan County Council	2,519
Clare County Council	1,375.30
Cork City Council	2,905.70
Cork County Council	2,045.40
Donegal County Council	871
Dublin City Council	17,260
Dun Laoghaire Rathdown	4,759
Fingal County Council	1,976.20
Galway County Council	1,048.30
Galway City Council	1,966.50
Kerry County Council	899.5
Kildare County Council	3,241.40
Kilkenny County Council	1,623.70
Laois County Council	758
Leitrim County Council	944.8
Limerick City Council & Limerick County Council	2,940.90
Longford County Council	1,858

[35] Aquafin was established by the Flemish Region in 1990, for the purpose of expanding, operating and pre-financing the wastewater treatment infrastructure in Flanders. The Flemish Environmental Holding is the sole shareholder in Aquafin. Aquafin collects household wastewater from the municipal sewers in collector sewers and transports it to wastewater treatment plants, where it is treated in accordance with European and Flemish standards.

[36] http://www.nutrientplatform.org/leden.html

[37] EPA Focus on Urban Waste Water Treatment in 2013
http://www.epa.ie/pubs/reports/water/wastewater/30086%20Urban%20Waste%20Water%20Web.pdf

Louth County Council	1,372.10
Mayo	
County Council	1,606.30
Meath County Council	1,630.80
Monaghan County Council	830.5
Offaly County Council	914
Roscommon County Council	868.5
Sligo County Council	473
North Tipperary County Council	864.4
South Tipperary County Council	1,232.90
Waterford City Council	726
Waterford County Council	474.6
Westmeath County Council	1,188.10
Wexford County Council	1,441.80
Wicklow County Council	1,055.10

Then, the sewage and the sewage sludge treatment of Luxemburg belong to the communes, which in majority of cases are regrouped in the syndicates.

6.2.4.3 Legislations for the appliance of sewage sludge on agricultural land. Thresholds on heavy metals, synthetic polymers, and nutrients

In the territories participating in the ARBOR project, the allowance or not of the use of sewage sludge in agricultural lands is dictated by several laws and ordinances that have been developed for this purpose.

Flanders, through the Manure Decree (12/2006), dictated that sewage sludge from municipal wastewater treatment plants can no longer be deposited on agricultural land. Exceptions are made when the quality is high enough to be used in agriculture. E.g. sewage sludge from the food industry where more than 90% of the sludge meets the VLAREA standards for the use as fertilizer or soil amendment with low content of heavy metals. Only a very small part (<5%) of the sewage sludge originating from MWWTP meets these standards, being the parameters that exceed the limits: zinc, copper, nickel, lead, toluene and mineral oil.

Table 47: Limits for heavy metals in sludge (mg/kg DM) to be applied on agricultural land) according to the VLAREA Decree, Flanders

Element	VLAREA	86/278/EEC
Cd	6	20-40
Cr	250	-
Cu	125	1000-1750
Hg	5	16-25
Ni	100	300-400
Pb	300	750-1200
Zn	300	2500-4000
As	150	

The Netherlands allows the application of sewage sludge on agricultural land under certain conditions. First, fertilizers out of sewage sludge should be in the so-called ‘Appendix-Aa’[38] of the *Fertilizer law* to be considered as an agricultural fertilizer. Otherwise it will be declared as a waste-product, because the minerals are recovered from waste (official status of sewage sludge). In that last case, the fertilizer can’t be traded to farmers to let the farmers use it on their agricultural land. E.g. Struviet (a phosphate fertilizers) out of sewage sludge is not in the Appendix-Aa yet. Ammonium-sulfate on the contrary (a nitrogen fertilizer) out of sewage sludge, is on the Appendix-Aa and is therefore officially an agricultural fertilizer. [39] Secondly, before applications of sewage sludge on agricultural land, the land should first be sampled. This has to be done once in every 10 years. Measurements has to be done on Cd, Cr, Cu, Hg, Ni, Pb, Zn, As. Levels may not be exceeded before adding sewage sludge on agricultural cropland. The amount of Nitrogen in the sewage sludge will count for 40% of the usable space of Nitrogen for a farmer. The amount of phosphate in the sewage sludge counts for 100%[40]

On the other hand, this issue in Ireland is in accordance with the Waste Management (Use of Sewage Sludge in Agriculture) Regulations (1998) and the Waste Management (Use of Sewage Sludge in Agriculture) Regulations (2001). This regulations set out the definition of a sludge (residual sludge from sewage plants from domestic & urban waste water, and residential sludge from septic tanks and similar), with treated sludge’s defined as sludge which has undergone biological, chemical or heat treatment or other processes with significantly reduce its fermentability and therefore any health hazards resulting from its use. They also outlined how sludge’s can be used on agricultural land, with only treated sludge allowed for use in agriculture, with untreated sludge allowed only if it is previously injected or worked into the land or is sourced from a septic tank for use on grassland which will not be grazed within six months of application. It also set out specific rules on the where, when, quantity and how sludge may be used in agriculture, while also defining heavy metal limits for both soils and sludge’s in an agricultural context.

Table 48: Limit values for amounts of heavy metals which may be added annually to agricultural land, based on a ten year average

Heavy Metal	Limit Value (kg/He/Yr)
Cadmium	0.05
Copper	7.50
Nickel	3.00
Lead	4.00
Zinc	7.50
Mercury	0.10
Chromium	3.50

[38] Appendix Aa: http://wetten.overheid.nl/BWBR0018989/bijlageAa/geldigheidsdatum_20-02-2015

[39] http://www.maiscoach.nl/2014/06/13/struviet-alternatieve-fosfaatbron-voor-snijmais/
http://www.nutrientplatform.org/business-cases/bedrijfsnaam/a-tm-z/149-gmb-2.html

[40] https://mijn.rvo.nl/mest-uitrijden?inheritRedirect=true

In addition to these regulations, the codes of good practice for the use of biosolids in agriculture were introduces to set guidelines for the treatment and use of wastewater sludge in the agricultural sector. This code applies in all parts of Ireland, produced in response to Directive 86/278/EEC. It identifies best practice for the production of biosolids and suitability of land for application. From a farmers perspective it presents best practice for the storage, transportation, land spreading, farming activity constraints and application rates for biosolids to tie into nutrient management planning.

Luxemburg, furthermore, has different threshold values for heavy metals and organic contaminants that had been established in Règlement grand-ducal from 23.12.14 in case of application of sewage sludge from communal sewage treatment plants on agricultural soils:

Table 49: Threshold values for heavy metals (Règlement grand-ducal, 23.12.14), Luxembourg

Heavy metals	Treshold value
PB	200 mg/kg DS
Cd	2.5 mg/kg DS
Cr	1.000 mg/kg DS
Ni	80 mg/kg DS
Ag	1.6 mg/kg DS
Zi	3000 mg/kg DS

Table 50: Threshold values for organic contaminants (Règlement grand-ducal, 23.12.14)

Organic compounds	Treshold value
PAHs	20 mg/kg DS
PCBs	0.2 mg/kg DS
Dioxins and Furans (PCDD/PCDF)	20 ngTEF/kg DS (TEF = toxic equivalency factor)

Moreover, there are additionally the following maximum concentration limits on heavy metals set for the soils (with pH between 6 and 7) where the sewage sludge can be applied:

Table 51: Threshold values for heavy metals for soils with PH levels between 6 and 7

Heavy metals	Treshold value
PB	200 mg/kg DS
Cd	2 mg/kg DS
Cr	150 mg/kg DS
Cu	100 mg/kg DS
Ni	75 mg/kg DS
Ag	1.5 mg/kg DS
Zi	300 mg/kg DS

In case the pH of the soil is lower, the authorities may, case-based, set lower heavy metal thresholds. Moreover, there are total maximum yearly application limits of heavy metals set (see table below) and the total amount of sewage sludge applied on agricultural soils for fertilizing reasons (the only allowed purpose of field application) cannot exceed 3 tonnes DM per ha of agricultural soil.

Table 52: Maximum yearly application limits of heavy metals

Heavy metals	Treshold value
PB	15 kg/ha/year
Cd	0.15 kg/ha/year
Cr	4.5 kg/ha/year
Cu	12 kg/ha/year
Ni	3 kg/ha/year
Ag	0.1 kg/ha/year
Zi	30 kg/ha/year

The law predefines also special “protection areas” where no sewage sludge can be applied (due to the water protection reasons). Moreover there are some unofficial requirements of the administration limiting the P content in the agricultural soils to the maximum of 26 mg/kg DM of soil, which can affect the total allowed amounts of sewage sludge which can be spread.

6.2.4.4 Sanitation requirements for the application of sewage sludge on agricultural land

As explained above, in Flanders only a very small part (< 5%) of the sewage sludge originating from MMWWTP meets the VLAREMA standards. Therefore it cannot be used as fertilizer or soil amendment.

The Netherlands specifies the following heavy metals tresholds values for the application of sewage sludge on agricultural land:

Table 53: Heavy metals thresholds values for the application of sewage sludge on agricultural land in the Netherlands[41]

Heavy metals	Treshold value
Cd (Cadmium)	1,25 mg/kg ds
Cr (Chroom)	**75 mg/kg ds**
Cu (Koper)	75 mg/kg ds
Hg (Kwik)	**0,75 mg/kg ds**
Ni (Nikkel)	30 mg/kg ds
Pb (Lood)	**100 mg/kg ds**
Zn (Zink)	300 mg/kg ds
As (Arseen)	**15 mg/kg ds**

[41] http://wetten.overheid.nl/BWBR0019031/geldigheidsdatum_20-02-2015#HoofdstukIII_Paragraaf4

Additionally, on the Irish legislation it is possible to find the following tables that specifies limits and sanitation requirements for the application of sewage sludge on agricultural land:

Table 54: Maximum permissible concentrations of certain heavy metals in soil in Ireland

Metal	Maximum permissible concentration	
	(mg/kg dry solids)	
	pH 5.0– 6.0	pH > 6.0
	And/or	And
	clay content 10 – 15 %	Clay content >15%
Zinc	100	150
Cadmium	1.0	1.5
Nickel	50	80
	For pH >5.0 and clay content >= 15%	
Copper	80	
Lead	80	
Mercury	1	
Chromium	100	

Table 55: Limit values for amounts of heavy metals which may be added annually to agricultural land, based on a ten year average in Ireland

Heavy Metal	Limit Value (kg/He/Yr)
Cadmium	0.05
Copper	7.50
Nickel	3.00
Lead	4.00
Zinc	7.50
Mercury	0.10
Chromium	3.50

Moreover, under the Irish Nitrates Regulations (S.I. 31 of 2014) farmers must not apply more than 170kgs of nitrogen from livestock manure per hectare per year. Compliance with the Nitrates Regulations is one of the Statutory Management Requirements under the Single Payment Scheme. In Ireland, in addition, there are no regulations for the addition of synthetic polymers due to no use of them.

6.2.4.5 Certification systems for quality assurance of sewage sludge

Certification systems for quality assurance of sewage sludge are not widely spread in the ARBOR regions. Neither Flanders nor the Netherlands has a specific certification system. There are only the quality requirements as specified in the Flemish legislation for certain applications, where the sludge that is used in agriculture needs to meet the requirements of VLAREMA and the fertilizer decree concerning the metal concentration and organic micro-pollutants.

Ireland adopted the “Department of Agriculture’s Code of Good Practice for the Use of Biosolids in Agriculture”, which reflects European best practice. It gives guidelines on the use of biosolids on farm land to ensure that the use of biosolids in agriculture will: Be compatible with good agricultural practice, not pose a risk to human, animal or plant health, maintain the integrity of the soil ecosystem, avoid water pollution, avoid air pollution and to minimize public inconvenience

In addition, Irish local authorities maintain a register of all sludge/biosolids movement and use and require advance notification of proposed land banks to be used for biosolids spreading. Any person using biosolids in agriculture is required to do so only in accordance with an approved nutrient management plan and the Department's Code of Good Practice.

The producer is obliged to control over the year the quality of the sludge and has to obtain the certificates, which give the composition and the properties (DM, ODM, pH, N, P, Cd, Pb, Cr, Ni, Zi, Ag, PAHs, PCBs and PCDD/PCDF) of the sludge as well as the information regarding the pre-treatment steps.

6.2.4.6 Incentives for the electricity and heat generation from sewage sludge

Different types of incentives for the electricity and heat generation from sewage sludge such as subsidies can be found in the legislation of the partner countries.

The Flemish policy, for example, stimulates the digestion of sludge through a financial subsidy called "green power certificates". The certificates are however only awarded if the biogas is also converted into electricity. In 2008, about 47% of the produced sewage sludge (MWWTP) was digested. Aquafin n.v. owns 17 digestion units for the MWWTP sludge with a total capacity of nearly 60,000 tds. Of those installations, 15 are equipped with gas engines. Together they produce 4.7 million kWh.

Aquafin n.v. was partner in the project Neptune, in which different innovative techniques for sludge treatment were evaluated. A pilot was constructed to improve the digestion of sludge through the Cambi-system. A thermal pre-treatment improved the production of biogas. In addition, other pilots evaluated the gasification of sludge at high temperature (1200-1400°C), where 70-80% dm sludge was converted into gas with a composition 40% CO and 50% H2 and an energetic content of 3,5 kWh/m³.

Incentives in the Netherlands work through the SDE+ subsidy available for sewage treatment systems which are able to produce electricity or green gas out of sewage sludge. This subsidy aims to help the production of renewable energy which is not always profitable, because the cost price of renewable energy is higher than that of energy derived from fossil fuels. The difference in cost price is called the unprofitable component and differs for co-digestion of manure (>50% of the mix is manure) and mono-digestion of manure (>95% of the mix is manure). SDE+ compensates producers for this unprofitable component for a fixed number of years, depending on the used technology[42]. However, before getting the subsidy, the energy should first be produced.

The Netherlands Enterprise Agency learns that the subsidy can be used for both, the produced electricity and the produced heat of the installation. What will be done with the electricity and

[42] http://www.rvo.nl/sites/default/files/2015/02/Tabel%20basisbedragen%20SDE%2B%202015_0.pdf

the heat is furthermore not interesting for the subsidy. When this will not be used, it is a loss for the producer, officially not for the Netherlands Enterprise Agency.[43]

According to RGD form Luxemburg (01.08.2014), there are incentives for electricity from sewage sludge inserted into national electricity grid. The incentives depend on the first year of injection of electricity into the grid. Starting with 65 €/MWh for the plants which injected for the first time in 2008, the incentives are reduced by 0.1625€ with every year.

At present there are no incentives for the production of electricity and heat generation directly from sewage sludge in Ireland.

6.2.4.7 Incentives for the nutrient recovery from sewage sludge

Among the ARBOR regions, to be compared with German case studies, there are no specific incentives for the nutrient recovery from sewage sludge as in the case of Luxemburg and Ireland.

On the other hand, in Flanders although there are no financial incentives, there is a policy that aims the stimulating of nutrient recovery. Nutrient removal is mandatory for agglomerations larger than 10,000 I.E. (based on the European Council directive 91/271/EEC and the fact that Flanders is identified as vulnerable zone in the Flemish VLAREM II regulation). Also, Aquafin participated in 2013 in a project concerning the recovery of struvite from sewage sludge.

In the Netherlands there are initiatives, supported by the government for making technologies for this purpose. One of them is the Nutrient Platform that works as a cross-sectoral network of Dutch organizations that believe in a pragmatic approach towards nutrient scarcity.[44]

[43] http://english.rvo.nl/subsidies-programmes/stimulation-sustainable-energy-production-sde
[44] http://www.nutrientplatform.org/business-cases/afvalstroom/afvalwater.html

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