Sustainable
Short Rotation Coppice

A Handbook

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Preface

Biomass plays a key role among renewable energy sources (RES), accounting for almost 70% of European renewables, and showing steady growth. In the future demand for wood as fuel for heating, power and as construction material or for biomaterials is expected to increase rapidly. This will be mainly driven by market forces and supported by the targets of the national and European energy policy. Solid biomass from Short Rotation Woody Crops (SRC) can contribute significantly to reaching Europe's 2020 targets.

The countries in Europe that have currently the largest areas of SRC for energy are Sweden, UK and Poland. In other European countries the production of SRCs is limited and takes place at very small scale, but there are plans and the political will to increase SRC in the near future. Therefore, there is a need to implement actions triggering and accompanying the implementation of local supply chains of SRC in other European countries. This is the aim of the SRCplus project (Short Rotation Woody Crops Plantations for Local Supply Chains and Heat Use.

The project SRCplus promotes the sustainable production of SRC in seven different target countries in Europe. The target regions of the SRCplus project are:

- Achental region (Germany)
- Eastern Croatia region (Croatia)
- Vidzeme region (Latvia)
- Rhone-Alps region (France)
- Zlin region (Czech Republic)
- Kentriki Makedonia region (Greece)
- Prespa region (Macedonia)

The overall goal of the SRCplus project is to support and speed-up the development of local supply chains of SRC by implementing various capacity building measures and regional mobilization actions for the key actors in local supply chains.

SRCplus has started in March 2014 and lasts for 3 years. The project is supported by the Intelligent Energy for Europe Program of the European Union (Contract No IEE/13/574). The SRCplus consortium includes 10 partners. The action is coordinated by WIP Renewable Energies, Germany.

The present publication "Sustainable Short Rotation Coppice – A Handbook" provides information on SRC for the target groups of the project: farmers, public land owners, small utilities of heat and CHP, woodchip traders, and any interested persons. The handbook presents the different agricultural practices in Europe, whereas the different framework conditions, such as climate, are considered. The added value of the handbook is the focus on sustainable supply chains and SRC benefits that are often not known to the key actors. The handbook was written in English and is translated into the national languages of the target countries.

1 Introduction

Short rotation woody crops (SRC or SRWC) are woody fast-growing tree species that are cultivated with the aim to produce high biomass yields in a short period that can be used for energy purposes. Similar terms can be found in the literature such as short rotation plantations (SRP), short rotation forestry (SRF), or short rotation coppice (SRC). These terms are sometimes used synonymously, but their definitions are slightly different.

SRWC that are harvested after a short period have to be either re-planted after harvest (sometimes practiconed for e.g. eucalyptus or robinia) or grown as coppice (usually practicionned for e.g. poplar and willow).

Box 1: What is coppice?

"**Coppice**" (Figure 1) is characterised by the ability of the selected tree species to re-grow with new sprouts after the plant is cut down. This handbook mainly focuses on the cultivation of trees in coppice cultivation. However, reference is also made to those species that have to be re-planted after harvest. Therefore, the abbreviation SRC is used throughout the handbook for both, short rotation woody crops and short rotation coppice.

Figure 1: „Traditional coppice" as it was a frequent management practice in the past for e.g. willows (in the front) and „modern coppice" of a short rotation poplar plantation (in the background of the image). (Source: Rutz D.)

Perennial SRCs are woody species such as alder, ash, southern beech, birch, eucalyptus, poplar, willow, paulownia, paper mulberry, robinia, Australian blackwood, sycamore, and others. In Europe, the main species used are poplar and willow. Thus, this handbook mainly focuses on these species.

SRC is an excellent alternative to annual energy crops and can be complementary to the existing agricultural system. In general, SRC cultivation is by definition a low-input agricultural practice that generally implies low GHG emissions due to limited applications of chemicals, but also because the crops are cultivated for a number of years which leads to limited management inputs. The use of pesticides is negligible and in most cases non-existent. This is not due to the absence of diseases or insects, but mostly because of the relative low economic value compared to conventional agricultural crops since the produced biomass is used for energy. The need for fertilizers is small compared to conventional agricultural crops: fertilization of trees is not common practice, and the crops are perennial and grown for several years before harvest, using the nutrients recycled in the soil-plant system from descent leaves and root die-off. Even in the cases when N fertilization is recommended, as for willow SRC, the amounts recommended are significantly lower in comparison to other common agricultural crops.

Besides being harvested for energy production, the cultivation of SRCs has many benefits compared to annual crops. They help to improve water quality, enhance biodiversity, provide ecosystem services (hunting, beekeeping, water supply, fire protection), mitigate animal diseases between farms, prevent erosion, reduce artificial input materials (fertilizers, pesticides) and mitigate climate change due to carbon storage. These advantages have to be promoted to produce sustainable woodchips from SRC, enhancing the positive impacts of SRC to the environment. Thereby, sustainability aspects must be considered: SRC has most positive impacts on marginal soils and especially as structural elements in the landscape, bordering for instance fields, roads, and power lines. The sustainability of the supply chains is specifically addressed in the SRCplus project (Dimitriou et al. 2014a, Dimitriou & Rutz 2014, Dimitriou & Fistrek 2014).

2 Site selection

The selection of a site for the establishment of SRC is a very important step for successful implementation. This chapter is divided in different factors-to-consider for appropriate site selection, i.e. factors related to site requirements, climate, plantation layout and other aspects for sustainable site selection.

2.1 Site requirements

A number of requirements need to be fulfilled for a site to be considered as appropriate for SRC establishment. The location of the field is an important factor, but also the existing soil and water conditions which are directly related to the yield, and therefore, to the revenues from the SRC plantation. The soil and water related factors can be species-specific. Therefore, the selection of the species (which is analysed in this Handbook in chapter 3) plays an important role for the case-specific site requirements. In this part of the Handbook, reference is made to the general things-to-consider when introducing different species, with special focus on willow and poplar SRC which are so far the most commonly used species in bioenergy production systems grown on agricultural land.

Soil: SRC species are usually not very demanding in terms of site requirements on agricultural soils. However, yields are better on good soils. They will grow on a wide range of agricultural soil types and productivity will be determined by site fertility, temperature, and availability of water and light, exactly as for all other agricultural crops. Soils with pH 5-7.5 will produce satisfactory growth, although research suggests that there is plant material (e.g. for willow and poplar) that is tolerant to pH outside this range (Caslin et al., 2010). In drier areas, light sandy soils will probably have a problem with water availability and therefore may be avoided. The same is valid for shallow soils which will provide low yields. Moreover, it has to be considered that initial weed control is important, which may be difficult on certain soils, such as organic or peat soils. Medium to heavy clay loams with good aeration and moisture retention are ideal for SRC cultivation, especially if they allow a minimum cultivation depth of 200-250 mm to enable mechanical planting. The cultivation on flood lands or sensitive wetland areas (Figure 2, Figure 3) needs to be carefully assessed since the cultivation (planting and harvesting) with heavy machinery can be challenging. A negative impact on wet soils may be soil compaction. On this land, the application of heavy machinery should be either made in very dry periods or when the soil is frozen.

Figure 2: Willow SRC planted on a peat extraction field in Belarus. Despite it is not recommended to plant SRC in high organic soils due to lower biomass production, willow SRC can be grown in such soils satisfactory and can also be used for soil restoration. (Source: Dimitriou I.)

Figure 3: A willow SRC plantation grown on a field with high groundwater level in Sweden. Despite the high water level, which should be avoided, willow SRC can still grow satisfactory since it tolerates anoxic conditions. (Source: Dimitriou I.)

Water availability: SRC's water demand is usually higher than that for other conventional agricultural crops cultivated in the same area. Therefore, areas with higher rainfall or areas with access to groundwater or other water availability (e.g. water bodies, wastewater) (Figure 4) should be preferred, if possible. Some SRC species such as willow are well-known to tolerate anoxic conditions due to water-in-excess, but the implied difficulties for harvest need to be taken into consideration when choosing a site.

The water demand of SRC varies depending on the species used. Moreover, great variations in terms of different water use efficiencies between different cultivars/varieties/clones of the same species have been reported. Therefore, nurseries or plant material traders should advise the farmer about the suitability of the plant material under the specific site conditions. Especially during the initial planting of the cuttings, when the roots are not yet developed, enough soil moisture is crucial to ensure the success of the plantation. So, the timing of initial planting must be well-planned, as serious losses occurred in plantations that were planted during very dry periods.

Increased impact on groundwater has been expressed when SRC is planted in dry areas. Especially in countries where water availability is limited and where species are used that are adapted to warmer climates, such as eucalyptus, the impact on groundwater has to be considered. Such concerns should be given high priority, especially if a substantial percent of a catchment area is to be given to SRC production. However, such serious impacts have not yet been proved in Europe, as so far only smaller parts of catchment areas have been cultivated with SRC (Dimitriou *et al*., 2012a). With the wide range of differing land uses, which are common in European agriculture, the water impact of SRC has been projected to be small. On the other hand, SRC provides benefits when used as buffer zones, when planted in areas of high-input agriculture. There, SRCs are an effective mechanism for excessive nutrient retention. Decreased nutrient losses and increased evapotranspiration reduce the leakage of hazardous amounts of nutrients in adjacent water bodies or groundwater.

SRC roots can grow deeper than annual crops in order to ensure access to available water. Deeper rooting of SRC has caused concerns about potential damage on drainage pipes. In fields where drainage is established, deep rooting is not expected as enough water is available near the surface. Here, roots usually remain in the upper 40-50 cm of the soil. If the existing drainage system is new, the grower may choose a different location for SRC to minimise potential risks. The age of the drainage system should be taken into consideration, especially in comparison to the expected lifespan of the SRC plantation. Fields with an already damaged or old drainage system can be considered for SRC cultivation, as the drainage would not have to be replaced.

Figure 4: Poplar SRC which is fertirrigated with municipal wastewater in south Spain. Despite the dry conditions, SRC can grow satisfactory even without irrigation, but will achieve better growth when irrigated with wastewater. (Source: Dimitriou I.)

Figure 5: A willow SRC field planted parallel to a rural road with easy access for machines and with broad edges that allow easier management. (e.g. harvesting) (Source: Nordh N-E.)

Access: SRC plantations should have good access to agricultural/rural roads (Figure 5) for the equipment required for SRC management. In general, areas with slopes steeper than 10% are not suitable for larger plantations with automised planting and harvesting practices, especially if wet conditions occur. For smaller plantations, where motor-manual planting and harvesting practices are implemented, the plantation can be established on steeper slopes. Excessive vehicle access to SRC sites will occur in winter when the crop is harvested. Due to the heavy loads of the harvested wood, sites should be as close as possible to paved roads (or alternatively with relatively easy access to hard roads).

Size: The size of the plantation has a considerable impact on the management of the plantation as well as on logistics and its related costs. Depending on the country and the purpose of the plantation, in order to be econiomicaly viable, plantation sizes should be minimum 2 to 5 ha. However, SRC plantations can be grown also on smaller areas (Figure 6), if there are e.g. several other plantations in the vicinity which allow using synergies (e.g. coordinated harvest at the same time to reduce related costs). Smaller plantations are also suitable if the farmer wants to have the plantation just for meeting the own energy needs and if he does most of the work manually.

Figure 6: A small-sized willow SRC field placed in the middle of an agricultural landscape; despite not being very big (about 2 hectares), the plantation is situated close to other SRC fields and therefore management with other SRCs is combined. (Source: Nordh N-E.)

The choice of the shape of the SRC fields can play an important role on the easiness and the time needed for the management of an SRC site, and will consequently have an impact on the economy of the plantation. Longer and rectangular fields are easier to manage when planting and harvesting (especially when direct chipping is applied), but also when fencing against mammals (e.g. rabbits, roe deer etc) is required. However, in practice, annual crops are often planted on these well-shaped fields. Therefore, smaller and irregular shaped fields are frequently selected for SRC, as its input and maintainance are much lower than for the cultivation of annual crops (JTI, 2014).

Location in the landscape: The management of SRC has more similarities with the cultivation of annual crops than with forestry. However, several visual features of SRC, such as the height of the trees (e.g. up to 8 m tall after three-four years, depending on the tree species selected and framework conditions), as well as being a row crop, add new characteristics in an agricultural landscape. SRC creates a three-dimensional new and visible feature in the landscape, in contrast to annual crops which keep landscapes generally rather open. Therefore, SRC can have a negative impact on the open landscape, but if well-designed could bring important landscape improvements.

Independent of the legislative framework conditions, which may require asking the owners of the neigbouring land for permission to grow SRC, it should be good practice to always get in dialogue with neighbours in order to avoid conflicts and to raise awareness and interest.

Furthermore, it must be considered that SRC should not be planted on or close to sites of historical importance, in case that the height of the plants would have negative impacts. Moreover, special caution needs to be paid on nature and landscape conservation and protection areas. The site-specific legislation on these areas must be respected. SRC fields underneath power lines should involve the utility managing the power line. Even the lowest SRC plantations (e.g. coppice) can reach up to 8 m before harvest and should not touch power lines.

If SRC is grown to provide biomass for a large-scale power station (Figure 9) and therefore concentrated in a small-radius area around the power station, the change in character of the landscape could be considerable if many plantations are needed. Here, the species and the density of planting have also an impact on the landscape picture.

However, in case of smaller-scale production, such effects are not expected. This can be assessed by a small calculation: if for instance 2 MW continuous power generation should be achieved, approximately 15-20 thousand tonnes dry wood biomass will be needed. This can come from 1,500-2,000 ha of SRC (if the biomass is 10 t DM/ha/yr). This amount of land corresponds to about 1.5% of the total surface of an area with the radius of 20 km (which is the economically justified radius from a hypothetical end-user of SRC biomass). Therefore, the expected impact on landscape in such a case cannot be considered substantial.

SRC can be smoothly integrated into existing landscapes with minimal disturbance if hedgerows and forest areas already exist, since in those cases sight lines are short. If sight lines are long or if SRC is established in a flat topography, potential plantations should provide interlocking blocks with organic rather than geometric shapes in order to better harmonise with the existing landscape. In these landscapes, SRC plantations should be rather large and link up with existing woodland (Figure 7) to give visual, but also environmental benefits. However, the deciduous nature of the crop diversity, which is created due to the varietal mixtures (e.g. with different clones providing different shapes and colours) and harvesting patterns, gives a dynamic feature in the agricultural landscape (JTI 2014).

Figure 7: A rectangular and rather small-sized willow SRC field established in an agricultural area, but close to the existing forest allowing a smooth change of the landscape. (Source: Nordh N-E.)

The following list shows a number of factors that an SRC project developer needs to consider, in order to avoid disturbances in the landscape due to SRC planting, but also taking into consideration potential environmental impacts. Thereby, it has to be considered that these are very general statements and that the site-specific situation always needs to be addressed in detail (Dimitriou et al, 2014a).

- Planting SRC in agricultural fields close to forest stands gives a feeling of a natural continuation in the landscape and should be preferred. However, planting in only forest areas should be avoided since the landscape would become very forest-homogenous.
- Harvesting different parts of the plantation after different growth cycles creates a more diverse landscape, which gives also a dynamic character to the landscape.
- Planting of SRC near important cultural sites may have negative visual impacts.
- Planting different clones with different habitus (vigorousness, leaf size and shape, colours) increases the visual diversity. Broad openings between fields provide opportunities for the recreation in the area (e.g. walking).
- SRC is very suitable to be grown alongside roads with heavy traffic, as this land is often not used. However, it must be considered, that, depending on the given road, safety is not reduced. In order to allow drivers to have a good view e.g. at bends and crossings, SRC fields edges in these cases need to be broader (Figure 8, Figure 10, Figure 11).
- On roads were traffic is not heavy, e.g. in rural areas, the impact of SRC plantations on driving is rather small, however, a field edge is still needed to allow easier management (e.g. turning of the harvesting machines).

- Large power plants that use SRCs are often in very industrial landscapes where the SRC establishment could be a measure to improve the general greenness of such an area.
- In open landscapes and areas where annual agricultural crops are grown, SRC can offer a variation in the landscape.
- SRC should be in general planted in areas with the less perceived landscape impact (e.g. close to forest, in hilly areas, away from culturally important sites) and in a way that will fit to the surroundings (e.g. smaller patches in forest areas, bigger fields in open agricultural areas, adjusted to the hill variation in hilly areas).

Table 1: Overview of factors determining the site selection for SRC plantations for energy

Local natural and geographic conditions	Infrastructural and technical aspects
• microclimate • soil • susceptibility to natural hazards • susceptibility to pest/disease attacks and damage by game • biodiversity issues	• distance to biomass customers • accessibility of the SRC plantation by roads for planting and management • power lines crossing the plantation • availability of appropriate planting and harvesting machinery

Figure 8: SRC fields close to a bigger road. Wider edges should allow drivers with open views. (Source: Nordh N-E.)

Figure 9: Harvest of a large willow SRC located close to a combined heat and power station (chimney in the upper left of the picture) that receive willow chips. The transportation costs are reduced when biomass for energy is produced close to the end user. (Source: Dimitriou I.)

Figure 10: SRC poplar plantation besides a road in Germany: the road visibility is not negatively affected. (Source: Rutz D.)

Figure 11: SRC willow plantation besides a road in Sweden: the road visibility is not negatively affected. (Source: Rutz D.)

2.2 Climate

Since there is a number of different species that can be used as SRC for biomass production, a vast range of climatic conditions can be appropriate for the establishment of SRC in Europe.

The most frequently species currently used in Europe, willow and poplar, originate from the northern temperate zone. They can tolerate a range of climatic conditions and are cold-tolerant. Grown on areas with low soil moisture would probably result in non-satisfactory yields and species or clones/cultivars with high water use efficiency should be preferred.

In southern Europe, plants that are sensitive to low temperatures can be used, but often the drought tolerance is an important characteristic for the selection of species and varieties. Special attention must be paid especially to the water availability during the year of plantation, as cuttings do not have yet established roots.

Moreover, the plant material that will be used in a SRC plantation should have been tested under the local conditions and empirically introduced with success in the market. There have been a number of examples with clones/varieties as a result of breeding programmes that have been proved very suitable in certain latitudes, but not in others while implemented in different latitudes, causing low yields or plantation losses. Therefore, it is advisable to use plant material that is provided by local nurseries and that has been tested locally in practice.

2.3 Plantation layout

Several issues must be considered for the layout of SRC plantations in a certain location, besides maximising the yield. They are related to the practical issues of managing a plantation, but also to increase positive impacts of SRC to the environment.

Flat fields or fields with a slope of no more than 10% are ideal from the operation point of view. However, SRC plantations are often established on steeper slopes as they can reduce soil erosion. The SRC plantations need to be designed in such a way that will allow appropriate access of all machinery involved in establishing and harvesting.

It is important to plan headers that are large enough to allow turning of machinery during harvest (harvester and/or accompanying tractors for chip collection if applicable). Such headers, which belong to the plantation, but which are not planted with SRC, allow increasing the biodiversity on the edges of the plantation: they can be cultivated with indigenous herbaceous plants. If specially designed automatic harvesting equipment for willow or poplar coppice is used, headers should be at least 6-7 m long. This area should be also large enough for transferring and storing the harvested chips (Figure 12) or wood logs for longer periods.

Figure 12: An SRC harvester using the braod edges of the field to temprorarily store the harvested chips. The humidity of the chips will be decreased before transported to the end user. (Source: Dimitriou I.)

The field layout should maximise row lengths in order to minimise the number of necessary turns of the machinery. Ideally, row lengths would allow filling of one or two trailers with woodchips before the harvester needs to turn (JTI 2014).

The establishment of new SRC plantations should not avoid or block existing public access. This is especially valid for areas with high recreational activities, e.g. in areas close to cities. Planning the public access carefully and consulting with relevant groups and stakeholders can avoid conflicts. Wide corridors between different blocks of SRC plantations will increase the public access and recreation value of the SRC plantations. Such corridors and wide edges, as well as long rows, also offer increased advantages with regard to phytodiversity and zoodiversity.

The plantation design should fit into the surrounding landscape as much as possible (as indicated above), and therefore it would be ideal if SRC is planted adjacent or close to e.g. existing forest stands (e.g. hedgerows and/or small woodlands). The edges are important as landscape features. The SRC edges should look as natural as possible, graded and varied in scale with the landscape, and hedges could be planted and managed annually. As an alternative for the edges, annual crops could be planted.

For the core part of the SRC plantation, different plantation layouts can be chosen depending on the used species and on the harvesting cycle (Table 2, Figure 13). Typical coppice plantations with willow and poplar use very high densities, where 5,000 to 20,000 cuttings per hectare are planted. In such plantations, and in order to allow easier operations by mechanical management for planting, fertilization and harvesting, planting in single or double rows is recommended.

Table 2: **Plantation design for willow and poplar in Germany (According to Wald 21)**

	Short rotation (3-5 years)	Medium rotation (6-8 years)	Long rotation (> 10 years)
Willow	• 13,000 cuttings / ha • Double rows: 2 m * 0.75 m • Density: 55 cm in the row	• Not applicable	• Not applicable
Poplar	• 8,300-11,000 cuttings / ha • Single-row: 2 m • Density: ~ 45-60 cm in the row	• 5,000 cuttings / ha • Single row: 2 m • Density: ~ 1m in the row	• 2,500-3,333 cuttings / ha • Single row: 2m • Density: ~ 1.5 – 2 in the row

For poplar plantations often single rows are planted. The distance between the rows should be 2 m and the distance of the cuttings in the rows should be 0.45 m to 2 m, depending on the rotation cycle. Double-row systems have been implemented also with poplar.

The use of double rows may enable faster and therefore cheaper management, especially for willow plantations with many thin shoots and very short rotation cycles. A typical design of these double rows is 1.50 between and 0.75 m within the double rows, and a distance of the cuttings in the rows of 0.5 m to 0.8 m (depending on the location, the clones or species used). Changing the spacing can affect the harvested end product, especially the longitude and diameter of the stems. Early consultation with the potential end users during the planning stage is necessary to fulfil their needs when harvesting.

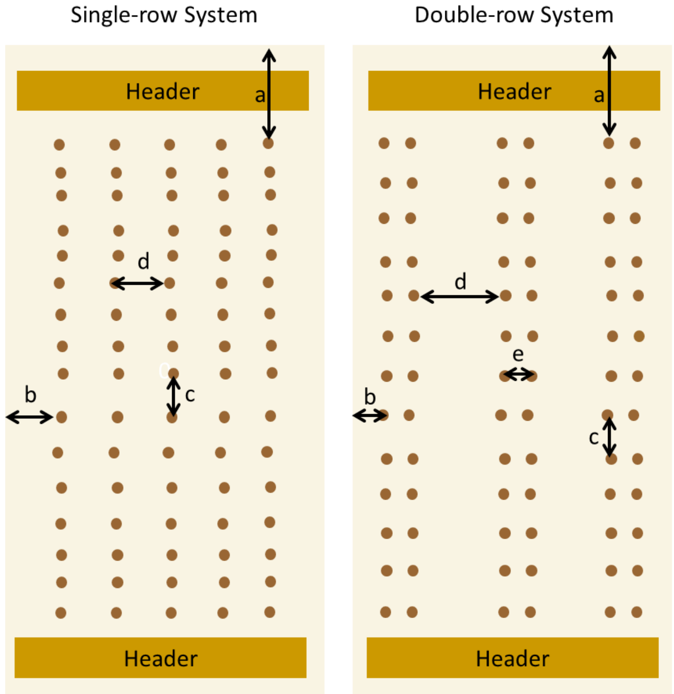

Figure 13: Examples of simplified plantation layouts with single- and double rows (not true to scale) (a = space of the header (8 m); b = space of the boarder to the edge of the field (2 m); c = space between the cuttings in the row (0.45-2 m); d = space between the rows (2 m); e = space within the double rows (0.75 m) (Source: Rutz D.)

Figure 14: Willow SRC fields of different ages and planted with different clones diversifies the landscape. Also different heights and colours contribute to the diversification; neighbours have easy access between the fields with the wide edges. (Source: Nordh N-E.)

2.4 Legislation

An important aspect for site selection is associated to legal aspects. Thereby, often legislation at different levels, such as national, regional and local levels applies. Usually a new SRC plantation replaces former land use which may be crop land, grassland, forest, abandoned land, etc.

In many countries it is not recommended and the legislation forbids installing new SRC plantations on forest land. Only in few countries SRC is classified as forest land. In some countries or regions, such as in Bavaria (Germany), establishing SRCs on grassland is forbidden. SRC is considered equal as annual crops on cropland if it is harvested within a certain time period (e.g. 20 years in Germany).

Besides such general rules for the establishment of SRCs, which differ in European countries, the protection status of the land has to be also considered. Thereby, SRC is not always immediately forbidden if any protectional status applies. It depends on the type of protection: it may be a difference if a landscape protection site, nature conservation site, or Natura 2000 site. Also legal issues to water management have to be taken into account: water catchment area, flood-prone areas of rivers or ground water sensitive areas.

Legislation may also have an impact on the selection of approved varieties and clones as sometimes this is prescribed. For the design of the plantation, the distance to neighbours is sometimes regulated and requests e.g. a 2 m empty space to the neighbouring land.

2.5 Sustainability aspects for site selection

With increasing demand on biomass for energy and for biobased materials, sustainability aspects are becoming more important in the discussion about bioenergy. The establishment and use of SRC can be a measure to increase the overall sustainability, but only if several aspects are considered. A detailed description on these aspects is available in the SRCplus report on “Sustainability criteria and recommendations for short rotation woody crops” (Dimitriou & Rutz 2014). The following description only provides an overview on the content of that report.

In general, SRC cultivation is by definition a low-input agricultural practice that implies low GHG emissions due to limited applications of chemicals, but also because the crops are cultivated for a number of years which leads to limited management inputs. The use of pesticides is negligible and in most cases non-existent. This is not due to the absence of diseases or insects, but mostly because of the relative low economic value compared to conventional agricultural crops since the produced biomass is used for energy. The use of fertilizers is limited compared to conventional agricultural crops: fertilization of trees is not common practice, and the crops are perennial and grown for several years before harvest, using the nutrients recycled in the soil-plant system from descent leaves and root die-off. Even in the cases when N fertilization is considered, as for willow SRC, the amounts recommended (about 80 kg N per hectare and year) are significantly lower in comparison to other common agricultural crops.

Moreover, due to technical constraints and physiological reasons (e.g. the height of the trees), fertilization equipment does not allow for fertilization each year, when the density of the plantations is high, as in the case of willow and poplar SRC. Tillage is also carried out once in the establishment period, and no other soil management occurs until the termination of the plantations, which is usually several decades.

If managed in a sustainable way, SRC can generate significant synergies with other agricultural practices, with ecosystem services and nature conservation measures. SRC usually helps to improve water quality, enhances biodiversity, provides ecosystem services (hunting, beekeeping, water supply, fire protection), mitigates animal diseases between farms, prevents erosion, reduces artificial input materials (fertilizers, pesticides) and mitigates climate change due to carbon storage. These advantages have to be promoted to produce sustainable woodchips from SRC, enhancing the positive impacts of SRC to the environment. Thereby, sustainability aspects must be considered: SRC has most positive impacts on marginal soils and especially as structural elements in the landscape, bordering for instance fields, roads, and electricity lines.

Due to its importance on the impact of SRC on the environment, the following description highlights the impacts of land use changes. They are classified into direct (dLUC) and indirect (iLUC). They are among the most critical impacts in any crop-based bioenergy value chain, as in the future land use competition becomes an increasing limitation for any commodity.

In order to develop recommendations on sustainable SRC cultivation, the former land use has a crucial role on the positive or negative impacts. A distinction is made whether the future SRC is planned to be grown on:

- **current agricultural land**: different types of agricultural land (ploughed land), depending on the soil quality and water availability
- **current grassland**: a distinction between intensively and extensively managed grassland needs to be done
- **current forest**: in many countries SRC should not be grown on land that is classified as forests (both from the legal viewpoint, but also due to environmental issues).
- **marginal land**: Different definitions of “marginal land” are available. Some land that is economically classified as “marginal” has high ecological values. SRC may be well suited on steep slopes (to prevent erosion), on flood-prone areas, under power lines, etc.

* **protected land**: the cultivation of SRC on protected land depends on the protection status and goals.

To achieve a resource effective biomass production with SRC, the high fertility agricultural land is most appropriate, since it produces in such areas the highest biomass yields per unit area (and profit for the farmer) with proper management. As mentioned above, and further analyzed below, an introduction of SRC in such areas seems to offer positive impacts in terms of water and soil quality, and biodiversity, compared to conventional agricultural crops that are usually cultivated in fertile soils.

However, with the current wood and energy prices, SRC is less competitive in many regions compared to cropping systems on arable land, and thus farmers are often interested to establish SRC mainly on abandoned agricultural land or grassland. A change of land use from grass to SRC can be discussed controversially because of the efforts in European agriculture to preserve and avoid reductions of carbon-sequestering ecosystems or ecosystems with high biodiversity value such as grassland. Being a perennial crop with minimal pesticide inputs, SRC is more akin to grassland than to other arable crops in terms of management, and the consequent impacts on soil and water quality are not expected to differ much. Relevant comparisons need to be analyzed, since land use transformation must be performed in a careful way to ensure compliance with the environment protection.

In general, the impacts of SRC cultivated on forest land are rather negative. Thus, many countries have elaborated legislations that prevent the cultivation of SRC on forest land.

All three land-use types (agricultural land, grassland, forests) can be managed in different ways. Depending on these management practices, as well as on soil and climatic condition, "marginal land" can be applied to all three land use types. Thereby, different definitions of marginal land exist, depending on the focus of economic issues, fertility, risks, etc.

Marginal land could be e.g. moderate or highly contaminated soils, flood-prone areas, land under power lines, parallel to rail trails, and land on landslip prone areas. These land types create opportunities; mostly because SRC can tolerate and grow satisfactory under unfavourable conditions (e.g. heavy metal contaminated soils, anaerobic conditions, less fertile sites, flooded areas). On these areas often not many other crops than SRC can be grown and offer an income. Although the expected biomass production and therefore the land-use efficiency will be rather low, there can be sites of interest to grow SRC since competition to other crops is avoided and several environmental advantages are offered, if SRC management is optimized. However, for certain areas, e.g. high biodiversity marginal land, there is an environmental risk to generate negative impacts through SRC cultivation.

Finally, all three land-use types (agricultural land, grassland, forests) can also have a protection status, according to different local, national and EU protection classification. In case that this status is related to certain ecosystems, habitats and protected species, the cultivation of SRC is rather negative. For protection areas that are related to landscape protection, the cultivation of SRC may have positive or negative impacts. In general, the site-specific protection goals have to be identified and the impact of SRC cultivation on the fulfilment of these goals assessed.

An overview on the different impacts of SRC implementation on the three land-use types is presented in Table 3.

Table 3: Impacts of SRC implementation on agricultural land, grassland and forests (Adapted from BUND 2010; Dimitriou & Rutz 2014)

Criterion	SRC compared to Agricultural land	SRC compared to Grassland	SRC compared to Forest
Use of pesticides	During set-up and removal phases similar to conventional agricultural land use; During the short rotation phase not needed.	During set-up and removal phases similar to conventional grassland; During the short rotation phase not needed.	Higher
Use of fertilizers	Considerably lower than in conventional agriculture	Considerably lower than at intensive managed grassland	Higher
Soil erosion	Considerably lower	During set-up and removal phases higher than grassland; During the short rotation phase similar to grassland.	Slightly higher
Biodiversity	Usually much higher than in intensively used agricultural land; On extensively used agricultural land it can be higher or lower.	Depends on the intensity of the used grassland as well as on species composition.	Depends on the forest type and the design of the SRC; Compared to natural forests, biodiversity in SRC is rather lower.
Climate and water	Higher evaporation, higher interception, higher wind protection and temperature balancing, reduction of dust and pollutants	Higher evaporation, higher wind protection and temperature balancing	Rather negative impacts
Carbon sequestration	Considerably higher	Higher or equal; depends on management practices.	CO_2 storage considerably lower, but annual sequestration higher

An important factor that influences the sustainability of the used land is the energetic output of SRC per ha in comparison to other crops, and thus, the potential to contribute to mitigate climate change. Although very site-specific, average figures are presented in Table 4. Furthermore, figures on the energy balance are shown in Table 5.

Table 4: Annual energetic output of SRC, energy crops and forest in kWh/ha

SRC	Corn (biogas)	Rapeseed (biodiesel)	Forest
16,000 – 60,000	37,000 – 55,000	11,000 – 21,000	10,000 – 27,000

Table 5: Energy balance as input/output ratio of selected crops ()

SRC (willow)	SRC (poplar)	Corn (whole plant)	Rapeseed (whole plant)	Wheat (including straw)
1:24*	**1:16 to 1:26****	**1:11***	1:9*	1:11*

Sources: *Börjesson & Tufvesson 2011; **Burger 2011

As described earlier, the land use change is only one aspect which has to be considered for the evaluation of sustainability. Impacts on phytodiversity, zoodiversity, soil, water and landscape change are described in more detail in the report "Sustainability criteria and recommendations for short rotation woody crops" (Dimitriou & Rutz 2014).

3 Tree species and clones

Several fast-growing tree species are used as biomass feedstock for energy purposes in Europe. In this Handbook emphasis is given on willow and poplar SRC, due to the fact that these are the species that have been of most interest in Europe and for which most research results have been reported. However, research results and information concerning other species that are cultivated as SRC, such as robinia and eucalyptus, but also alder, ash, and birch, are included, too. Despite this, the provided information is presented by considering a large range of European areas.

3.1 Willow

Willows, sallows, and osiers form the genus *Salix* (Figure 15, Figure 16). This genus includes around 400 species of deciduous trees and shrubs and is found naturally primarily on moist soils in cold and temperate regions of the northern hemisphere. Willow is the species most commonly used in SRC plantations for energy in Europe. Willow species have been widely used in SRC plantations due to a range of suitable characteristics such as fast growth and high yields, ability to grow well under a variety of soils (e.g. ideally for pH 5-7.5, but also outside this range) and environments (from heavy clays to lighter soils), good ability to coppice (thus without needing replanting after harvest), roots that can stand highly anoxic conditions (thus can be planted in waterlogged conditions), ability to tolerate elevated nutrient and heavy metal concentrations (thus can be planted in harsh environments e.g. for phytoremediation). Willows have also another advantage that made them the most common species in SRC plantations for energy: their wide genetic variation with many different species offer different physiological characteristics that can be used in the field. Furthermore, willow is a species which can be easily bred. Thus, several crossings of different willow clones can be produced, which provide improved plant material with combinations of the different clones crossed.

Figure 15: Leaves of willow (*Salix vimininalis*) which is commonly used for SRC in nothern parts of Europe (Source: Aronsson P.)

Figure 16: Willow flower in early spring (Source: Rutz D.)

Willow genetic improvement programmes in Sweden and the UK have made significant progress in breeding willow for short rotation coppice used for bioenergy. To expand production, cultivars suited to a wider range of European environments and future climates are needed and have been developed during the last years. The primary aims of the above-mentioned breeding programmes were to produce high yielding disease and pest-resistant varieties with a growth habit that facilitates mechanical harvesting. The majority of the cross breeds made by the Swedish breeding programme at Svalöf-Weibull AB (SW) have involved *S. viminalis*, *S. dasyclados* and *S. schwerinii*. The original parental material was based on Swedish and central European collections, later supplemented by collecting expeditions to central Russia and Siberia. The UK breeding programme based at IACR-Long Ashton (funded by the European Willow Breeding Partnership - EWBP) utilised over twenty different species held at the UK National Willows Collection. These included exotic equivalents of *S. viminalis* and *S. caprea* such as S*. rehderiana*, *S. udensis*, *S. schwerinii*, *S. discolor* and *S. aegyptica.*

As a result of this work, all new willow SRC plantations now involve newly bred varieties/clones, which are more productive and have greater resistance against pests and diseases, which provides more stable yield levels. The choice of varieties/clones depends on the specific need of the grower and the climatic conditions of the site. It also depends on the availability of cuttings from the producers. Cutting producers need at least one year in order to be able to provide sufficient cuttings of each variety. Once they know which varieties/clones are required they can cut back their plantations to produce one-year old shoots for cutting production the following winter. There are presently about 25 certified EU varieties available, of which about ten are in mainstream commercial use today. Approximately one or two new varieties are developed annually. A list of commonly used clones, produced within the two above-mentioned breeding programmes, is given below in

Table 6. For more information about special characteristics and suitability of willow clones, willow cutting providers should be contacted.

Table 6: A list of commonly used willow clones produced by the European Willow Breeding Partnership (EWBP) in UK and by the Swedish breeding programme at Svalöf-Weibull AB (SW) (modified from Caslin *et al*., 2012)

Clone	Species	Sex	Special characteristic	Breeding programme
Beagle	*S. viminalis*	Female	Higher than average dry matter content at harvest	EWBP
Endeavour	*S. schwerinii x S. viminalis*	Female	Not tolerant to saline conditions	EWBP
Gudrun	*S. dasyclados*	Female	Susceptible to leaf rust, slow growth during first year	SW
Inger	*S. triandra x S. viminalis*	Female	Good performance in dry soils, high dry matter content, low calorific value	SW
Jorr	*S. viminalis*	Male	Relatively susceptible to frost	SW
Olof	*S. viminalis* x (*S. viminalis* x *S. schwerinii*)	Male	Susceptible to rust, higher water content in chips	SW
Resolution	(*S. viminalis x* (*S. viminalis* x *S. schwerinii*)) x (*S. viminalis* x *S. schwerinii*))	Female	High yields in first rotation, good growth in dry areas, chips with low bulk density and calorific value	EWBP
Sven	*S. viminalis* x (*S. schwerinii x S. viminalis*)	Male	High yields in first rotation, low leaf rust, chips with low bulk density but high calorific value	SW
Terra Nova	(*S. triandra x S. viminalis) x S. miyabeana*	Female	Relative low yields, but good performance in harsh enviroments (altitudes, dry soils)	EWBP
Tora	*S. schwerinii x S. viminalis*	Female	High yields, low leaf rust, high yield in second rotation, suitable for almost all environments	SW
Tordis	(*S. schwerinii x S. viminalis*) x *S. viminalis*	Female	High yields, suitable in dry soils, low leaf rust, low bulk density, high calorific value, low dry matter	SW
Torhild	(*S. schwerinii x S. viminalis*) x *S. viminalis*	Female	Relative low yields, low dry matter	SW

3.2 Poplar

Poplar (Figure 17, Figure 18) belongs to the genus *Populus* of the *Salicaceae* family, and it is, together with willow, the most common species in SRC plantations for bioenergy in Europe. The natural distribution of poplar extends from the tropics to the latitudinal and altitudinal limits of tree growth in the Northern hemisphere. Species of the genus *Populus* are deciduous or (rarely) semi-evergreen and divided into six sections: Abaso (Mexican poplar), Aigeiros (Cottonwoods and black poplar), Leucoides (swamp poplars), Populus (white poplars and aspens), Tacamahaca (balsam poplars), and Turanga (arid and tropical poplars).

Figure 17: A poplar SRC plantation grown in an agricultural landscape (Source: Nordh N-E.)

Figure 18: Poplar (Max 3 clone) leafs in spring in Germany (Source: Rutz D.)

For the plantation of SRC, usually poplar clones are used. Crossbreeds are usually made between *Populus trichocarpa*, *Populus maximowiczii*, *Populus deltoides, Populus tremula*, *Populus nigra*, *Populus koreana*, and *Populus tremuloides*.

The main clones that have been used in the past for SRC include the clones 'Max 1', 'Max 3', 'Max 4', 'Hybride 275', 'Muhle Larsen' and 'Androscoggin', as shown in Table 7. Further clones that were used for SRC include ‘Rochester’, ‘Weser 6’, ‘Beaupré’, ‘Münden’, ‘Monviso’, ‘Pegaso’, and ‘AF2’.

Populus species are dioecious (i.e. individual trees are either male or female), and can be regenerated by coppicing and from cuttings. Various species of the genus have been widely planted around the globe, both within and outside its natural distribution. In Europe, larger trees from mature poplar stands are commercially used as saw timber, veneer and reconstituted wood products, but also for pulp. During the last years, the interest in establishing poplars in SRC systems to be harvested and used for bioenergy and fuelwood has increased, and several countries in northern Europe (e.g. Sweden), central Europe (e.g. Germany, France, Belgium, and others), and southern Europe (e.g. Italy and others) have developed plant material suitable for SRC. Several varieties/clones have been available in the market, and the grower needs to consult the nurseries and the variety/clone producers for further information that would enable an appropriate choice of plant material based on the site-specific characteristics.

In comparison to willow, poplars grown for bioenergy in Europe are commonly considered to grow mostly in areas with: i) milder climates than for willow, thus central and south Europe are the areas that the interest for poplar is higher, although there are poplar plantations that produce satisfactory yields in northern Europe as well; ii) in sandier and drier soils than willow, which is probably related to lower water needs of poplar than willow, although poplars can grow and produce high yields even in clay soils; iii) less dense plantations as for the willow SRC systems (e.g. distances of 2-3 meters between the trees and harvest in longer rotations > 10-15 years), although there are poplars planted in coppice systems having the same densities and in general management as for willow SRC (extensive examples on such issues are desrcribed in the following chapters); iv) smaller surface of stands since poplar SRC can perform very well in plantation schemes that are not as intensive as willow SRC and do not need special equipment for e.g. planting and harvest if longer rotation periods are chosen (in such cases forest equipment or manual work will be needed for planting and harvest).

Despite these potential differences between the two dominant SRC species in Europe, there have been examples where willow and poplar can grow equally well in the same areas. This is due to the very wide selection of plant material available for these species (different clones and varieties available, suitable for different countries/climatic conditions), and the different management strategies selected by farmers (shorter versus longer rotations, intensive versus less intensive management etc). Such issues are dealt with in other parts of this handbook.

Table 7: A list of commonly used poplar clones for SRC (adapted from Sailer Baumschulen GmbH)

Clone	Species	Sex	Special characteristic
Max 1	*P. nigra* x *P. maximowiczii*	Female	
Max 3	*P. nigra* x *P. maximowiczii*	Female	High biomass production
Max 4	*P. nigra* x *P. maximowiczii*	Female	
Matrix	*P. maximowiczii* x *P. trichocarpa*		
Androscoggin	*P. maximowiczii* x *P. trichocarpa*	Male	Medium biomass production at all soils; Hybrid and Matrix with high growth rates, especially at cooler and more humid locations
Hybrid 275	*P. maximowiczii* x *P. trichocarpa*		
Muhle Larsen	*P. trichocarpa*	Female	
Fritzi Pauley	*P. trichocarpa*	Female	Medium biomass production at all soils
Trichobel	*P. trichocarpa*		
Koreana	*P. trichocarpa* x *P. koreana* x *P. maximowiczii*		High biomass production after 2nd rotation; In Germany not approved

3.3 Black locust

Black locust (*Robinia pseudoacacia* L.) (Figure 19) is a foreign tree species for Europe, originating from eastern United States. It was introduced to Europe during the 17th century. Since then, a rapid spreading occurred in Europe, first as ornamental tree, and later by extensive plantations for timber production and by natural propagation. Nowadays, large areas covered with black locust can be found in central and in southeastern parts of Europe. The species is comparatively drought-resistant, and is nitrogen fixing. For these reasons, black locust has been proved to be a suitable tree species for soil regeneration and reclaiming former mining sites. Robinia is charaterised by its ability to grow on bare soils under extreme conditions, the fact that it is fast-growing with good coppice ability after harvest, and its high wood density. Hence, it proved to be very useful as SRC for bioenergy production. Large areas of forest stands were established with black locust in central Europe (mainly Hungary but also in other countries such as in Italy and Poland), but the interest in growing Robinia for SRC on agricultural land is lately also increasing, especially in areas where land reclamation is aimed. It has to be mentioned, however, that black locust is considered in some cases as invasive species and needs to be controlled with care.

When referring to the production on agricultural soils, black locust grows on a broad range of soils in comparison to other SRC species, but not on very dry or heavy soils. It prefers sites with loose structural soils, especially silty and sandy loams and is resistant to environmental stresses such as drought, high and low temperatures, and air pollutants. For good black locust growth, soil aeration and water regime are the most important soil characteristics.

Propagation of the plant is possible through root cuttings, greenwood cutting, seedlings or micropropagation. Propagation using root cuttings and greenwood cuttings provides a guaranteed quality, but is more expensive than seed propagation. As for harvesting, black locust has thorns, in contrast to other fast growing trees such as willow and poplar, which makes it difficult to handle manually, and it is thus preferable to chip it in the field. Black locust can sprout from the roots, so after the third or fourth harvest regrowth will also occur between the rows, which make efforts with the specially designed harvesters for willow SRC very difficult. In addition, black locust has harder wood than other fast growing trees, and the harvesters must be more durable and powerful than that used normally.

Although black locust offers advantages as nitrogen-fixing species and has a better wood quality with higher density and a higher calorific value compared to poplar and willow, the management of the plantation in SRC is more problematic. 1-year old seedlings are used in dense (about 10,000 seedlings) black locust SRC plantations (compared to the cheaper cuttings of willows or poplar), harvest can be problematic as descrived above, and yields can be as high as for willow or poplar, but this depends very much on the management and location of the plantation. Frost and breaking of shoot and branches from winds can threaten black locust yields, especially in the early stages of the plantations.

Figure 19: Robinia grown for energy in Hungary (Source: Simon L.)

3.4 Eucalyptus

Eucalyptus (Figure 20, Figure 21) is a genus of fast-growing tree species originated from Australia that have been used for many years in southern Europe for pulp and paper production. During the last years, the use of wood biomass from eucalyptus for energy is gaining interest not only in southern Europe, but also in higher latitudes (e.g. in the UK and Ireland). The genus *Eucalyptus* contains more than 700 species. The most common species used in large plantations for biomass production in southern Europe are *E. globulus* and *E. camaldulensis*, and in northern Europe *E. gunnii* and *E. nitens* which are more tolerant to colder climates.

Eucalyptus SRC plantations are traditionally planted in single-stem plantations in 3 x 3 m distances (or similar) and harvested after 7-12 years for pulp production. However, depending on the market situation, the wood has in some case been used in the energy market as well. Recently, interest in coppice plantations with eucalyptus for bioenergy has increased, testing and introducing more intensive production systems. Such systems resemble the willow coppice system with very short rotations of 2-4 years, and management that is closer to agriculture than forestry, producing wood for energy use.

In Europe most of such agricultural SRC systems are currently in the testing phase, in contrast to other parts of the world (e.g. Brazil, Australia) where SRC with eucalyptus have been implemented in a larger scale. Planting usually occurs with rooted seedlings, which are usually a result of hybridization of species that are considered suitable for the climates where they are introduced. Fertilization, especially with nitrogen, is a pre-requisite to achieve high yields, but despite the high yields that can be achieved in a range of climatic conditions in Europe, *Eucalyptus* is a controversial genus from an environmental point of view. Serious concerns are usually expressed on its negative impact on a series of aspects, such as soil quality, groundwater tables, biodiversity and forest fires. Such concerns from local stakeholders should be taken into account when planning to establsih SRC with eucalyptus. In most cases research results have shown that most of the perceptions towards eucalyptus are exagerated and that effects on the environment are similar to any intensive production system in agriculture.

Figure 20: A eucalyptus SRC plantation for biomass for energy after 6 years growth in New Zealand (Source: Dimitriou I.)

Figure 21: Eucalyptus plantation with longer rotation cycle in Argentina (Source: Rutz D.)

3.5 Alder

Alder is the common name of a genus (*Alnus*) of flowering trees belonging to the family *Betulaceae*. The genus comprises about 30 species of monoecious trees and shrubs. They are distributed throughout the northern temperate zone with a few species extending into Central America and the northern Andes.

In general, the experience with alder for the SRC cultivation is still small. Some trials and plantations were just established. Alder has high light, nutrient and water demand, but can tolarate temporary innodation. The grey alder (*Alnus incana)* grows up to altitudes of 1,500 m and prefers limy soils and temperate cold climate. The black alder *(Alnus glutinosa)* prefers humid locations with high water availability and temparate climate.

Figure 18 Alder plantation in Germany with a protection fence against game (left) and alder leaves (right) (Source: Rutz D.)

3.6 Other species

There are a large number of other species that have been candidates for SRC for biomass production for energy in Europe, such as *Acacia saligna*, *Ulmus* sp, *Platanus* sp., *Acer* sp., *Corylus avellana*, *Paulownia* sp., and others. Their introduction has been with lower success than the previous-mentioned species. Some are exotic and/or invasive species and have not been thoroughly tested and environmental concerns over potential invasiveness have been raised, while others seem to be adapted better in certain climates.

Box 2: Why should I plant other species?

In general, it is not very difficult and risky for farmers to make own trials and to collect experiences also with other species than only poplar and willow. So, it is recommended to grow a small part of the SRC plantation with these other species. This increases the diversity of the plantation and also the acceptance in the public. The biomass can be harvested at the same time and usually with the same equipment which is used for the main plantation. However, it is most likely that for the area where you plant the other species yields are lower than for the main plantation.

4 Cultivation of SRC

In this chapter information is provided about different management steps for the cultivation of SRC related to the establishment phase (site prepearation, planting) and to management issues while the SRC is growing. Thereby, the main focus is on willow and poplar.

4.1 Site preparation

SCR grown on agricultural land requires very good initial preparation of the soil, exactly as for other conventional agricultural crops. Succesful weeding has been proved as one of the most important factors for success in terms of SRC yields throughout the life-span of the plantation, and therefore several management steps aiming at avoiding weeds (Figure 22) in the establishment are practiced.

Figure 22 Willow plants in an SRC field (red circle) surrounded by weeds in a field where weeding failed. Despite that the willow plants will outcompete the weeds during next years, production will be lower than the expected. Therefore, the recommended weeding steps are of high importance and should be followed. (Source: Dimitriou I.)

The pressure from weeds depends on the former land use and the seeds in the soil. Especially land that was set-aside for a long period, the risk that many weeds would germinate is rather high, as weeds have distributed their seeds (Gustafsson *et al*., 2007). Land preparation in the year before planting is very important in order to eradicate perennial weeds.

In general the easiest way of weed control is the use of herbicides, but also mecanical control is possible, although it can be quite risky and demanding. Weed control is usually only necessary in the first year of plantation establishment. Considering the duration of the SRC cultivation of more than 20 years, the initial impact of using herbicide in the first year is rather small.

Box 3: Minimizing the use of chemicals is an important factor to increase positive public perception

> The need for applying chemicals (herbizides, pesticides) depends on various factors. The main factors are the size of the plantation as manual weeding of large plantations is very challenging, as well as the profit expectations.
>
> However, the application of chemicals should be either avoided or minimised wherever possible.

The field could be set-aside for one year, during which perennial weeds are controlled with a glyphosate preparation in summer. If the area is covered by an arable crop the year before planting, the weed can be controlled after harvesting using the same glyphosate preparation and suitable ground cultivation. In the case of excessive weed growth, cutting and removal of the vegetation should be considered to allow for effective weed control. In this case, sufficient time should be given to allow regrowth and active herbicide uptake. If there are problems with insects, application of organophosphate pesticides may be used in this pre-ploughing stage. If there are any perennial weeds remaining in late spring, an additional spraying with glyphosate may be undertaken, as late as possible before planting. The perennial weeds must have about 3-4 leaves to achieve an effective spraying. For this late spraying, it is important that the ground is not worked before spraying (Gustafsson *et al*., 2007).

In case of organic agriculture the application of herbicide is not tolerated. Then mechanical control, either manually or with light machinery is usually necessary. Thereby, the size of the plantation plays an important role as mechanical weed control for large plots may be difficult. There have been also trials with black foils (mulching foils) that cover the soil in order to prevent the germination of weeds.

The field must be ploughed during autumn in case that hard winters or soil compaction is expected. In case that soil compaction is not an issue, ploughing can be done before planting in early spring. Thereby, approximately ten days should be waited before the site can be ploughed after herbicide application. If the soil is heavy clay, shallow ploughing is recommended, and the depth reached after harrowing must be 6-10 cm. For other soils, a minimum plough depth of 20-25 cm will be required to allow better planting, especially if the planting material will be cuttings. Large stones should be lifted and removed from the field, as these can damage mechanical planters and harvesting machines.

Figure 23: A newly planted willow SRC field cleaned from weeds that existed before site preparation (Source: Aronsson P.)

Extensive damage (Figure 25) due to rabbits, hares, roe deer, mouse (depending on the country), has been reported in newly established SRC plantations. However, fencing is usually not recommended due to the high costs. Fencing must be only considered in areas of high risk for such damage, and if subsidies exist that will cover a part of the costs. The fencing should be temporary only during the first years, as established SRC is less susceptible. For sites with reported danger from damage from animals, e.g. big mammals such as roe deer, or moles, that can cause serious damage in many parts of Europe, repellents have been developed in order to keep these away by odour from the SRC plants (Figure 24). This increases the site preparation costs and may be practiced only when singe-stem SRC plantations are designed in areas of high risk for such attacks (Caslin *et al.*, 2012).

Figure 24: Installation of a repellent to disperse roe deer in Germany (Source: Rutz D.)

Figure 25: Damage of a poplar stem from a roe deer in Germany: damages occur often at the border of a plantation (Source: Rutz D.)

4.2 Planting material

The used planting material is determined by the decision on the plant species and planting scheme. Several factors influence the decision about which species should be used. They are related to the site-specific conditions and suitability of the species, but also to the availability, accessability, and guaranteed good quality of the plant material, especially when large amounts of plant material are needed. For SRC planted to produce biomass for energy, the most prevailing way of planting is in dense plantations that will coppice (grow after harvest without replanting), and therefore planting with cuttings (Figure 26, Figure 27) is most common since the costs are substantially reduced compared to planting with seedlings. Less often, SRC for energy are designed as singe-stem plantations with much lower density. In such cases seedlings are often used.

Figure 26: Cuttings of about 25 cm length are frequently used. Here: cuttings of poplar Max3 clones (Source: Rutz D.)

Figure 27: 20 cm willow cuttings used for planting of willow SRC plantations (size comparison with a common pen) (Source: Aronsson P.)

In the case of willow and poplar SRC, the planting material consists of one-year-old SRC rods that are cut in about 25 cm long cuttings. Cutting material is generally harvested in winter when the buds are fully dormant. They are stored until planting at -4°C, before being delivered a few days before planting in boxes to the fields. Once delivered, it is important that the boxes are kept in shaded and cool conditions before planting (Gustafsson *et al*., 2007). As previously mentioned, commercially available plant material consists of improved clones/varieties. Many of these improved commercial varieties/clones are protected by European plant breeders' rights. This means that it is usually illegal to produce propagation material for sale without permission. Therefore, cuttings are produced by specialist growers in nurseries, contracted and licensed by mother companies, which supply plant material as one-year-old rods or cuttings for mechanical planting. This applies for both, willow and poplar planting material. SRC farmers or project developers should contact the licensed companies producing and delivering the plant material (Figure 28) well in advance before planting to secure that the appropriate material for their sites are ordered. In most cases the companies issue guarantees for minimum establishment success.

A successful establishment depends on good cutting quality. Therefore, the cuttings should be prepared from one-year-old shoots which had the unripened wood at the tip of the harvested rod removed. The cuttings, when planted, should have a minimum length of 15 cm and a minimum diameter of 0.8 cm to ensure an adequate carbohydrate reserve sustaining the cutting before establishment. Other quality charactersitics that willow or poplar cuttings should have to allow successful planting include sufficient lignification, in order to prevent deformation while cuttings are inserted into the prepared ground, and no discoloration or wrinkling of the surface that indicates dehydration and therefore bad storing conditions. This would increase chances of establishment failures.

Figure 28: One year old rods that will be used as cuttings for willow SRC planting. The rods are delivered by a private cutting producer company in Sweden. The cutting material quality is important for the development of the SRC plantation and therefore should be provided and guaranteed by an authorised company. (Source: Dimitriou I.)

Seedlings used for single-stem plantations of different species must be purchased by authorised nurseries or dealers that should be also in the position to provide all information about the specific characteristics of the different species or varieties. This is of high importance since failures, due to non-appropriate material, will cost time and money if replanting is required. For both, cuttings or seedlings of a certain species, it is recommended to order material of different varieties that will allow a diversification in terms of susceptabiltiy to different pests and diseases. This reduces the risk for plantation failure in gerenal.

4.3 Planting

Different strategies and operations exist for planting. They can be adapted depending on the species chosen, the available planting equipment, the labour costs, the planning for harvest etc. All these factors will be analysed in the coming part of this chapter. It has to be noticed that in this chapter mainly SRC planting with cuttings and managed as coppice is considered, since this practice is mainly used for SRC. Practices are quite similar to the widely used forest practices if SRC is planted with seedlings. Therefore, they are mentioned here, but not analysed in detail.

It is important to plan the process of planting carefully so that management and harvesting can be performed rationally, and to achieve the most efficient space use in the field. Since planting in rows is the most appropriate method of SRC planting, the rows should be laid out so that they are as long as possible. Ideally, the end of the row should be an access road. At the end of the row there must be a turning area of 8-10 m, also called header, as the harvesting machines need space to be able to turn. If facing deep ditches, the turning area should be 10 m, otherwise 8 m is sufficient. A boundary zone of around 2-3 m should be left on the other boarders of the SRC plantation.

Planting is usually done **in spring**, in April-May in northern Europe and earlier in southern Europe, when weather conditions allow soil preparation. Planting with cuttings is also possible in later periods (May or June) since the material used is stored at low temperatures. Early planting offers advantages as the growing season is longer. However, the cuttings start to produce roots only if there is enough water available and if the soil is warm enough. The key factor for the success is the water availability, as too long dry periods avoid root development so that the cuttings dry out. In summary, the water availability is a more important factor than the early or late timing during spring. Past and actual weather conditions, as well as the weather forecast, are important to determine the right planting time.

A practice that is sometimes promoted is the “**cutback**” of the new rods during the first year. Cutback of one-year old shoots (especially of willow) has been practiced in order to promote more rigorous growth with more shoots and better root establishment during the second year. Although this goal is achieved with cutback after the first year after planting, higher biomass production during the plantation lifespan has not been proved, and therefore cannot be recommended as a compulsory operation procedure. If decided, cutback can be performed using a mower, mowing blade or some form of scythe mower. The added value of cutback after the first year of establishment is still discussed controversially.

There has been substantial research on the density and the design of the SRC plantations. This decision is related to the the species chosen and the existing machinery available for harvesting. If harvest occurs with specially designed machines for SRC, the double row system is preferred (see chapter 2.3). It has to enable the machines entering the SRC field without damaging the plants after 3-4 years of growth. This design implies distances of 1.50 between and 0.75 m within the double rows, and a distance of the cuttings in the rows between 0.5 m and 0.8 m (depending on the location, the clones or species used). This would require 5,000-20,000 cuttings per hectare, depending on the species. Generally willows are planted denser in comparison to poplar.

The planting can be done by different methods. One option is to use specially designed mechanical **planting machines** using 1-year old long rods as planting material (Figure 29). They can plant 2 or 3 double rows at the same time. These machines automatically make the cuttings from rods and plant the double rows in one step. The capacity of such machines is approximately 1 hour per hectare. Other machines are only able to plant pre-cutted plantings (Figure 30).

Figure 29: A willow SRC planting machine. The machine plants three double rows and needs in four persons to operate and the driver. (Source: Nordh N-E.)

Figure 30: Planting machine for automatic planting of poplar SRC cuttings (Source: Wald 21)

Figure 31: Manually-planted poplar plantation in single rows with 50 cm cuttings (Source: Dimitriou I.)

Manual planting can be preferred in case that mechanical planting equipment is not available or too far away to bring it cost-efficiently to the plantation (Figure 31, Figure 32, Figure 33). Also if labour costs are lower than for hiring the equipment or if the plots are very small (usually below 1 ha), manual planting is an option. In that case, it is important to keep the rows parallel to each other and to keep the distances between the plants within the rows equal to each other in order to avoid intercompetition. The use of lines may be a helpful practice to ensure this.

Figure 32: Pushing cuttings by hand into the soil: the bud must show always upwards! (Source: Rutz D.)

Figure 33: Pushing cuttings by foot into the soil if the soil is too compact (Source: Rutz D.)

For willow and poplar several planting systems were tested to replace the dominant double-row system in order to achieve higher production. One such system is the **horizontal planting** method (Figure 34) of willow billets with a layflat planter. Instead of planting cuttings vertically into the soil, whole roots or cuttings are planted horizontally into the soil. This has been widely used in slope stabilization and site restoration of river banks projects, and has been also tested for SRC production. Results show that biomass production with horizontal planting can be equally high as for the double-row system, but consequent management (harvesting) can be challenging. Moreover, in cases where royalties need to be payed as a result of breeding rights, horizontal planting can become more expensive for the famer since more plant material is needed than in the double row system with cuttings.

Figure 34: Horizontally laid willow rod: the rod still needs to be covered with soil (Source: Rutz D.)

After planting, the site may be rolled to consolidate the surface and to provide the best possible conditions for the application of residual herbicides. However, the need for that depends on the soil properties and weed pressure. If planting machinery is used, often the machine rolls the soil in parallel to the planting step.

4.4 Management of the plantation

There are different management steps after planting to maintain the SRC plantation. These will be described in detail in this part of the Handbook in a “chronological” order. Emphasis is put on the widely used species of willow and poplar grown as coppice on agricultural soils, and not on single-stem plantations, since these are managed similar to forestry operations.

Weed control after planting: As previopusly mentioned, weed control during the establishment phase of SRC is extremely important. This includes weed control measures before planting, but also during the first phase of growth in the first year of establishment. Weed control is important since plants compete for light, water and nutrients. In a plantation with a lot of weeds the SRC plants will be weaker and will grow slower. A frequently applied method to contol this is to apply a suitable soil herbicide to prevent weeds germinating, directly after planting and before the cuttings have started to produce shoots (Gustafsson *et al*., 2007). As explained in chapter 4.1, one may consider controlling weeds only mechanically, especially for smaller plots.

Later in the season, once the effect of the herbicide has expired, the plantation must be regularly observed in order to decide if further weed control is needed. Mechanical measures may be required (Figure 35) to keep the weeds under control during that period. If weed control is performed with a cultivator it is recommended to perform three operations during the season. However, if a weed harrow is used, more operations may be required (e.g 6-8 depending on the location). The method or equipment used is of minor importance, but it is very crucial that weed control is performed, if weeds occur. The timing for weeding after planting of SRC is of utmost importance for a potential success of a plantation. As a rule of thumb for willow cultivation, mechanical weed control should be made if there are 2-3 weed species higher than about 8 cm. If weed control is done according to the recommendations then no other weed control will be needed during the consecutive years, since the SRC plants will outshadow the weeds after the second year of growth.

Figure 35: A one year old willow SRC plantation dominated by weeds. The field could only be treated with mechanical weeding, since willow leaves have started to emerge (not visible in the picture). (Source: Dimitriou I.)

Insect control: In case of problems with insects in a specific site, an insecticide may be applied with this herbicide application since the insects will be in the larvae phase and therefore easier to face. High volume applications (instead of concentrated, low-volume applications) are recommended to give good surface coverage of the herbicide and adequate penetration of the insecticide. However, the need of chemicals should be carefully assessed and avoided where possible. Usually, the application of insecticides is not necessary.

Cutback after first year: As previously mentioned, harvest of the plants after the first year of growth during winter (after leaf fall) may be practiced to obtain more rigorous growth with more shoots and better root establishment during the second year. During the first growing season, the inserted cuttings will produce 1-3 shoots depending on the clone with a maximum height of 2-3 m. The cutback should occur as close as possible to ground level using a reciprocating type mower, which should produce a clean cut. Other types of swathers can cause excessive damage.

Despite cutback was an established practice when SRC systems have started to develop in the beginning of the 1990's, the issue of cutback after the first year of establishment is still controversial. Although more shoots are achieved and roots are bettere established when cutback, higher biomass production during the plantation lifespan, when compared to SRC stands without cutback, has not been proved. Therefore, it cannot be recommended as a compulsory operation procedure. However, if a post-planting herbicide is needed, i.e. in climates or sites where rigorous weed growth is expected, cutback gives a necessary second opportunity for herbicide application.

Some practicioners recommend in poplar plantations to cut back all shots except the largest one (Figure 36). This should support the development and growth of the single-stem. However, experiences have shown that the effort to do so is too high and the benefits negligible.

Figure 36: One-year old poplar shoot in Germany where the secondary shoot was cut to improve the growth of the primary shoot (Source: Rutz D.)

Fertilization: As for any crop grown on agricultural soil aiming at high production, SRC needs nutrient inputs that are taken out with harvest. In the case of SRC, and since it is a perennial crop, the internal nutrient inputs occurring from the leaf litter but also from root and fine root dying off must be considered, together with the nutrient status in soil of the site which should be analysed before the plantation is established. There has been extensive research conducted concerning the amount and the frequency of fertilization for the main SRC species (willow and poplar) in several countries, but it seems that it is not possible to propose concrete recommendations since in most cases fertilization needs are site-specific.

Fertilization during the first year of establishment is not recommended, to avoid the promotion of weed growth, since the roots of SRC plants are not fully established and effective uptake cannot be ensured. Once the SRC plantation is established, fertilization may be considered. Several experiments showed that on moderate to fertile soils, particularly in the early rotations, there is usually no positive response to fertilizer application. Sites with naturally poorer nutrient conditions may need these early applications to maintain productivity. It is usually nitrogen that may need to be added in SRC plantations at the initial rotations, since soils are often well-supplied with phosphate and potassium, especially in the earlier rotations. Therefore, inorganic nitrogen fertilisers may be used (Aronsson *et al.*, 2014).

Sludge from local wastewater treatment plants can be also used (this is reported later in this Handbook), but it should be supplemented with extra nitrogen. The need for nitrogen varies, depending on the age of the SRC plantation and the development of the shoots. In older plantations nitrogen will be released from the layer of fallen leaves that is formed, which means that the need for fertilisation is reduced. In principle, it is the amount of nitrogen contained in the shoots that is removed during harvesting, that must be replaced by fertilisation.

Nutrient offtake figures for harvested willow SRC vary, but are in the range of 150 – 400 kg N, 180 – 250 kg K, and 24 – 40 kg P per hectare for a 3-year rotation based on about 8 t DM/ha/yr biomass production in Sweden. For comparison, intensively managed grass would require about 900 kg N/ha over 3 years, which shows the low N requirements of SRC compared to other crops. To calculate the amounts of N that might be needed for SRC fertilisation, the efficiency of nitrogen use should be taken into account, since a significant proportion of nutrients will be used by soil microflora, lost to the atmosphere, or bound up in the SRC plant roots and leaves, although these latter will be recycled in the leaf litter and fine root turnover.

Phosphorus and potassium additions to SRC are usually not necessary. Increasing phsopshorus amounts in the soil requires many years of consecutive applications and the low requirements of SRC do not justify such applications. Potassium can be relatively stable in soils and therefore unavailable for easy plant uptake. Returning the wood-ash to the site (more details on such practices are given later in this Handbook) can balance most of the potassium exported from the site during harvest.

As a very rough fertilisation recommendation for willow SRC, that has taken into account all the above things-to-consider and potential soil analysis and expected yields, nutrient application in SRC should not exceed the equivalent of 120-150kg N, 15–40 kg P and 40 kg K per hectare per year (and probably staying closer to the lower values indicated) (Gustafsson *et al*., 2007). The same calculation principles should be used for the other species that are used for SRC. A potential SRC grower should take into account that technically fertilisation applications in SRC plantations can be possible during the first and possibly the second year of growth, but not in the third or fourth year due to the plant height that does not allow the machines to enter the plantation without high risk for damage.

Recent research with fertilisation of SRC plantations, grown with newly bred clones, have indicated that fertilisation response of such material is more evident than when older clone material is fertilised (Aronsson *et al*., 2014). This probably provides an answer to the question if a farmer should fertilise or not. Plantations with new breeding material will probably imply that fertilisation must occur even with larger amounts of nitrogen than suggested before (if of course nitrogen leaching does not occur, which also does not seem to be the case). However, the answer to the question if a farmer needs to fertilise or not depends on the current price of the fertiliser (or of 1 kg/N) and the expected yield increase.

5 Harvesting of SRC

Harvesting is a very important topic in the SRC life cycle as it involves 50-80% of the overall production costs (Liebhard 2007). Therefore, it considerably influences the economy of a SRC project.

Harvesting should be carried out in winter after leaf fall, before bud burst and ideally when the soil is frozen. Depending on the purpose of the final product, harvesting of SRC is done in 2 to 20 years intervals. Various practices, techniques and equipment are available to harvest SRC. They depend on the following factors:

- **Crop species and variety**: number and diameter of stems
- **Desired end product**: woodchips, pellets, logwood
- **Quality of the end product**: shape of the woodchips, moisture content
- **Availability of machines**: own machines or cooperation with a contractor
- **Cultivation shape**: single- or double row, distance between rows
- **Size and shape of the field**: large or small fields, slopes
- **Amount of the harvested wood**: logistics requirements, interval of harvesting
- **Soil moisture**: drivability with machinery

In general, the stems should be cut during the first harvest close to the soil and in subsequent harvests about 1-2 cm higher per harvest. The cut should be sharp, without fringes and horizontal so that the size of the cut is minimised.

5.1 Yields

Yields of SRC depend very much on the location of the site which is mainly characterised by climate (temperature and water availability) and soil type. Species, varieties and clones have to be carefully selected for each location in order to maximise yields. In northern Europe, a main criterion for the selection may be cold (frost) tolerance, whereas in southern Europe it may be drought tolerance. Considering the large differences within Europe, Table 8 shows some key characteristics and yields for willow, poplar and black locust.

Besides the abiotic factors, also human factors influence yields considerably: management practices, general husbandry, selection of SRC species and variety, pest and weed control, and nutrient management.

The harvest cycle/interval depends on the overall purpose of the SRC plantation. It is typically between 1 and 7 years, but may also be extended to 20 years. Usually after 20-30 years the cultivation is either replanted or replaced by other crops.

Feasible annual yields in Europe are in the range between 5 and 18 t/ha of dry woodchips (DM; 0% moisture). The total amount of biomass for one harvest is calculated by the annual yield, the years of cultivation and the water content, which is typically about 55% for fresh harvested wood. For instance, if the annual yield is 10 t/ha of dry woodchip, if the harvesting cycle is 4 years and if the water content is 50%, the total amount of harvested wet biomass is about 80 t/ha, the amount of dry woodchips is 40 t/ha.

Usually, yields of the first harvest are lower than the yields for the second and third harvests. After that, depending on the framework conditions, yields may be stable for the next yields and then decrease, once the plantation is getting older. General recommendations on how to maximise yields are given in Box 4.

Table 8: Overview of the main characteristics of Short Rotation Coppice (SRC) (Source: modified after Dallemand et al. 2007)

Species	Willow	Poplar	Black locust (Robinia)
Part of Europe	Northern, central and western Europe	Central and southern Europe	Mediterranean Europe, Hungary, Poland
Crop density stools/ha	12,500 – 15,000	8,000 - 12,000	8,000 - 12,000
Harvesting cycle (years)	1 - 4	1 - 6	2 - 4
Av. stump diameter at harvest (mm)	15 - 40	20 - 80	20 - 40
Av. height at harvest (m)	3.5 - 5.0	2.5 - 7.5	2.0 - 5.0
Growing stock at harvest (fresh t/ha)	30 - 60	20 - 45	15 - 40
Moisture content of the wood (% weight)	45 - 62	50 - 55	40 - 45

Box 4: How can SRC yields be maximised? (modified after Lindegaard 2013)

Plan early: You really need to start thinking about planting your SRC plantation in advance of planting, preferably one year in advance. This will give you the necessary time to make your application for incentives and prepare your land according to best practices. In late summer / early autumn you can get started by removing weeds and ploughing your land.

Know your land: Like all crops SRC will do best on the most suitable land. Therefore, you must know the key parameters of your land: soil properties and water availability. If you plant a crop on your worst land then you will almost certainly get disappointing yields. E.g. willow SRC does best on fertile arable fields with a pH range of 5.5-8.0. They do well on heavy brown earth soils with high clay content whilst silty and light sandy soils should be avoided. SRC willow needs an annual rainfall of between 600-100 mm. Field drains will be affected - so plant at least 30 metres from important drains. As with all crops, cost effectiveness is achieved from large, regular fields. Smaller, odd shaped fields will increase down time and increase the cost of planting and harvesting.

Weed control: SRCs are very fast growing, but should have minimal competition from weeds in the establishment. Weed control starts with the preparation of the land in autumn and continues during the first year of the plantation. Whenever possible, techniques without chemical input should be used to control the weeds, but this depends on the size of the plot, weed species, SRC species, etc.

Use the best varieties: SRCs should be thoroughly tested and approved before they are used. They are much higher yielding than non-improved varieties. If possible, varieties that are locally bred are preferable. You need a mixture of varieties that provide high yields and a wide genetic background to guard against disease and pest outbreaks. Making the correct variety choice is essential for success and a measure to avoid or reduce pests and diseases.

Liaise with your planting contractor: In many cases, you will not plant the SRC fields yourself, but ask a contractor for this service. Contact your contractor early in advance and ask for references. Ask other farmers about their experiences with the contractor. Gaps in the plantation where cuttings do not sprout are often related to mistakes during planting. If the planting takes longer, but a better success rate is achieved and the amount of gapping up is reduced, then it will be worth it. Remember: quality of planting is more important than an ultra-low price.

Gap up: However rigorous you and your planting contractors are, there will always be gaps where a cutting was missed or failed to establish. When you cut back, you will have loads of material available to gap up. After the first harvest, you can push 1 metre rods into the gaps, or plant cuttings. This depends on the used crop variety.

Reduce damage caused by game animals: Game animals, such as rabbits, hares and deer can cause serious damage to new plantations, especially in small plots and when there is a high game density. Cooperate with the local hunters and support them to erect raised hides to control and scare game. The use of flavour may also help to scare game away. Another measure is to erect rabbit/deer fencing. This is very expensive, but it may be worth it in the long run. High yields over a 20 year period will depend on those critical first few months of establishment. You should shop around to get the best deal from a local contractor.

Fertilise with organic waste: SRCs thrive on nutrition. You should be able to apply organic fertilizers such as slurry, digested sewage sludge, manure or digestate from biogas plants. It is best to apply fertilizers to established plantations after harvesting. Usually, fertilizing is more needed the “older” the plantation gets. Remember to adhere to regulations, legislation and conditions for incentives that may be relevant for fertilizing your specific plot.

Maximise your harvest yields: When you come to harvest your crop you want to make sure that all the SRC in your field ends up being harvested. In many cases, you will ask a harvesting contractor to do the service. Using an experienced harvesting contractor is essential to minimise machine operator error and spillages from overfilled trailers. Also, it is important that the harvester blades are set correctly to make sure that the crop is cut low down – this is where the stems are thickest and have the greatest mass. Furthermore, the regrowth is better if the cuts are very sharp and not unravelled. Furthermore, the woodchip quality is better if blades are very sharp.

Minimise storage losses: Try to minimise storage losses after harvest. Storage and after-treatment (drying) of the woodchips/routs depends on the harvesting method, time when the woodchips are needed and needed quality of the woodchips. Find out your best method to reduce storage losses at minimal costs.

5.2 Cutting cycles

Typical harvesting intervals are between 1 and 7 years, but may also be extended to 20 years. Usually after 20-30 years the cultivation is either replanted or replaced by other crops. There are no strict rules for cutting cycle length, as decisions should be made on a site-by site basis considering different framework conditions (Tubby & Armstrong 2002), Thus, the time of harvest is decided by the operator of the SRC plantation. He defines the harvesting timing according to the following factors:

- **SRC species**: best regrowth timing, maximisation of yields of the specific crop
- **Site capture**: a closed leaf canopy catches most sunlight and is thus at its peak of productivity; the timing for this depends on the species that influences the ideal harvesting time.
- **Desired end-product**: woodchips, logwood; quality of the material
- **Availability of harvesting machinery**: at peak harvesting time, contractors may be fully booked; early planning is necessary.
- **Condition of the soil**: preferred harvesting on dry and/or frozen soils; in some years and regions, it is better to postpone harvesting as soil conditions are not good enough and harvesting would damage the soil and the plants.
- **Desired cash-flow timing**: this depends on the overall management objectives of the operator.
- **Prices for woodchips**: operators may 'wait' for high prices for wood to get more revenues; however prices are not predictable and depend on speculations.
- **Own demand for heating**: if woodchips are used for own heating, they should be available every year.
- **Other benefits**: timing to increase biodiversity, to protect game.

The harvesting cycle has large impacts on the harvesting logistics. The longer the interval between two harvests, the higher is the amount of biomass per harvest, which is the multiplication of one year's growth with the number of years. Some operators may not have the logistics' capacity (storage facilities, trucks, workforce) to deal with the large amounts of biomass of harvests after long intervals. In order to spread the workload and the risks, it may be also considered to rotate harvesting of different SRC plots so that every year there is one harvest, instead of having harvests of all plots at the same time.

Furthermore, also the needed harvesting technology is determined by the harvesting cycle. The older the plants are, the thicker are the stems and the heavier must be the machinery. In general, diameters of the stems of the boundaries of a plot are larger, as trees receive more light and water, than the plants within a plot.

5.3 Properties of harvested material

Usually, the final product of SRC is woodchips, which are mainly used for combustion processes. They may be also used for the pulp and paper industry or for other bio-products. For instance it was foreseen to produce large amounts of woodchips from SRC for the production of BtL (Biomass-to-liquids) biofuels in Germany (Rutz et al. 2008).

Depending on the harvesting method, different intermediate products are produced that influence the properties of the woodchips, mainly the size and shape, as well as the moisture content. Intermediate products can be classified into the following categories (DEFRA 2014):

- **Rods**: harvested stems up to 8 m in length
- **Bundles**: bounded rods in bundles
- **Billets**: cut material of 5 – 15 cm longitude
- **Chips**: cut material of up to 5 x 5 x 5 cm in size

The harvesting methods for these intermediate products are named as "whole rod or shoot harvesting", "chip harvesting" or "cut-and-chip method", and "billet harvesting" or "cut-and-billet method" (Kofman 2012).

Freshly harvested wood generally has a moisture content of 40 – 60%. Many consumers of woodchips, especially those of small-scale boilers require moisture contents below 30%. The lower the moisture content the higher is the quality of the woodchips and also the higher is the storability.

Loose rods (Figure 45) and bundles can be stored on the headers or on the farm and dry down to approximately 30% water content in 4-6 months. The intermediate between rods and chips are billets, which can be stored in piles. Due to the spaces between the billets, natural ventilation occurs in the storage piles which facilitates drying and which prevents the difficulties associated with chip storage (chapter 5.5).

Although the production of rods, bundles and billets have the advantage that drying is relatively easy, chipping of the dried material has usually negative impacts on the quality of the woodchips. This is due to the fact that cuts of fresh material are sharper than cuts of dry biomass. Furthermore, more particles are formed if dry wood is chipped instead of fresh wood and the size of the chips is less homogeneous.

5.4 Harvesting methods

There are different harvesting methods available. SRC crops can be cut and chipped **in one harvesting operation**. Alternatively, SRC crops can be cut first and left (as rods/stems or pre-chipped to billets) in the field in order to air-dry, whereas the chipping is carried out as a **separate operation** at a later stage.

There are different technologies available for the harvesting of woodchips which can be combined with each other. They can be classified according to the automation level and the type of machinery, as presented in Table 9.

The machinery for harvesting SRC is under continuous development. The following machinery can be used for mechanised harvesting:

- **Wood harvester**: harvesters from forestry management are readily available. They cut trees with stems of larger diameters. As the stems of SRC usually do not get very thick, smaller and lighter harvesters can be used. Harvesters usually do not include equipment for chipping, so that additional machinery is needed. Sometimes gripper-heads are mounted on an excavator (Figure 40).
- **Tractor mounted equipment**: Tractor mounted equipment is available in several variations. It can be mounted on existing tractors of the SRC operator and can include tools for combined cutting and chipping, only cutting the trees, or only chipping. If combined, the equipment may fell down the rods and then chip it by feeding them horizontally to the chipper or they may cut it and directly chip it in an upright position as proposed by Ehlert et al. (2013).
- **Self-propelled machines**: self-propelled machines are dedicated harvesters (Figure 38, Figure 39) or modified forage harvesters (Figure 37) that cut and chip the crops simultaneously, similar to e.g. a combine which harvests whole corn plants for ensiling. Several manufacturers are offering these machines already. In case that they do not produce woodchips, but billets, they are also called billet harvesters.

Self-propelled machines and tractor mounted equipment that cut and chip in one operation are developed from forage or sugarcane harvesters. Harvesters of several manufacturers, such as Claas (Jaguar) (Figure 37), Austoft (7700), and New Holland (Figure 38, Figure 39) can be equipped with special headers for SRC harvesting. Further improvements and developments can be expected in the coming years, if more SRC are cultivated.

Figure 37: Claas self-propelled SRC harvester „Jaguar“ (Source: Dimitriou I.)

Figure 38: New Holland self-propelled harvester and woodchip trailer (Source: Rutz D.)

Figure 39: Header of the New Holland self-propelled harvester (Source: Rutz D.)

Figure 40: Gripper-head mounted on an excavator for harvesting poplar in Austria (Source: Mergner R.)

For very thin rods such as for willows, bale presses exist that produce round bales similar to stray or hay bales. Such technology is offered e.g. as “Biobaler” (Figure 41) from Andersons Canada (Caslin et al. 2010).

Technologies for separate chipping (Figure 43) are readily available, for instance from Jenz, Komptech, Husman, Jensen, Pezzolato, Spapperi, Heizomat, Vogt, etc. They can be mobile or stationary, mounted on trailers, or directly on the tractor, or self-propelled. Often, they have a crane which is used to feed the system. If they do not have an own crane, a dedicated crane may be used. Regarding the chipping process, there are three different types of technologies available:

- **Drum chipper**: drum chippers have a rotating large steel drum with up to 20 knives mounted on it. The drum spins towards the output chute and also serves as the feed mechanism, drawing the material through as it chips it. Chippers of this type are very loud and need special safety measures, as it can lead to injury or death if an operator becomes snagged on material being fed into the machine. The chips produced may be very large and if very thin material is inserted, it may be cut into slivers rather than chips. Modern drum-style chippers usually have a material capacity of 15–50 cm.
- **Disc chipper**: The disc chipper has a steel disk with 2-4 knives mounted upon it as the chipping mechanism. In this design, usually reversible hydraulically powered wheels draw the material from the hopper towards the disk, which is mounted perpendicularly to the incoming material. As the disk spins, the knives cut the material into chips. These are thrown out the chute by flanges on the drum. This design is not as energy-efficient as the drum-style design, but produces chips of more uniform shape and size. Consumer-grade disk-style chippers usually have a material diameter capacity of 15 to 46 cm. Industrial-grade chippers are available with discs as large as 4.1 m in diameter.
- **Screw chipper**: The interior of a screw chipper consists of a stretching, conical and screw-shaped blade. This spiral shaped long blade has its edges sharpened for wood chopping. The blade rotation of the chipper is set to parallel direction to the openings of the wood refuse, as the wood is being pulled in by blade's spiral motion.

Dedicated wood harvesters from forestry are heavy forestry vehicles employed in cut-to-length logging operations for felling, delimbing and bucking trees. A forest harvester is typically employed together with a forwarder that hauls the logs to a roadside landing. Harvesters are readily available from many manufacturers such as John Deere, Caterpillar, Hyundai, Valmet, Rottne, Dorfmeister, etc.

A new concept was developd by the company Anderson: A so-called biobaler (Figure 41) converts woody biomass from 2.5 inches diameter into a 120 cm netted and compacted round bale ready for industrial usage.

Figure 41: „Biobaler" from Andersons Canada (Source: Anderson Group)

Table 9: Harvesting methods, their description and characteristics (with input from LWF 2011, Kofman 2012)

Description	Characteristics
Manual and motor-manual harvesting using a bill hook, chainsaw, brush cutter or similar implement	
- Cutting and felling the rods with a bill hook chainsaw, brush cutter or similar implement - Manual collecting of the rods or with a tractor - Either storing of the rods for drying or direct chipping - Manual or crane feeding of the rods to a small chipper	- Personal contribution possible - Demanding and dangerous work - Low productivity - Reduced costs, as existing equipment can be easily used - Suitable for small plots of less than 5 ha and for own or communal woodchip burners - Work should be done by minimum 2 workers that rotate their activities.
Mechanical harvesting using a harvester	
- Harvesting of larger trees with a harvester machine from forestry. - Collection of the trees or bundles with a tractor or forwarder. - Either storing of the trees/bundles for drying or direct chipping. - Crane feeding of the trees to a chipper.	- Less ergonomic demanding activities for workers due to high automation. - Drying of the bundles/trees on the field is possible. - Services have to be done usually by a contractor – harvesting costs are expensive. - Only economic for lager plots. - Suitable for woodchip boilers of any kind.
Mechanical harvesting using tractor-mounted equipment of self-propelled machines	
- Either tractor-mounted equipment of self-propelled machines (forage harvesters with modified headers for direct chipping) - Harvesting and chipping occurs simultaneously - Trailers that transport the woodchips directly from the field have to be available at the same time of harvesting. - Woodchips are directly used, stored or dried.	- Less ergonomic demanding activities for workers due to high automation - Economic for medium-sized to lager plots - Mainly suitable for larger woodchip heating and CHP plants - Drying of the woodchips is challenging and can be expensive. - Besides the moisture content, the quality of the woodchips is high, as cutting of fresh wood creates clean and homogeneous woodchips.

Figure 42: Forwarder that collects the stems from the field in Austria (Source: Mergner R.)

Figure 43: Woodchipsper mounted on a traktor in Austria (Source: Rutz D.)

Figure 44: Harvested willow SRC in winter in Sweden: The double-rows are visible (Source: Rutz D.)

Figure 45: Stored willow harvest at the border of a SRC plantation in Sweden (Source: Rutz D.)

5.5 Drying and storing of woodchips

After SRC biomass is harvested, it usually needs to be stored before it is either used for self-consumption or sold. Woodchips, whole rods, stems and billets can be stored on the headers of the plantations or brought to the place where it will be later used.

A very important quality attribute is the water content (Table 10) or moisture content (for the definitions, see Box 5) of the wood. Air-drying can reduce the moisture content from 50-55% down to about 30% within few months.

Table 10: Water content of wood classified in four categories

Category	w (water content)
Absolute dry wood	0%
Air-dry wood	15%-20%
Storable wood	< 30-35%
Fresh wood	> 50%

Storing freshly chipped wood for a longer time is very difficult as it is associated to the following risks (LWF 2012):

- **Loss of biomass**: 2-4% biomass losses per month due to on-going biological processes and decomposition.
- **Health risk**: production of fungi spores that have negative health impacts.
- **Quality**: increase of the water content in unprotected piles due to precipitation and re-accumulation of condense water at the top of the pile.
- **Technical risk**: freezing woodchips form clumps which are difficult to handle, stones may cause damages of equipment.
- **Spontaneous combustion**: microbial activity increase temperatures in the pile which can lead to self-ignition.
- **Environmental impacts**: odours may harass neighbours and leachate may pollute water bodies.

However, woodchips from air-dried wood with water content of about 30% can be relatively easily and safely stored on open piles. Covering the piles or storing them under roofs prevents to increase the water content after precipitation. Also fresh woodchips can be stored under roofs and further dried down to 30% water content, but good ventilation and eventually mixing with a wheel loader is important in order to avoid self-ignition.

The water content of woodchips should be reduced ideally to levels below 20%. European standards classify woodchips into 5 water content (moisture content on wet basis) categories (M20, M30, M40, M55, M65) (Rutz et al. 2012). Due to the small particle size, woodchips are sensitive to microorganisms if the water content is too high. Increased microorganism activities lead to increased temperatures of the material which has even caused self-ignition in woodchip storage facilities.

The higher the water content (see Box 5), the less energy efficient is the combustion (see chapter 8.3), since part of the energy is “lost” for vaporization. The lower heating value for wood is much higher if wood is dried (4.3 kWh/g), than for fresh or wet wood (1.5 kWh/g) (Liebhard 2007). The relation of the heating value of wood relative to the water content is shown in Figure 46. The higher the water content, the lower is the heating value.

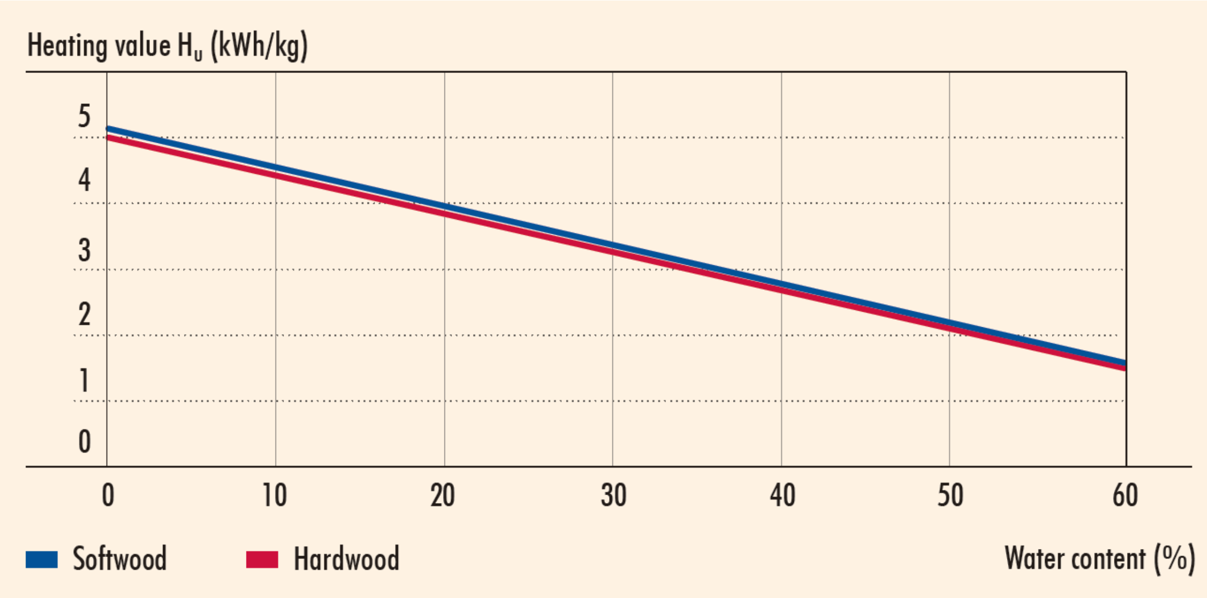

Figure 46: Heating value of wood relative to the water content (Source: FNR 2012)

Box 5: What is the difference between the moisture and the water content?

Important information on the fuel quality is the water content in the fuel. In order to be able to calculate and compare the water content, the two physical measuring parameters, **water content (w)** (also called "moisture on wet basis") and **fuel moisture (u)** (also called "moisture on dry basis"), are used.

The water content (w) refers to the water mass m_W bound in the fresh biomass (m_d + m_W), whereas the fuel moisture refers to the water mass m_W in the dry biomass (m_d).

$$w = m_W / (m_d + m_W)$$

$$u = m_W / m_d$$

Values for the moisture can be converted into values for the water content. For instance, the water content of 50 % corresponds to the moisture of 100 %. Values for moisture can increase above 100 %. 'Moisture' is a term that is commonly used in forestry and timber industries. In the energy sector, often the 'water content' or 'moisture content on wet basis' is used.

Various simple to sophisticated technologies for drying exist (Table 11). Woodchips are often dried in **charge driers** that can be containers trailers or storage facilities through which the hot air is blown (Figure 47 to Figure 52).

Containers or trailers usually have a double bottom with a grate floor or grate pipe through which the hot air is blown. Often, agricultural trailers are self-adapted, which is a considerable cheap solution. Woodchips are usually not moved or mixed in these containers or trailers which results in an inhomogeneous and uncontrolled drying.

More sophisticated are **feed-and-turn driers**. Hot air is blown through a double grid bottom and a mobile paddle mechanism mixes and conveys the woodchips during the whole drying time. A carriage moves the paddle wheel across the dryer for several times during the whole drying process. The direction is changed by final switches and the respective automatic control system. Feed-and-turn driers can be operated in batch or continuous mode.

In a **belt dryer** woodchips are continuously and evenly applied through an infeed chamber onto a perforated belt. The belt, predominantly in horizontal position, carries the product through the drying area which can be divided into several cells. In these cells drying gas flows through or over the wet product and dries it. Each cell can be equipped with a ventilating fan and a heat exchanger and thus adapted to different required conditions.

An ideal and cheap heat source for drying is the waste heat, e.g. of industrial processes or of biogas plants (Rutz et al. 2012).

Table 11: Drying technologies and their main characteristics (Source: Rutz et al. 2012)

Drier type	Characteristics
Charge drier	Hot air is passing the material in horizontal or vertical bunkers, either in fixed silos, lorries or containers. It is one of the simplest driers as the material is not actively moved. It is also very cheap and suitable for small capacities.
Feed-and-turn drier	Hot air is blown through a double bottom (grid bottom) through the product. Turning devices such as paddles mix and convey the product.
Belt drier	Hot air dries the material that is slowly forwarded on a belt. The investment costs are relatively high.

Figure 47: Container and air heating pipes for woodchips drying at a biogas plant in Munich, Germany (Source: Rutz D.).

Figure 48: Container for woodchips drying in Munich, Germany (Source: Rutz D.).

Figure 49: Charge dryer on a trailer using the waste heat of a biogas plant in Germany (Source: Rutz D.).

Figure 50: Feed-and-turn drier for woodchips installed at a biogas plant in Germany (Source: Rutz D.).

Figure 51: Floor-integrated ventilation slot in the floor of the storage facility of the Biomass Trade Centre Achental, Germany (see Figure 52) (Source: Rutz D.).

Figure 52: Ideal woodchip storage facility at the Biomass Trade Centre Achental, Germany (Source: Rutz D.).

Finally, a dedicated method for drying woodchips from SRC was developed) and patented (PCT/EP2005/009241) by the Technical University of Dresden (Germany). The system is based on the principle that the fresh and humid woodchips heat-up themselves if stored in a pile. Perforated pipes facilitate air to enter the pile and an outlet pipe acts as a chimney and releases the warm air that was heated by the woodchips. This air ventilation process is an effective method for drying the wood without external energy input. With this method, it is possible to reduce the water content to 30% within three months (Grosse et al. 2008). The pile can be established directly at the header of a plantation or at the place of woodchip consumption.

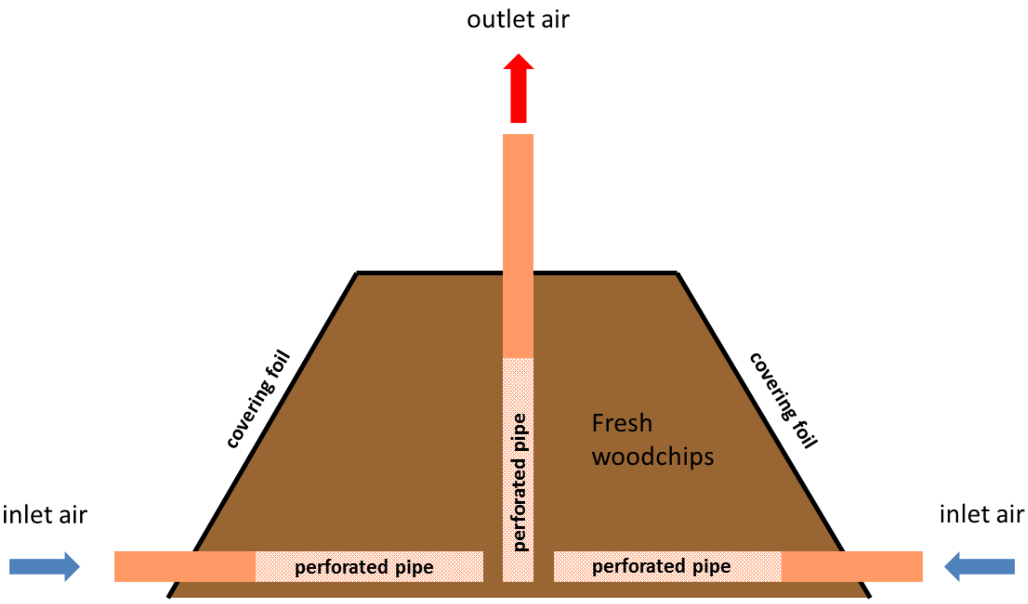

Figure 53: Scheme of an air-ventilated woodchip pile for drying (Source: Rutz D.)

6 Logistics and transport

Transport costs and distances to potential customers should be carefully considered before a SRC project is started. Transport of woodchips should be minimised as much as possible, since too long transport has negative impacts on GHG balances and economies of the value chain. The maximum recommended distances and the suitable type of transport for woodchips depends on the local circumstances, but can be summarised as listed below:

- **0-40 km**: own tractors
- **30-90 km**: heavy duty trucks with capacities of 70-95 m²
- **>70 km**: trains

It is furthermore important to consider the access of the plantations to roads already in the planning phase, as heavy machinery and heavy loads are used. Maximum allowed weights for roads and especially for bridges need to be respected.

The weight of woodchips per volume depends on the water content, species, size and shape of the woodchips as well as on the bark/wood ratio. One ton of absolute dry woodchips has the volume of about 6.5 to 7 cubic metre woodchips. Table 12 shows the weight of several SRC species and other species per cubic metre woodchips and in relation to the water content.

Table 12: Weight of woodchips per bulk m³ woodchips of SRC species and other species (average/typical values; real values depend on several factors!)

Water content [%]	0	15	20	30	50
			Mass [kg]		
Poplar (SRC) (density 353 kg dry matter/solid m³)	164	145-174***	181**	203** 167-200***	284**
Willow (SRC) (density 420 kg dry matter/solid m³)	168*	181-217***	181**	208-250***	n.a.
Alder (SRC) (density 530 kg dry matter/solid m³)	n.a.	177-212***	n.a.	204-245***	n.a.
Robinia (SRC) (density 750 kg dry matter/solid m³)	n.a.	264-317***	n.a.	304-365***	n.a.
Spruce (non SRC) (density 379 kg dry matter/solid m³)	151	178	189	216	302
Beech (non SRC) density 558 kg dry matter/solid m³)	222	261	278	317	444

*(Source: CARMEN 2014, * SLL n.d., ** Biomasseverband OÖ n.d., *** ETA Heiztechnik GmbH n.d. (first value for G50, second value for G30), other sources)*

The plantations should have areas at the beginning and at the end of each plantation which is not cultivated by SRC, but e.g. by nice flowering herbaceous plants which increase the environmental value. These areas are also called **headers of the plantation**. They serve as space to maneuver the harvesting and maintenance machinery. Harvested material can be stored on these headers of the plantations. However, the harvested material is sometimes also directly brought to the place where it will be later used.

7 Removal of SRC

Various reasons can be behind the decision to terminate and remove an SRC plantation after several years of growing. A farmer may decide to convert the land back to grassland or arable land, or to replant SRC whereas he replaces the old SRC plantation with newer varieties. The termination of an SRC plantation is considered by many farmers that have not grown SRC before, as a major obstacle to cultivate SRC. The opportunity to get the land fast back to the original status should remain open. There has been some reservation from potential SRC farmers towards this issue, but awareness raising and knowledge transfer helps to overcome this challenge. Removing a SRC plantation is technically not complicated, as the roots in a plantation are relatively shallow despite being established for many years.

There are several methods and steps that should be taken into account for removing and terminating an SRC plantation. The method has to be chosen according to the desired use of the land after removing the SRC. For the conversion to grassland simple moulding and adjacent seeding the grass may be sufficient. In some cases, this may be also sufficient for the recultivation into ploughed land. The capacity of the moulder machinery (cultivator) (Figure 54, Figure 55) to cut the wood into small pieces influences the decision if further treatment is necessary.

A more rigourous method is the combination of mechanical and chemical applications. When the last harvest is made, the stools should remain at place and form new shoots during the spring. When shoots grow up to 30-40 cm long, an application of an herbicide may be conducted to the entire plantation. Due to the susceptability of willows or poplars to herbicides, the active growin parts will die. The crop should be left for at least two weeks after spraying to allow full absorption and translocation of the herbicide. When the shoots have died back, the stools themselves can be mulched by using a heavy-duty cultivator into the top 5-10 cm of soil. After the stumps have been completely killed, the soil may be prepared with a heavy large diameter disc along the rows which cuts up the stools and residual roots without raking them up to the ground surface.

Once the stools have been broken down, the land can either be replanted with new SRC willow or converted back to produce other agricultural crops, without having to remove the stools which do not affect the next crops.

Figure 54: Cultivator for moulding the remaining SRC stumps in Austria (Source: Mergner R.)

Figure 55: Recultivated soil in Austria (Source: Mergner R.)

8 Use of SRC products

Already in the planning stage and during the set-up of the plantation, the harvesting cycle is defined, as different harvesting cycles require different spacing between the trees. In case that the spacing is dense and the harvesting cycles are between 2 and 8 years, the harvested material will usually always be chipped into woodchips which can be used for different purposes. If the harvesting cycles are longer, it may be considered to harvest the stems as logwood (industrial wood) instead of chipping which may generate more revenues. Logwood can be used for different purposes, depending on its quality. This mainly applies to poplar or eucalyptus, as e.g. SRC willows do not produce stems that are thick enough for logwood in a typical SRC cycle. The cultivation and use of logwood is not further considered in this handbook as the focus is on the energetic use of woodchips.

8.1 Quality of woodchips

Different applications for the use of woodchips require different qualities of the woodchips (Figure 56, Figure 57). The key quality parameters for specifying woodchips are:

- **Moisture/water content**: the lower the water content, the higher is the heating value.
- **Homogeneity and size of the woodchips**: The dimensions should be suitable for the appliance and its fuel handling system.
- **Content of fine particles**: fine particles (dust) are a health risk.
- **Shape of the woodchips**: the cuts of the woodchips should be sharp and fringing minimised in order to increase bulk density and ensure smooth feeding of the system.
- **Origin**: sustainability of the cultivation and management system; the closer the origin of the woodchip to the end user, the lower are the transport distances and the lower is the CO_2 emissions for transport.
- **Ash content**: the lower the ash content, the higher is the energy output and the lower is the ash quantity which has to be discharged.
- **Contaminants**: woodchips should contain no impurities (soil, stones).
- **Composition**: the higher the wood content and the lower the bark, leaves and small branches content, the higher is the fuel quality.

A main criterion for the quality of woodchips is the water content which was described already in chapters 5.3. and 5.5. For SRC woodchips, the water content is mainly influenced by the harvesting practices, logistics, and drying procedures.

The homogeneity and size of the woodchips, the content of fine particles, and the shape of the woodchips is mainly determined by the harvesting equipment and technologies. Also the occurrence of contaminants is influenced by the harvesting technologies, but in addition by the type of storage. If woodchips are stored on the field the risk of increased fractions of contaminants is higher. The composition and the ash content is mainly determined by the cultivation style and plant species. In general, woodchips from SRC have higher ash contents, as the share of bark and little branches in relation to heart wood is much higher, since the stems or routes have relatively small diameters.

Figure 56: High quality (left) and low quality (middle, right) (non-SRC) woodchips in Germany (Source: Rutz D.)

In order to determine the quality of woodchips standards are used. The European Committee for Standardisation (CEN) developed such standards for the properties of woodchips, briquettes, firewood, and pellets, but also for test methods, conversion rules and quality assurance. These standards were amended in 2014 and developed further as international ISO (the International Organization for Standardization) standards. The following standards apply to woody biofuels:

- ISO 17225-1:2014-09 (former EN 14961-1:2010) Fuel specifications and classes – Part 1: General requirements
- ISO 17225-2:2014-09 (former EN 14961-2:2011) Fuel specifications and classes – Part 2: Graded wood pellets
- ISO 17225-3:2014-09 (former EN 14961-3:2011) Fuel specifications and classes – Part 3: Graded wood briquettes
- ISO 17225-4:2014-09 (former EN 14961-4:2011) Fuel specifications and classes – Part 4: Graded woodchips
- ISO 17225-5:2014-09 (former EN 14961-5:2011) Fuel specifications and classes – Part 5: Graded firewood

Figure 57: Fresh woodchips from willow SRC in Sweden (Source: Rutz D.)

The objective of the ISO 17225 series is to provide unambiguous and clear classification principles for solid biofuels; to serve as a tool to enable efficient trading of biofuels; to enable good understanding between seller and buyer as well as a tool for communication with equipment manufacturers. It also facilitates authority permission procedures and reporting (ISO 2014).

An example for a woodchip declaration is given by Alakangas (2009) in Table 13, specifying, according to EN 14961-1, the normative parameters dimensions (P), moisture on wet basis

(M), and ash (A), as well as the informative parameters bulk density (BD), calorific value (Q), sulphur (S), nitrogen (N), and chlorine (Cl).

Table 13: Example of product declaration for woodchips (Source: Alakangas 2009, modified)

EN 14961-1		
General details	Producer	EAA Biofuels
	Location	Jyväskylä, Finland
	Origin	1.1.1.1 and 1.1.1.2 (Whole tree)
	Traded form	Woodchips
	Quantity (t)	4.00
Normative	Dimensions	P45A
	Moisture, w-%	M35
	Ash, w-% dry	A1.5
Informative	Bulk density, kg/m^3	BD250
	Net calorific value as received, MJ/kg	Q11.5
	Sulphur, w-% dry basis	0.05
	Nitrogen, w-% dry basis	N0.3
	Chlorine, w-% dry basis	Cl0.03

As mentioned, the ISO standard is needed if woodchips are traded in order to inform the purchaser about the quality issues. This influences the price of the charge.

However, the details of this standard may be also interesting for the plantation owner who directly consumes the woodchips himself, as it gives indications on how to improve the quality of the woodchips.

8.2 Options for the use of woodchips

The following list shows options for the utilisation of woodchips:

- For small-scale combustion and heating systems (farm size or for few households)
- For **larger combustion and heating systems** (for micro district heating networks for several connected households
- For dedicated **combined heat and power plants** (CHP) for woodchips (ORC cycles, steam turbines)
- For woodchip **gasification** for power generation.
- For **co-firing** of woodchips in large (fossil fuel based) power plants
- As feedstock material for **biorefinery processes** (e.g. pyrolysis, gasification, torrefaction, biochemical conversion ethanol, bioplastics)
- For further processing into **pellets** for different purposes
- For **niche applications**: As mulch in the gardening and landscape maintenance business, as bedding material for animal breeding, as substrate for mushroom production, as structure material for biofilters or as playground surfacing material

The main application for woodchips today in Europe is for heating purposes, for CHP and for co-firing. Therefore, chapter 8.3 provides details on the combustion of woodchips and pellets.

In the future, the demand of woodchips for biorefinery processes may increase. SRC plantations are already established for the production of so-called second generation liquid biofuels. Biomass-to-liquid (BtL) fuels are under development. They convert lignocellulosic biomass, such as woodchips from SRC, by thermo-chemical conversion into synthetic biofuels. A bit more advanced is the biochemical conversion technology, where lignocellulosic material is converted biologically into sugars and then fermented into ethanol (Figure 58). Ethanol is a substitute for petrol. Several European and international pilot and demonstration plants are increasingly investigating the use of woodchips for this process, as the focus so far was mainly on using herbaceous biomass (such as straw, grasses, etc.). In integrated biorefinery concepts, also other products, such as lignin, power, heat, bioplastics, bio-chemical can be produced. This creates a future market for SRC woodchips.

On smaller scale, woodchips can be also converted by thermochemical conversion into pyrolysis oil which could substitute e.g. heating oil or could be further processed. Already frequently applied today, as it is even suitable also for single farmers, is the gasification of woodchips and subsequent use of the produced gas in an engine for power generation (Figure 59).

At its initial phase, pellets were purely produced from saw dust from saw mills, which was considered as waste product (Figure 60). Today, pellets are also produced from dedicated wood (woodchips) such as from SRC plantations. In order to keep the quality standard and as SRC woodchips have rather more bark compared to woodchips from forestry, it may be recommended to use woodchips only from SRC plantations with longer cutting cycles, as this decreases the bark/wood ratio.

Besides the energetic use of woodchips, they can be also used for niche applications, but this depends on the local demand. Woodchips could be used as mulch in the gardening and landscape maintenance business, as bedding material for animal breeding (e.g. for horses), as substrate for mushroom production, as structure material for biofilters (e.g. in waste-biogas plants) or as playground surfacing material. Due to its limited application, no further details are described here.

Figure 58: Second generation ethanol plant of ABENGOA in Spain (Source: Rutz D.)

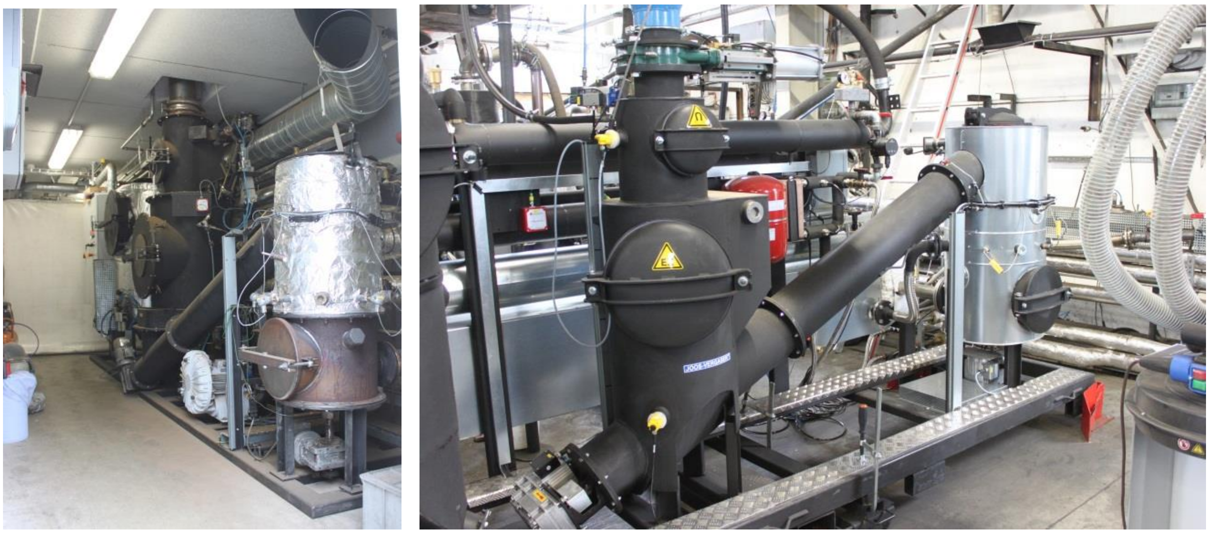

Figure 59: Small-scale gasifyers in a container (left) and during manufacturing (right) of the company „SpannerRE²“ (Source: Rutz D.)

Figure 60: Pellet press (left) and high-quality pellets (right) (Source: Rutz D.)

8.3 Combustion of woodchips and pellets

The main application of woodchips and pellets their combustion for heat generation as sustainable energy practice (see Box 6). Therefore, the following descriptions provide basic information on the combustion process. More detailed information is available e.g. from Hiegl et al. (2011) or Rutz et al. (2006).

Plant based biomass is essentially composed of carbon (C), hydrogen (H) and oxygen (O). The proportion of carbon determines the energy released during combustion (oxidation). Also the hydrogen contained in solid biomass delivers energy when combusted. Together with the carbon it determines the heating value of the dry fuel. The oxygen only supports the combustion process, but has no influence on the energetic content of the fuel.

Wood fuels have a high carbon content of 47 to 50%. The oxygen content of wood fuels lies between 40 and 45% and the hydrogen content between 5 and 7%. Alongside these three elements, they consist of other elements as well. These can, despite their small proportions, have strong effects on the exhaust emissions. Sulphur, chlorine, and nitrogen are among the elements that have the greatest effect on the polluting exhaust emissions. Fuels can, in part, be differentiated depending on the considerable emission-relevant components.

The energy content per mass is expressed in the lower and higher heating values (see Box 7) as it is shown in Table 14. For woodchips, often the energy content per volume – per cubic metre - is used. An example therefore is shown in Table 15. Depending on the type of wood, size of the woodchips, and moisture, a cubic metre of woodchips is about 200 – 300 kg.

Typically, woodchip boilers (Figure 61, Figure 62) are used for heating systems starting from about 20 kW, whereas pellet boilers are also used for smaller heating systems. Heating with woodchips is usually only economical for larger households, farms, or several households, or even smaller villages. Pellet heating is usually only done at single or multiple household level.

The technology for woodchip and pellet heating is mature and provided by many manufacturers. It consists of a storage bunker, feeding system, biomass boiler, exhaust system, and a heat distribution system (often including a buffer tank).

The investment for a woodchip or pellet boiler is often higher than for a fossil fuel boiler, but, usually the fuel costs are much cheaper, so that in the long-term woodchip or pellet boilers are more economical than fossil fuel boilers.

Box 6: Why is biomass renewable?

The main greenhouse gas of the combustion processes is **carbon dioxide** (CO_2), which is mainly responsible for the increase in global temperature. Carbon dioxide is emitted during combustion of fossil fuels (e.g. lignite, hard coal, oil, natural gas), but also of biomass. The difference, however, is that biomass extracts **CO_2** from the atmosphere during its growth (photosynthesis). Also for short rotation plantation, the trees remove CO_2 from the atmosphere for a period of e.g. 4-6 years of growth, after they are e.g. combusted in a woodchip boiler. Due to this short and closed cycle, biomass from SRC is renewable and helps to protect our climate.

Yet, biomass energy sources are not entirely '**CO_2-neutral**', as fossil energy sources are still used for the preparation and utilisation of biomass (e.g. for harvest and transport). Furthermore, for new SRC plantations, the impact of the land use change has to be considered, which may have positive or negative effects on the release or accumulation of carbon in the soil. In comparison to annual crops, the accumulation of soil carbon in SRC plantations is usually higher and thus, has an additional positive effect on climate change mitigation.

Box 7: What is the difference between the lower and the higher heating value?

Important information on fuel properties are provided by the heating values.

The **lower heating value** (LHV) (net calorific value (NCV), lower calorific value (LCV)) indicates the quantity of heat that is released with the complete combustion (oxidation) of biomass. This value does not consider the condensation heat (heat of evaporation) of water vapour contained in the exhaust gas. Thus, the lower heating value decreases with increasing water content of the biomass.

The quantity known as **higher heating value** (HHV) (calorific value, gross energy heating value, upper heating value (H_o), gross calorific value (GCV), higher calorific value (HCV)) is determined by bringing all the products of combustion back to the original pre-combustion temperature, and in particular condensing any vapour produced. For biomass the HHV lies at an average of about 6 % (bark), 7 % (wood) or 7.5 % (agricultural produce) above the LHV (Table 14). However, this is only valid for solid fuels in an absolutely dry and water free condition (wf). For moist biomass this discrepancy increases. Table 15 shows values for the typical SRC crops willow and poplar in comparison to other fuels.

Table 14: Combustion characteristics of solid fuels (Hiegl et al. 2011) (average/typical values; real values depend on several factors!)

Fuel type	LHV [MJ/kg]	HHV [MJ/kg]	Ash content [%]	Ash softening point [°C]
Poplar wood	18.5	19.8	1.8	1,335
Willow wood	18.4	19.7	2.0	1,283
Beech wood	18.4	19.7	0.5	No entry
Spruce wood	18.8	20.2	0.6	1,426
Bark (coniferous)	19.2	20.4	3.8	1,440
Wheat straw	17.2	18.5	5.7	998
Wheat grain	17.0	18.4	2.7	687
Hard coal	29.7	No entry	8.3	1,250
Lignite	20.6	No entry	5.1	1,050

Figure 61: Small woodchip heating system (24-50 kW heat capacity) with the boiler (left), the feeding system (middle) and the woodchip storage (right) of Fröling (Source: Rutz D.)

Table 15: Overview on the energy content of SRC and other woodchips in relation to the water content (average/typical values; real values depend on several factors!)

Water content [%]		0	15	20	30	50
	Unit	**Heating value [kWh]**				
Poplar (density 353 kg dry matter/solid m³)	kg	5.00	4.15	3.86	3.30	2.16
	Solid m³	1765	1723	1705	1662	1525
	Bulk m³	706	689	681	666	610
Willow (density 420 kg dry matter/solid m³)	kg	4.54*	3.76**	n.a.	2.97**	n.a.
	Solid m³	n.a.	n.a.	n.a.	n.a.	n.a.
	Bulk m³	n.a.	680-810**	n.a.	620-740**	n.a.
Alder (density 530 kg dry matter/solid m³)	kg	n.a.	4.06**	n.a.	3.23**	n.a.
	Solid m³	n.a.	n.a.	n.a.	n.a.	n.a.
	Bulk m³	n.a.	720-860**	n.a.	660-790**	n.a.
Robinia (density 750 kg dry matter/solid m³)	kg	n.a.	4.11**	n.a.	3.27**	n.a.
	Solid m³	n.a.	n.a.	n.a.	n.a.	n.a.
	Bulk m³	n.a.	1,090-1,300**	n.a.	990-1,190**	n.a.
Spruce (density 379 kg dry matter/solid m³)	kg	5.20	4.32	4.02	3.44	2.26
	Solid m³	1970	1930	1900	1860	1710
	Bulk m³	788	770	762	745	685
Beech (density 558 kg dry matter/solid m³)	kg	5.00	4.15	3.86	3.30	2.16
	Solid m³	2790	2720	2700	2630	2410
	Bulk m³	1116	1090	1077	1052	964

*Source: CARMEN 2014, *Verscheure 1998, ** ETA Heiztechnik GmbH n.d. (first value of bulk m³ is related to G50, second to G30, other sources)*

Figure 62: Medium sized woodchip heating system (3,000 kW heat capacity) with the boiler (right) and the buffer tank (left) of the Biomassehof Achental in Germany (Source: Rutz D.)

For larger combustion facilities, the Organic Rankine Cycle (ORC) can be used for electricity generation. ORC is a thermodynamic process which powers a generator for electricity generation. In comparison to other CHP systems, such as gasification (Figure 63), the ORC process is usually applied at much larger scale.

At even larger scale, woodchips or industrial pellets are also co-fired in large, often coal- or lignite-fired, power plants. They usually generate electricity through a steam turbine. Ideally, these power plants also use the heat to supply a district heating network. Co-firing of woodchips is predominantly done in Europe in The Netherlands, Great Britain, or Belgium.

Figure 63: ORC system (1,520 kWel) of the Grünfuttertrocknungsgenossenschaft Kirchdorf a.H. eG in Germany (Source: Rutz D.)

9 SRC and its environmental impacts

In general, due to its low-input requirements in comparison to annual crops, SRC has many positive environmantal impacts. The risk of negative environemental impacts is generally very low. Some impacts on the environment were already described in chapter 2.5 and in the subsequent chapters. In the following chapters, some specific impacts are addressed in more detail, as described in the SRCplus report on “Sustainability criteria and recommendations for short rotation woody crops” (Dimitriou & Rutz 2014).

9.1 Phytodiversity

Phytodiversity is the diversity and multitude of plants and its plant communities. For phytodiversity, a series of experiments were conducted in SRC fields mostly in Sweden and Germany, but also in other countries, identifying, quantifying and evaluating the differences between SRC and alternative land uses such as cereal and grass production in agricultural land, but also differences between SRC and forest (Dimitriou et al., 2012a). An overview of the findings is presented below:

- SRC plantations can increase phytodiversity of agricultural landscapes: as an additional structural landscape element.
- SRCs provides habitats for species compositions different from those of the surrounding land uses and can thus increase plant species diversity, especially in areas dominated by arable lands and coniferous forests.

- The species composition of the SRCs is a mixture of species from grassland, ruderal (species first to colonize disturbed sites) vegetation and species from woodland, whereas arable lands contain predominantly ruderal and arable field species.
- SRCs have been quantified to be up to three-times richer in plant species than arable lands, and in some cases have been proved to be richer than coniferous forests and mixed-forests

Figure 64: Vegetation in a 3 years old poplar plantation in spring in Germany (Source: Rutz D.)

Figure 65: Vegetation and foliage in a poplar SRC in autum in Germany (Source: Rutz D.)

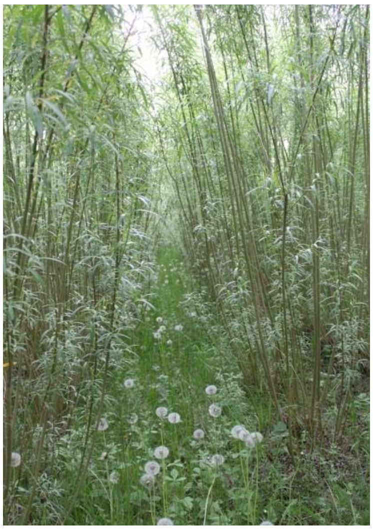

Figure 66: Vegetation in a willow SRC plantation in spring in Sweden (Source: Rutz D.)

Figure 67: A willow field planted with two different clones might cause increased number of other plant species in the plantation (Source: Weih M.)

- The contribution of SRCs to species diversity of an agricultural landscape changes over time. With decreasing irradiance for the ground vegetation the percentage of forest species increases. Thus, planted tree species, plant density, and plantation and rotation age influence species composition.

- Willow plantations are more suitable for supporting forest species than poplar plantations due to higher irradiance and irradiance variation in poplar SRC.

The impact of a new SRC plantation depends always on various factors and need to be considered by the plantation owner. Simple and cost efficient measures to increase phytodiversity can be easily implemented. They can include the plantation of different clones and species within the plantation, seeding of flowering plants on the headers of the plantation, planting indigenous shrubs on the boarders and between the plantation, leaving some open gaps in the plantation where spontaneous plants can germinate, etc.

The following recommendations can be given in order to prevent negative impacts and to increase positive impacts on **phytodiversity** (Dimitriou et al., 2012a).:

- The establishment of SRCs in areas with high ecological status should be avoided (e.g. areas with protection status for nature conservation, areas with rare species, wetlands, peat bogs, swamps).
- High structural heterogeneity provides habitats for different plant requirements and thus increases diversity. High structural diversity at one SRC location can be achieved by (1) planting different tree species and clones and by (2) harvesting the plantation at different times so that the trees have different rotation ages within one area.
- Edges of SRCs have great species diversity, and planting several smaller plantations instead of one big SRC is advised as smaller plantations have longer edges for their size than larger ones. If that is not possible, planting long rectangular plantations can provide more benefits considering increased phytodiversity.
- An increase in forest ground species can be achieved by reducing the irradiance reaching the ground vegetation. This can be done by long rotation periods, high plant densities and planting willow instead of poplar. Another possibility is aligning planting rows in the east-west direction to reduce radiation reaching ground vegetation by shading the planted crop.
- The plantations edges needed to enable easier harvesting should be as wide as possible to allow e.g. indigenous flowering plants that attract insects. The mowing cycle of the headers should be adjusted in order to maximize environmental benefits.
- Species composition in SRCs is influenced by irradiance (see above) and soil properties. High humus quality and plant nutrient availability supports nitrogen indicator species. Increasing soil acidity benefits indicator species for acidic soil reaction.
- The species coverage proportions in SRCs are more heterogeneous and higher than in arable lands.
- The more diverse the surrounding, the lower is the species proportion of the SRC plantations on species number in the landscape (gamma-diversity, e.g. the total species diversity in a landscape).
- The higher the number of habitat types the higher the gamma-diversity and the lower the species proportion of SRC plantations on gamma-diversity.
- Species composition of the soil seed bank had low influence on the actual SRC vegetation and this influence decreased with increasing useful life as SRC plantations.

Figure 68: The edge of a willow SRC field neighboring a winter wheat field; increased phytodiversity is evident (Source: Nordh N-E.)

9.2 Zoodiversity

Zoodiversity is the diversity or multitute of animals and its animal communities. For zoodiversity, similar information as the phytodiversity has been collected and analyzed.

SRC with willow in Sweden is a well-known means to attract **game** such as raw deer and plenty of plantations in Sweden have been established for hunting. Moreover, wild pigs have been reported to find habitat in agriculture landscapes, which is indicative of increases of mammals. Deer, hare and rabbit can cause problems to SRC plantations, and sometimes the increase of their numbers can be negative and can cause the loss of the plantation. However, hare numbers could decline further if planting of SRC were to become widespread, since this species favours mixed farmland and is unlikely to thrive in densely planted coppice stands.

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Figure 69: A rabbit in a willow SRC plantation. In some areas, different mammals can cause extensive damage to SRC, buit fencing is not required since it adds high costs to the management operations. (Source: Dimitriou I.)

Figure 70: Roe-deer entering a willow SRC plantation. SRC plantations are well-known for attracting mammals present in the area, since they offer refuge and food. (Source: Nordh N-E.)

There have been several discussions on the increase of **birds** into landscapes introduced with SRC plantations. A detailed list of the most important findings for related research is listed below (Dimitriou et al., 2012a).

- SRCs are in general richer in avian species diversity and abundance compared to other arable land but contain hardly any specialized breeding bird species.
- Regularly breeding birds on SRCs are mainly common and hence not endangered.
- Endangered breeding bird species occur on a small scale and they are predominantly limited to young SRCs or to the margins of SRC plantations.
- The habitat suitability of SRCs for breeding birds is in general strongly dependent on the age and structure of the planted willows/poplars, and different bird species are associated with different age classes of SRC.
- As the plantation ages and growth height increases, the breeding bird composition shifts from open land species to shrub-nesting birds and then to species originally inhabiting forest habitats.
- The highest species richness and abundance was found in 2-5 year old coppice stocks.
- The avian diversity and abundance is also linked with planting density of coppice stems and with increased number of weeds.
- The different numbers of breeding bird species are due to many further factors, such as variety of areal sizes, intensities of management, landscape context and regional species pool. The landscape context is also crucial for the impact of SRCs on the breeding bird diversity of agricultural areas.
- The overall effect on the zoodiversity will depend to a large extent on which land the SRCs are replacing and how the surrounding landscape is.

If a substantial amount of a homogenous and intensively managed landscape (e.g. 20%) will be introduced with SRC, then there would be more (Dimitriou et al., 2012a):

- breeding bird species, because the SRCs provide new habitat structures.
- breeding bird species associated with forests, if some areas of SRCs would grow into the tree-like-stadium (height of poplars/willows > about. 8 m).
- scrub breeding bird species, if some SRC areas are in a shrub-like stadium with large increase in vegetation height and density (height of poplars/willows > about. 1 m).
- no qualitative difference to cropland for birds requiring open-field habitats for nesting and foraging.
- breeding bird species which need ecotones and benefit from edge effects (trees or shrubs to open land), increasing with small and oblong SRCs.
- more breeding bird species which profit from small areas of unmanaged grassland, not mowed areas with high grasses and herbs at the border of a SRC.
- slightly more endangered species, because of some SRC-associated structures (e. g. tall herb vegetation, ecotones) or rather a higher amount of structural richness.

Another positive impact of SRC is the diversity of **invertebrates**, such as earthworms, web-spinning spiders, beetles and butterflies that have been found in SRCs, both in the above-ground biomass and in the soil. An increase of earthworms in established SRC plantations for a number of years is recorded (compared to arable fields). However, despite the increased number of individuals in SRCs, intensively managed SRC are unlikely to provide botanically rich sites and consequently are unlikely to be of great value as habitats for endangered ground dwelling invertebrates. The occurance of invertebrates is supported by the general low-input (pesticides) of SRC cultivation practices.

Figure 71: An observation tower placed at the edge and an opening of a willow field for birds but also for game. Severel bird species are attracted mostly by the edges of an SRC plantation. (Source: Dimitriou I.)

Figure 72: Pollination is an important ecosystem service provided by willow flowers. (Source: Nordh N-E., (left) Rutz D. (right))

As s special ecosystem service, **honey bee** keeping should be mentioned, as SRC provides the following benefits for honey bees as well as for wild bees (solitary and communal bees):

- As a low-input crop in comparison to annual crops, bees, which are sensitive to agrochemicals, benefit from less pesticide inputs.
- Especially willows provide the early-spring pollen for bees which is important for the bees after the winter break of bee activity.
- Resins from poplar and alder buds are an important source of propolis. Propolis is a resinous mixture that honey bees collect from tree buds, sap flows, or other botanical sources. It is used by the bees as antiseptic material to keep the hygiene in the hive as well as a sealant for unwanted open spaces in the hive.
- Accompanying vegetation on the ground level of the plantations provide important sources of nectar.
- The robinia flowers produce large quantities of nectar, thus providing a valuable source of feed for bees.
- Most SRC plantations require areas (called headers) for the harvest machinery which are not planted with SRC, but could be planted with indigenous wild flowers that would provide feed for the bees.

Figure 73: Wide edges between willow SRC fields that enable other plant species to grow, but also creating a corridor for wild life (Source: Nordh N-E.)

The following recommendations to prevent negative impacts and to increase positive impacts on zoodiversity can be given when planning the establishment of SRC in a certain area (Dimitriou et al., 2012a):

- Where possible, SRCs should be designed with a large edge to interior ratio

- A mix of varieties and clones should be used.
- Rotational harvesting in mixed age-class blocks should be preferred.
- Large blocks of SRC should be separated, e.g. by rides and hedges.
- Where possible, and in case of growing willow, planting of willow hybrids (*Salix* sp.) with a range of different flowering times should be preferred.
- The use of pesticides should be generally avoided. Biological measures may help to mitigate the risks of pests.
- A percentage of the SRC area should be reserved for small habitats like strips of grass and stepped wood boundaries.
- New SRC plantations should not be established in high wildlife-value habitats like wetlands, wet meadows, set asides, dry fallows, semi-natural grassland.

9.3 Soil

The positive effects on soil quality, when SRC is cultivated instead of agricultural crops, have been mentioned as one of the great advantages of SRC when implemented in agricultural landscapes. A detailed list quantifying the advantages of SRC is presented below, when looking at cases when SRC plantations have been established for several years in an agricultural landscape (e.g. over 15 years) (Dimitriou et al., 2012b).

- Carbon (C) storage in soil organic matter is higher under SRC than under conventional agricultural crops such as cereals or intensively managed grassland.
- Soil organic matter stability is higher under SRC than under conventional agricultural crops and supports C sequestration in the soil.
- Soil erosion is lower under SRC than under conventional agricultural crops.
- Total soil N content is higher and the proportional nitrogen (N) availability for plant growth is lower caused by an increased C/N ratio of soil organic matter under SRC than under conventional agricultural crops.
- Phosphorus (P) availability to the plants is lower under SRC than under conventional agricultural crops.
- The bulk density is slightly higher under SRC than under conventional agricultural crops.
- The soil pH can be slightly lower under SRC than under conventional agricultural crops.
- The microbial activity is slightly lower than the new biomass (leaves, roots) is created. This contributes to the accumulation of organic matter compared to the soil under conventional agricultural.
- Cadmium (Cd) concentrations in the soil under SRC are lower than under conventional agricultural crops.

Figure 74: Stem of a 3-years old poplar Max3 clone in March in Germany: leaves of the previous season still cover the soil (Source: Rutz D.)

Additionally, and in general, soil compaction can be lower in SRC than other crops since harvest occurs much more often in the latter. Furthermore, soil compaction can be avoided if harvest occurs when soil is frozen in winter, when also the demands for wood for energy are highest. Also, an increased number of mycorrhiza (usually between the between the fungus and the plant roots – ectomycorrhiza) under poplar, willow, birch and eucalyptus SRC, compared to neighbouring arable soils, which is beneficial for nutrient cycling.

Finally, SRCs can be used for phytoremediation of contaminated land. Phytoremediation is the treatment of contaminated land (e.g. with heavy metals, pesticides, solvents) through the use of plants without the need to excavate the contaminant material and dispose of it elsewhere. Especially some willow species have the capacity to absorb heavy metals.

Figure 75: Willow SRC fields (in the background) next to tilled arable fields (photo taken in autumn). The soils are not disturbed as for other arable crops when SRC is planted, and soil carbon is higher in SRC than in other conventional agricultural crops. (Source: Nordh N-E.)

The following recommendations can be given when planning and designing an SRC plantation in order to prevent negative impacts and to increase positive impacts on soil:

- SRC could be cultivated in fields with low initial soil organic matter content to increase this content and with this the fertility and C storage of the soil.
- SRC should be cultivated especially in areas with a high risk of erosion (wind or soil), e.g. with relief, to lower the loss of fertile topsoil and nutrients by water and wind.
- Application of municipal residues such as sewage sludge for recycling of nutrients to SRC can be encouraged, since SRC can contribute to prevent nutrient losses and can extract heavy metals efficiently.
- SRC should be used to remediate soils with increased Cd concentrations caused e.g. by the long-term use of Cd-containing P-fertilizers or other sources of environmental pollution.
- SRC fields should be established at the same location for at least three cutting cycles to achieve soil quality improvements concerning C storage and Cd uptake.
- SRC should be harvested in winter in cold-climate countries when soil is frozen to avoid soil compaction.

9.4 Water

When investigating the impact of SRC on water, research has been focused on quality issues such as nutrient leaching to groundwater. Thereby, the expected impact is usually positive. However, also the impact on the water that is percolating to the groundwater, on the groundwater level itself and on the nearby water bodies has to be considered. Here, the expected impact is usually negative, especially in areas where water is scarce in summer. Detailed conclusions from experiments conducted in SRC plantations comparing SRC with other agricultural uses in terms of water quality and quantity are presented below (Dimitriou et al. (2012c):

- Leaching of NO_3-N to the groundwater is substantially lower from SRC than that from traditional agricultural crops.
- Leaching of PO_4-P to the groundwater is almost equal or in some cases slightly higher from SRC than from agricultural crops.
- The slightly increased leaching of PO_4-P to the groundwater was not correlated to sewage sludge applications to SRC.
- SRC as shelterbelts are shown to reduce diffuse pesticide pollution.
- Substantially less groundwater is drained from a willow stand compared to grassland, but translating this effect on a catchment area with 20% SRC, the negative impact on the water table is moderate.
- Harvesting of a willow SRC stand leads to a higher groundwater recharge in the first year of regrowth, because less water is lost through transpiration and interception.

The following recommendations when selecting the location and planning the layout of SRC plantations can be given to prevent negative and to increase positive impacts on water:

- SRC could be cultivated in fields located close to N sources (e.g. animal farms, N vulnerable zones, wastewater treatment plants etc.) to decrease N outflow to adjacent water bodies.
- SRC should be cultivated in areas where low groundwater level is anticipated (potentially flooded areas and areas near water bodies which can potentially flood).
- Application of solid municipal residues such as sewage sludge for recycling of nutrients does not affect water quality, and should therefore be encouraged.
- More frequent harvests lead to a higher average groundwater recharge, and therefore should be encouraged to ameliorate possible negative impact of groundwater recharge reductions.

9.5 Use of ash and sewage sludge as fertilizer

SRC is a non-food, non-fodder crop grown on agricultural soils. Therefore, it could be an acceptable solution for treating sewage sludge from wastewater treatment plants applied to farmland, since the risk of direct contamination of the food chain is minimal. This method is in line with political decisions in Europe encouraging recycling of phosphorus (which is a finite source) and of nitrogen in agriculture. Moreover, it contributes to increase the carbon in agricultural soils. However, sewage sludge may contain, besides nutrients, also heavy metals. Thus, the level of heavy metals in soil after sludge applications must be controlled. Moreover, their fluxes into the soil-plant system should be regulated, to avoid contributing to a metal accumulation that might affect the heavy-metal content of a subsequent food crop. There are regulations in all European countries concerning the total amount of sludge applied and the permitted concentrations of heavy metal in soils after sludge application. These regulations vary from country to country and therefore, consultation with the local environmental protection agencies is required for such applications.

Sewage sludge is not a balanced fertilizer in terms of plant nutrients, since it contains some nitrogen (mainly organically bound) and high amounts of phosphorus, but very little potassium. Therefore, mixtures of sludge and wood-ash can be applied to SRC plantations when wood-ash is available (Dimitriou et al., 2006). Wood-ash contains high amounts of potassium and very little phosphorus, but no nitrogen. This more balanced fertilizer replaces conventional inorganic fertilization in SRC, although in some cases additional nitrogen can be used to fulfil the fertilisation requirements for nitrogen. The accumulation of hazardous heavy metals and phosphorus in sludge-ash mixtures should be minimized by plant uptake.

At harvest, shoot parts that contain heavy metals are removed from the system and burned. Ash from the combustion includes bottom ash with low heavy metal concentrations and fly ash with high concentrations. Only bottom-ash is applied to the SRC plantation, again. Fly ashes with the heavy metal concentrations are dumped safely in landfill sites and thus, removed from the cycle.

The sludge-ash mixtures are applied to SRC during the establishment phase and after every harvest – in other words, every three to five years – in order to compensate for the removal of nutrients by harvesting. In practice, the amounts of the mixtures applied are adjusted to the maximum phosphorus amounts allowed (they are usually restrictive, e.g. for Sweden are equivalent to about 22 to 35 kg of phosphorus per hectare per year).

Figure 76: Spreading of sewage sludge (here in mixture with wood-ash) is a common practice in Sweden. (Source: Dimitriou I.)

Cadmium is considered as one of the most hazardous metals for human health. Primarily willow is able to take up high amounts of cadmium in their shoots. They are harvested every three to four years and several times due to a life-span of a SRC plantation (Dimitriou and Aronsson, 2005). When the biomass is burned, cadmium and other heavy metals will remain in the different ash fractions. This allows separating them from the ash that is used for fertilisation. As this environmental service is usually not paid, often the whole ash with all its nutrients is dumped on landfills.

9.6 Agroforestry systems

Agroforestry is a land use management system in which trees, in this case SRC species, are grown around or among crops or pastureland. It combines agricultural and forestry technologies to create more diverse, productive, profitable, healthy, and sustainable land-use systems.

Opportunities for agroforestry systems with SRC exist especially on very large fields with high risk of soil erosion. Studies have shown that the SRC plantation has a positive impact on the microclimate. Even the increased shadow in summer has a positive impact on the yields of wheat and rapeseed production next to the SRC field (Figure 72).

Furthermore, examples exist in which agroforestry with SRC includes breeding of animals, such as chicken. Especially in the tropics, agroforestry has been shown to imporve soil qualities and thus, food and nutrition security for small-scale farmers (Kaufmann et al. n.d.).

Figure 77: Agroforestry system on a 40 ha field in Dornburg, Germany: The poplar SRC bands act as wind break and influence positively the microclimate on this large field. Formerly, the 40 ha was just monocultures of annual crops. (Source: Rutz D.)

10 Economy of SRC

Calculations concerning the economy of SRC vary considerably and there have been many cases where SRC proved to be a good business for the farmer, but also cases where the economy of SRC has not been proved profitable as pre-calculated. This is due to the fact that the economy depends on several factors that are site-depended. Such factors concern both the expenses for SRC management, which can vary from country to country, or between areas in the same country, or even between farms in the same country (if e.g. there are already machines or not that can be used for SRC operations), but also the profit since the prices for selling the wood biomass can vary from place to place, and of course from country to country.

Especially the selling price of wood depends on the prices of the other energy sources in one country or area, and can also vary in time, depending on the period of the year. All these factors makes it difficult and risky to generalise when talking about the economy of SRC. Therefore, in this part of the Handbook a number of concrete examples with economic details of SRC practices in several parts of Europe with varying management are provided instead of general calculations (Dimitriou *et al*., 2014b). Thereby, comparisons are easier to be made and real facts can be compared. To enable a more holistic view, background information on the SRC practices, management, and other related information are given before the general economic calculations with expenses and profits are listed.

10.1 Example 1: Willow SRC in Grästorp, Sweden

This example presents the cultivation of willow SRC on agricultural land. The woodchips from willow, but also other wood sources, are used for bioenergy production in a local district heating plant. At the Puckgården farm (50 ha total size), 21 ha are grown with willow SRC for biomass production for energy. The rest is grown with oat, wheat, pea and rape seed. Puckgården is a member of a local willow-farmer association of 12 farmers that grow about. 100 ha of willow. They cooperate in all aspects of willow management: the association orders harvest from entrepreneurs (who are paid separately by each member based on labor time costs), and transports and sells the chips to the local district heating plant (DHP). The farmer is also chipping other biomass feedstock at Puckgården and sells it to the DHP. The DHP compensates the farmers in €/m^3 woodchips, which is advantageous to the farmers since fuel quality differences are not taken into consideration.

The different willow fields at Puckgården were established in 1991, 1992 and 1993, when the planting subsidy was 10,000 SEK (about. 1,110 Euros, 1 € = 9 SEK) and was covering all plantation costs at that time. The farmer has applied about 100 kg N per hectare the second year each time after harvest. The plantation also receives some wastewater from the local farms, but the nutrient amounts per hectare are low and it is more used for compensation of water during summer.

The willows are harvested every 4^{th} year in early spring (March) when frozen conditions in the soil are still present. The harvest is conducted with a Claas Jaguar direct chipping machine by a local entrepreneur. The biomass production has varied between 8 and 10.7 t DM/ha yr. The willow chips are stored in piles for about 1 month aside the fields, before transported and sold to the local DHP in Grästorp. The DHP has a capacity of 3.5 MW and is owned 40% by the municipality and 60% by Lantmännen (agricultural cooperative owned by the great majority of active farmers in Sweden). The DHP provides municipal buildings in the municipality of Grästorp (population about 5,641) and to private apartments in the area with heat. During a period of 6 months the DHP’s boiler is run only by willow chips (the rest of the year with other forest chips), but the chips need to be stored for a period of 1 month at Puckgården at the sides of the fields to become drier in order to be accepted in the DHP plant.

Below, calculations about production costs and income in €/ha/yr for price levels in 2011, are presented. Single farm payments are not included. Planting-related expenses (i.e. planting equipment, cuttings and labour costs) were about. 1,110 €/ha and are included in Table 15. Planting subsidy was 1,110 €/ha and is also included in Table 15.

Table 16: Production costs, income and profit in €/ha/yr for the willow field at Puckgården.

Costs (€/ha/yr)	
Fertilization	38
Supervision/maintenance	22
Harvest	139
Transportation	105
General expenses	55
Interest rate	11
Total	**370**
Income (€/ha/yr)	
Chips	864
Total	**864**
Profit (€/ha/yr)	494

* Calculations were made using the currency rate 1 € = 9 SEK and for a willow field of 4-years cutting cycle grown in the 5th cutting cycle

** All costs except land ownership costs are included

*** Costs for administration, telephone and driving are included in the “General expenses”

If the lower production and higher costs, due to the initial cutting cycles, are included, the calculations for the willow plantation are in Table 16.

Table 17: Calculations for the profit of the willow plantation at Puckgården during the 5th cutting cycle of 4-years, but also when all cutting cycles are taking into account (including the less productive first cutting cycle).

	Biomass production (t/ha/yr)	Chip price (€/t DM)	Production costs (€/t DM)	Planting subsidy (€/ha/yr)	Profit (€/ha/yr)
5th cutting cycle	9.5	91	38.5		**494**
All cutting cycles	8.8	91	52	50.5	**392**

* Calculations were made using the currency rate 1 € = 9 SEK and for a willow field of 4-years cutting cycle grown in the 5th cutting cycle

** All costs except land ownership costs are included

10.2 Example 2: Willow SRC at SIA ECOMARK, Latvia

This example describes woodchip production from willow SRC established on abandoned land and from other available wood sources in Latvia. The demand for qualitative woodchips or briquettes and pellets for production of heat and/or electricity, but also wood material for construction is of increased importance in Latvia. These are the main reasons behind the start-up of companies growing willow on agricultural soils in Latvia. The main goal of such companies is to produce renewable resources and sell raw material for heat and electricity production with fast-growing species grown on abandoned agricultural land and converting them to productive SRC fields. The Sia Ecomarc company has an agreement with the Swedish company Salixenergy AB to produce and sell planting material in Latvia from newly established stands. One year old shoots have been used to produce cuttings as planting material for newly established plantations. Since 2012, the company has two planting machines for double row planting to establish new plantations while being more independent from service providers.

This business has its origin from a small scale willow plantation that was planted for demonstration and for learning by doing the willow cultivation on agricultural soils. The initial plantation was planted with the best available willow clones at that time, namely the Swedish bred clones Tora and Torhild, but also with material from Lithuania and Hungary. The Hungarian S*alix alba* clones could survive in Latvian conditions, but their shoots are suffering from winter frost damage all years since 2008. The initial idea to grow trees as agriculture crop in the form of coppice for wood energy production comes as inspiration from Sweden. At these initial times the agriculture land was rather a cheap and economically advantageous resource (500-700 €/ha). During the last years the land has become more expensive and currently even the abandoned areas are available for up to 1,000 €. The company also deals with improvement of land with removing of naturally established deciduous forest mixed stands that are used for chip production. During the last quarter of 2012 SIA Ecomark started to produce woodchips.

SIA Ecomarc plans to use an industrial chipper and to produce about 7,000 m^3 per month. The woodchips are produced from different material available in the market: chips from agricultural and forest residues, sawmills, fuel wood, bushes and small size tees from abandoned agricultural lands. Customers can also buy chipping services from the company. The willow plantations established in spring 2012 are going to be harvested in winter 2014-2015.

The related real costs (for 2013) of the different management steps of this case study are presented below. Note that the company does not yet harvest willow plantations, therefore there are no data on this management activity.

- price for licensed planting material: 0.065 €/cutting or 0.325 €/m (costs per ha equals to 780-975 €);
- soil preparation: 230-360 €/ha (including spraying of chemicals, ploughing, removing of tree roots and stones, disk or power harrowing before plating);
- planting: 215 €/ha;
- mechanical weed control (power harrowing of strips between double rows): 55 €/ha (conducted once);
- weed control with herbicides (Stomp CS): 80 €/ha.

10.3 Example 3: Poplar SRC in Göttingen, Germany

The German boiler and heating system manufacturer Viessmann launched a few years ago their program “Efficiency plus”. Within this program, a main goal is to supply their industrial buildings with heat produced out of woody biomass and mainly with poplar SRC. The biomass boiler is fed with woodchips from SRC, which grow on 180 ha agricultural land.

In order to supply the bio-boiler with woodchips, Viesmann established a testing company / pilot plant to lease or purchase local agricultural land and plant SRC on it. Their own plantation site of registered origin was harvested 2007 and in May 2008 the feedstock was used for planting the first 130 hectares of poplar SRC. Moreover, other SRC species like Paulownia, Igniscum, Salix and others, have been planted on other small areas.

The SRC plantations were harvested in 2009/10 for the first time and the produced woodchips were used for the heating of the Viessmann factory.

This SRC plantation of the heating engineering company Viessmann is one of the best practice examples in Germany, because of the following reasons:

- From the initial stages of the project, all the following partners have been involved: nature conservation authority, water management office, local authorites and municipalities, the agriculture administration, the local Farmer's Union and the local Hunting Cooperative.
- At the location in Allendorf and the SRC plantation respectively, several research projects have been conducted, with some still running, like "ELKE", "ProLoc II" and "Naturschutzfachliche Anforderungen an KUP". These ensure the sustainability aspects involved for SRC in Germany.
- The project was attributed several awards, like the German sustainability award (2009, 2011), the Energy Efficiency Award 2010 and the Energy Globe World Award 2012.

The first seedlings were planted 2008, but there are no data available in terms of density (e.g. seedlings per ha) and amount of seedlings. This is due to the fact, that for each plantation, a single seedling-plan was developed. Some climatic data about Allendorf are presented below:

- Altitude: 250 – 708 m height above sea level
- Soil: Upper bunter sandstone
- Mean annual temperature: 6.5 – 8.5 °C

Taking into account the fact that Viessmann produces heating systems, such as wood boilers, the SRC plantation fits perfectly into the bioenergy chain of Allendorf. Furthermore, using biomass for SRC in the existing bioenergy chain seems ideal and reduces the pressure to increase woody biomass out of forests, which are more for recreation and other uses in the area. However, some new techniques have to be improved, mainly referring to harvesting and the quality of the woodchips produced.

A calculation was performed based on the harvesting practices occurring in Allendorf. The results of this calculation are shown in Table 17, together with some assumptions that are also indicated.

Table 18: **Overview of calculated costs and revenues (in €) of the SRC plantation in Allendorf (Source: von Harling and Viessmann ; 2009)**

Costs / revenues categories	Costs	Revenues*	Comments
Cuttings	1,650		11,000 cuttings per ha
Cuttings (own production)	0		
Herbicide in autumn (chemical protection)	20		Price / cutting 0.08-0.23 €/piece (0.15 €/piece)
Application of chemical protection	22		
Ploughing, autumn	94		Application of chemical protection (autumn): 5 l/ha
Herbicide, spring (chemical protection)	12		Application of chemical protection (spring): 3 l/ha
Application of chemical protection	22		
Harrowing, spring	47		
Costs for planting and setting	1,100		
Mulching, early summer	33		
Havesting costs	7,500		Chipper 15 €/t Transportation logistics 10 €/t
Financial statements & taxes	2,071		
Social employment charges	1,036		
Consulting	31		
Personnel costs Viessmann	3,000		
Reconversation (1,000 €/ha)	1,000		
Selling the woodchips to Viessmann		19,500	Selling price (woodchips): 65 €/t absolute dry matter
Subsidies		571	
Tenure receipts (lease of meadows and pastures)		166	
Bonus (energy crops)		300	
Receipts for selling the cuttings from own production		0	
Balance	**-4,000**	**6,899**	**2,899**

*Assumption: 30 years utuilisation (harvesting every 3rd year)

10.4 Example 4: Willow SRC in Brittany, France

100 ha of willow were planted in Brittany, from 2004 to 2007, for local heat production as part of an "EU Life Environment" research project. The aim of the project was to plant SRC in the region and demonstrate its utility for wastewater treatment. A special focus was put on the economic viability of the project's set up, on finding the best cultural practices for the area and on the ways to develop the local chain of heat production. Different studies were

conducted in order to set criteria and analyze results to be able to export the concept to other areas interested. Results in the Wilwater project are presented according to three different models, according to the main goal of the project:

- Objective 1: produce woodchips for heat production
- Objective 2: protection of natural environments, irrigation with treated wastewater or protection of drinking water catchments
- Objective 3: sludge spreading from water treatment plants

The Wilwater project was launched to find a multi-criteria approach to SRC, in order to overcome the economic problems linked to the production of SRC in France. Indeed, SRC plantations for heat production being on small-scale in the country and political support for SRC being marginal, it was important to find new ways to introduce SRC. All the actors involved in the projects also insist that they had more than just economic motivations:

- motivations to become more autonomous (by producing their own energy, to make their sludge spreading systems durable, to create local chains of supply)
- motivations to create new regional and local partnerships (capacity building between stakeholders)
- motivations in terms of image (communication on innovating activities)

Cooperation partnerships were launched between local municipalities, who run local heat production units, local municipal wastewater treatment plants, farmers and local energy companies. Several pilot sites were set up during the project, with specific business strategies for each of them. Below is the business strategy of one of the sites set up during the Wilwater project in the village of Pleyber-Christ:

Pleyber-Christ is a village of 2,800 inhabitants. Wastewater is spread on willow SRC (100 m^3 /ha over a 3 year period) that is then used as woodchips for the production of heat for municipal buildings (150 kW). Annual consumption of energy is estimated at 217 MWh, equivalent to 110 tons of woodchips at 25% humidity. SRC were planted on public land by an agricultural business using a STEP machine (cost 2,800 €/ha including preparation of the land). Sludge spreading is done by village farmers regrouped in a cooperative (CUMA de Pleyber-Christ) the 1st and 2nd years. The 3rd year the willow is too high for the type of machine used. Harvesting starts the 3rd year and then every 3 years, it is done by a regional cooperative machinery service (CUMA Breizh Energie) that invested in a STEMSTER machine. The cooperative of village farmers is in charge of the transport of the woodchips to a drying unit, that is run by a cooperative community-oriented enterprise (Société Cooperative d'Intérêt Collectif) created for that action. The project received subsidies at different levels (50% for the heat production system for example from the regional level). It is estimated that the municipality will save 20,000 € per year by replacing fossil energy with SRC.

From 1998 to 2001, 13 ha of SRC were planted in Brittany in 10 different zones to test economic and technical feasibility of SRC plantations.

From 2002 to 2006, 5 ha were planted in a village to test sludge spreading on SRC, linked to the construction of a heat plant for the village.

The Association d'Initiatives Locales pour l'Energie et l'Environnement (AILE) was a partner in these projects and launched the Wilwater Project to enable a follow-up of these experiments.

A focus on wastewater treatment/spreading was introduced after a change in law: farmers could no longer spread sludge on their fields (food crops) and had to find other lands. Municipalities launched partnerships with farmers and local industries to find innovative ways to overcome this change.

SRC were planted using a specific planter and 4 different varieties of willow, chosen for productivity aspects and their resistance to rust (Björn, Tora, Torhild and Olof). Plant density is of 16,000 per hectare. Anti-germination products were applied, as well as biodegradable plastic coverage. Agricultural machinery was built to be able to do mechanical weeding between the lines. Specific machinery was also made to be able to spread sludge on 2 and 3 year old willows.

In order to adapt to climatic conditions in Brittany, it was chosen to harvest in two stages: harvesting and then production of willow chips when the wood is dry and all leaves have fallen. The STEMSTER harvesting machine, owned by a regional cooperative machinery service (CUMA Breizh Energie) can harvest up to 250 ha of SRC per winter: it therefore can cover all plantations in the area.

The use of woodchips made from SRC in a local system of heat production is essential for the project to reach an economic balance. It seems to be a pre-requisite condition of the success of this project that the woodchips are used at a very short distance by a local collective heating system or directly by the farmer for a personal use. Municipalities in Brittany already had local heat production systems or were in the process of investing in new installations. SRC plantations were therefore part of a local reflection for the development of a local bioenergy chain. Examples of local use of woodchips:

- local farmer to produce heat for 3 houses
- heat production for a village school
- heat production for administrative buildings in a village

Below calculations about production costs and income in €/ha/yr for price levels in 2007 are presented (Table 19 to Table 21).

Table 19: Production costs, year of plantation €/ha/yr

Costs (€/ha/yr)		
Soil preparation		250
Fertilizing		100
Anti-parasite treatment		90
Anti-germination treatment		305
Plantation		1,800
Maintenance (mechanical weeding)		85
Weeding (other)		210
Coppicing		60
	Total	***2,900***

* Land ownership costs are not included

Table 20: Production costs, harvesting €/ha/yr

Costs (€)	low estimate	high estimate
Plantation (see detail above Table 1)	2,300 €/ha	2,800 €/ha
Fertilizing (spreading) - 1 or 2 times on a 3 year cycle	180 €	480 €
Including harvest every 3 years, using STEMSTER equipment, chipping and transport	850 €/ha	1,800 €/ha
Annual cost over a 20 year period		
- **With spreading**	424 €/ha/yr	824 €/ha/yr
- **Without spreading**	370 €/ha/yr	680 €/ha/yr
Storage of woodchips (25% humidity)	6 €/t	36 €/t
Yield (estimate) (25% humidity)	10.7 t/ha/yr	13.3 t/ha/yr

The investment in the STEMSTER harvesting machine can be optimized on an annual harvest of 200 ha.

Table 21: Profit of SRC plantation (plantation and harvesting costs are reduced because not subcontracted, done by the farmer)

Profit (€/ha/yr)	**maximized harvest (200 ha)**	**today**
with no spreading; sold without drying	38	-250
with no spreading, used on the farm	406	118
with spreading; sold without drying	-43	-331
with spreading; used on the farm	325	37

10.5 Example 5: Willow SRC in Enköping, Sweden

This project presents a 76 ha willow SRC plantation that is irrigated with wastewater from the municipal wastewater treatment plant. The biomass is used for energy in the local heat and power plant.

Nynäs Gård, which is the name of the farm, cooperates with ENA-Energi, which is a combined heat and power station, and the local municipal wastewater treatment plant. The willow plantation is irrigated with about 200,000 m^3 of water mixture of treated and untreated wastewater (20,000 m^3 of untreated nutrient-rich wastewater). There is a 15-year contract between the farmer and the wastewater treatment plant that binds the farmers to receive wastewater in his willow plantation. Moreover, in the agreement it is stated that ENA-Energi will receive willow chips from Nynäs Gård receiving the market price. The harvest was arranged in the beginning by Ena Energi, but lately the farmer contracts himself entrepreneurs in the area.

The 76-ha willow plantation was planted in 1998 and 2000. The area is divided in different fields, with the bigger one being about 30 ha and other parts being between 6 and 15 ha. The planting subsidy, that was valid in the planting years, was 5,000 SEK (about 550 Euros) per hectare and was covering approximately half of the establishment costs. The soil was treated before planting with glyphosate to treat couch grass, and was ploughed and harrowed for mechanical weeding before planting. Mechanical weeding was practiced even the year after planting. The 76-ha surface is planted with a number of different willow clones in stripes of 15 double-rows (0.75 and 1.25 m within and between the willow rows, respectively, about 0.5 m distance between the willow plants in a row). The plants are irrigated with the wastewater during the vegetation period during about 100 days.

The willow plantation is harvested every three years with a specially designed harvester that produces willow chips. The chips do not have to be stored to reduce water content, but can be transported directly to the combined heat and power plant that is situated around 2 km away from the willow plantation. The boiler has a heating capacity of 55 MW and electrical capacity of 24 MW. Willow chips are used mixed with other wood biomass sources as a fuel for heat and power production.

Below are presented calculations about production costs and income in €/ha/yr for price levels in 2011. Single farm payments are not included. Planting-related expenses (i.e. planting equipment, cuttings and labour costs) were about. 1,222 €/ha and are included in Table 22. Planting subsidy was 555 €/ha.

Table 22: Production costs, income and profit in €/ha/yr for the willow field at Nynäs Gård

Costs (€/ha/yr)	
Supervision/maintenance	22
Harvest	238
Transportation	148
General expenses	55
Interest rate	15
Sum	***478***
Income (€/ha/yr)	
Chips	896
Wastewater compensation	219
Sum	***1115***
Profit (€/ha/yr)	**637**

* Calculations were made using the currency rate 1 € = 9 SEK and for a willow field of 4-years cutting cycle grown in the 3rd cutting cycle

** All costs except land ownership costs are included

*** Costs for administration, telephone and driving are included in the “General expenses”

If the lower production and higher costs, due to the initial cutting cycles, are included, the calculations for the willow plantation at Nynäs Gård are as in Table 23.

Table 23: Calculations for the profit of the wastewater irrigated willow plantation at Nynäs Gård during the 3rd cutting cycle of 4-years, but also when all cutting cycles are taking into account (including the less productive first cutting cycle).

	Biomass production (t/ha/yr)	Chip price (€/t DM)	Production costs (€/t DM)	Planting subsidy (€/ha/yr)	Wastewater compensation	Profit (€/ha/yr)
3th cutting cycle	9	99.5	53		219	**637**
All cutting cycles	8.3	99.5	65	227	219	**529**

* Calculations were made using the currency rate 1 € = 9 SEK and for a willow field of 4-years cutting cycle grown in the 3th cutting cycle

** All costs except land ownership costs are included

Glossary and Abbreviations

***Note:** The Glossary and Abbreviations list describes and defines various specific or common expressions, terms and words, which are used in this handbook. A major aim of this list is to facilitate translations of the handbook into national languages. Several expressions are adapted from Wikipedia.*

Barrel of oil equivalent (boe): The amount of energy contained in a barrel of crude oil, i.e. approx. 6.1 GJ, equivalent to 1,700 kWh. A "petroleum barrel" is a liquid measure equal to 42 U.S. gallons (35 Imperial gallons or 159 litters); about 7.2 barrels are equivalent to one tonne of oil (metric).

Billets: cut SRC rods into 5 – 15 cm longitude (large woodchips)

Bundles: bounded SRC rods in bundles

Capacity: The maximum power that a machine or system can produce or carry safely (the maximum instantaneous output of a resource under specific conditions). The capacity of generating equipment is generally expressed in kilowatts or megawatts.

Carbon dioxide: CO_2 is a naturally occurring chemical compound composed of two oxygen atoms covalently bonded to a single carbon atom. It is a gas at standard temperature and pressure and exists in Earth's atmosphere in this state, as a trace gas at a concentration of 0.039% by volume.

Chips: cut SRC rods into pieces of 5 x 5 x 5 cm in size (see woodchips)

CHP: Combined heat and power: (Syn. Co-generation): The sequential production of electricity and useful thermal energy from a common fuel source. Reject heat from industrial processes can be used to power an electric generator (bottoming cycle). Conversely, surplus heat from an electric generating plant can be used for industrial processes, or space and water heating purposes (topping cycle).

CO_2: see Carbon dioxide

Co-generation: see combined heat and power generation (CHP)

Condensing boiler: Condensing boilers are water heaters with high efficiencies (typically greater than 90%) which are achieved by using the waste heat in the flue gases to pre-heat the cold water entering the boiler. They may be fuelled by gas or oil and are called condensing boilers because the water vapour produced during combustion is condensed into water, which leaves the system via a drain.

Coppice: Coppice is the ability of the selected tree species to re-grow with new sprouts after the plant is cut down.

Cuttings: Cuttings are 25 cm long pieces from one-year-old SRC rods which are used for planting

DH: District heating

District cooling: District cooling is a system for distributing chilled water or water/ice mixtures from a centralized location for residential and commercial cooling such as air conditioning.

District heating: District heating is a system for distributing heat (by hot water or steam) generated in a centralized location for residential and commercial heating requirements such as space heating and water heating.

Feedstock: Any input material into a process which is converted to another form or product.

Fossil fuel: Fossil fuels are formed in millions of years by natural processes such as anaerobic decomposition of dead organisms.

Gamma diversity: The term gamma diversity (γ-diversity) was introduced by R. H. Whittaker together with the terms alpha diversity (α-diversity) and beta diversity (β-diversity). Whittaker's idea was that the total species diversity in a landscape (γ) is determined by two different things, the mean species diversity in sites or habitats at a more local scale (α) and the differentiation among those habitats (β). According to this reasoning, alpha diversity and beta diversity constitute independent components of gamma diversity: $\gamma = \alpha * \beta$

Global warming potential: GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. GWP is expressed as a factor of carbon dioxide whose GWP is standardized to 1. For example, the 20 year GWP of methane is 72, which means that if the same mass of methane and carbon dioxide were introduced into the atmosphere, that methane will trap 72 times more heat than the carbon dioxide over the next 20 years.

Greenhouse gas (GHG): Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapour and carbon dioxide. Other greenhouse gases include methane, ozone, chlorofluorocarbons, and nitrous oxide.

GWP: see Global warming potential

Header: Area at the end and the beginning of a plantation thet is used for turning the machinery, storing the harvest, etc. During the period of no management prctices, the headers can be planted with annual crops, grass or indigenous flowering plants.

Heat: Heat is energy transferred from one system to another by thermal interaction. In contrast to work, heat is always accompanied by a transfer of entropy. Heat flow from a high to a low temperature body occurs spontaneously. This flow of energy can be harnessed and partially converted into useful work by means of a heat engine. The second law of thermodynamics prohibits heat flow from a low to a high temperature body, but with the aid of a heat pump external work can be used to transport energy from low to the high temperature. In ordinary language, heat has a diversity of meanings, including temperature. In physics, "heat" is by definition a transfer of energy and is always associated with a process of some kind. "Heat" is used interchangeably with "heat flow" and "heat transfer". Heat transfer can occur in a variety of ways: by conduction, radiation, convection, net mass transfer, friction or viscosity, and by chemical dissipation.

Heating value: the amount of heat released during the combustion of a specified amount of a fuel (biogas, biomethane).

Installed capacity: The installed capacity is the total electrical or thermal capacity of energy generation devices.

Invertebrates: animals that neither possess nor develop a vertebral column, derived from the notochord. This includes all animals apart from the subphylum Vertebrata. Familiar examples of invertebrates include insects, crabs, lobsters and their kin, snails, clams, octopuses and their kin, starfish, sea-urchins and their kin, and worms.

Joule (J): Metric unit of energy, equivalent to the work done by a force of one Newton applied over a distance of one meter. 1 joule (J) = 0.239 calories; 1 calorie (cal) = 4.187 J.

Kilowatt (kW): A measure of electrical power or heat capacity equal to 1,000 watts.

Kilowatt-hour (kWh): The most commonly-used unit of energy. It means one kilowatt of electricity or heat supplied for one hour.

kW_{el}: electrical power (capacity)

kWh: see Kilowatt-hour

kW$_{th}$: thermal (heat) capacity

m³: A cubic meter is the volume of 1x1x1 m. One cubic metre is about 1 t of water.

Moisture: Ratio of the mass of water content of a material (biomass) and the mass of the dry material itself.

Oil equivalent: The tonne of oil equivalent (toe) is a unit of energy: the amount of energy released by burning one tonne of crude oil, approx. 42 GJ.

ORC: Organic Rankine Cycle

Organic Rankine Cycle: The ORC process is named for its use of an organic, high molecular mass fluid with a liquid-vapour phase change, or boiling point, occurring at a lower temperature than the water-steam phase change. The fluid allows Rankine cycle heat recovery from lower temperature sources such as from biogas plants.

pH: Value that indicates the acidity or alkalinity of solutions (or soil). Soils with a pH less than 7 are acidic and solutions with a pH greater than 7 are basic or alkaline. Pure water has a pH of 7.

Rods: harvested SRC stems up to 8 m in length

Shoot: In botany, shoots consist of stems including their appendages, the leaves and lateral buds, flowering stems and flower buds. The new growth from seed germination that grows upward is a shoot where leaves will develop. In the spring, perennial plant shoots are the new growth that grows from the ground in herbaceous plants or the new stem or flower growth that grows on woody plants.

SI: The International System of Units (abbreviated SI from French: Système international d'unités) is the modern form of the metric system and is generally a system of units of measurement devised around seven base units and the convenience of the number ten.

SRC: Short rotation coppice, short rotation woody crops

SRF: short rotation forestry

SRP: short rotation plantations

SRWC: Short rotation woody crops

Water content: Ratio of the mass of water content of a material (biomass) and the mass of the moist material itself.

Watt (W): A standard unit of measure (SI System) for the rate at which energy is consumed by equipment or the rate at which energy moves from one location to another. It is also the standard unit of measure for electrical power. The term 'kW' stands for "kilowatt" or 1,000 watts. The term 'MW' stands for "Megawatt" or 1,000,000 watts.

yr: Year

Latin and common plant names

***Note:** In general, these are species that are used either directly for SRC, used for crossbreeding of clones, or mentioned to be suitable for SRC. For some species, the experiences for its suitability for SRC are limited. The common English names are widely used, but sometimes not precise.*

The names of clones are described in chapter 3.

Botanical name	**Common English name**
Alnus spp.	Alder
Alnus glutinosa	Common alder, Black alder, European alder, Alder
Alnus incana	Grey alder, Speckled alder
Amorpha fructicosa	Indigo bush
Acacia melanoxylon	Australian blackwood
Acacia saligna	Coojong, Golden wreath wattle, Orange wattle, Blue-leafed wattle, Western Australian golden wattle, Port Jackson willow
Acer pseudoplatanus	Sycamore (sycamore is used for various different species of the genus *Ficus*, *Acer*, *Pseudoplatanus*)
Betula spp.	Birch
Broussonetia papyrifera	Paper mulberry (same species as *Morus papyrifera*)
Corylus avellana	Hazel, Hazelnut
Cynara cardunculus	Cardoon
Eucalyptus spp.	Eucalyptus
Eucalyptus globulus	Tasmanian blue gum, Southern blue gum, Blue gum
Eucalyptus camaldulensis	River red gum
Eucalyptus gunnii	Cider gum, Gunnii
Eucalyptus nitens	Shining gum
Fraxinus excelsior	Ash
Morus papyrifera	Paper mulberry (same species as *Broussonetia papyrifera*)
Nothofagus	*Southern beech*
Paulownia	Paulownia
Platanus occidentalis	Sycamore (sycamore is used for various different species of the genus *Ficus*, *Acer*, *Pseudoplatanus*)
Populus spp.	Poplar
Populus deltoides	Eastern cottonwood
Populus koreana	Korean poplar
Populus maximowiczii	Maximowicz' Poplar, Japanese Poplar
Populus nigra	Black Poplar

Populus tremula	Aspen, Common aspen, Eurasian aspen, European aspen, Quaking aspen (Not to be confused with Populus tremuloides, the American aspen, also called trembling aspen and quaking aspen)
Populus tremuloides	Quaking Aspen, Trembling Aspen (Not to be confused with *Populus tremula*, the European aspen, which is also called quaking aspen)
Populus trichocarpa	Western Balsam Poplar, Black Cottonwood
Robinia pseudoaccacia	Black locust, Robinia, Acacia
Salix spp.	Willow (Most species are known as willow, but some narrow-leaved shrub species are called **osier**, and some broader-leaved species are referred to as **sallow**)
Salix aegyptiaca	*Egyptian willow, Musk willow*
Salix caprea	*Goat willow, Pussy willow, Great sallow*
Salix dasyclados	n.a.
Salix discolor	American willow
Salix rehderiana	n.a.
Salix schwerinii	n.a.
Salix triandra	Almond willow, Almond-leaved willow
Salix udensis	n.a.
Salix viminalis	Common osier
Ulmus spp.	Elms

General conversion units

Table 24: Prefixes for energy units

Prefix	Abbreviation	Factor	Quantity
Deco	Da	10	Ten
Hecto	H	10^2	Hundred
Kilo	K	10^3	Thousand
Mega	M	10^6	Million
Giga	G	10^9	Billion
Tera	T	10^{12}	Trillion
Peta	P	10^{15}	Quadrillion
Exa	E	10^{18}	Quintillion

Table 25: Volume terminology of different types of woody biomass in different languages

Language	Terminology		
English	Solid cubic meter **Solid m^3**	Bulk cubic meter **Bulk m^3**	Stacked cubic meter **Stacked m^3**
Croatian	Puni kubni metar **m^3**	Nasipni metar **Nasipni m^3**	Prostorni metar **Prostorni m^3**
Czech	Plnometr-pevný metr **(plm) [m3]**	Sypný metr **(prms) [m3]**	Prostorový metr-rovnaný **(prm) [m3]**
French	Mètre cube de bois plein **m^3**	Mètre cube apparent plaquette **MAP**	Stère **stère**
German	Festmeter **Fm**	Schüttraummeter **Srm**	Schichtraum. (ster) **rm**
Greek	Συμπαγές κυβικό μέτρο **κ.μ. ή m^3**	Χωρικό κυβικό μέτρο χύδην **χ.κ.μ. χύδην**	Χωρικό κυβικό μέτρο στοιβαχτού **χ.κ.μ. στοιβαχτού**
Italian	Metro cubo **m^3**	Metro stero riversato **msr**	Metro stero accastato **msa**
Latvian	Kubikmetrs (cieškubikmetrs) **m^3**	Berkubikmetrs **m^3_{ber}**	Kraujmetrs vai sters **m^3_{kr}**
Macedonian	poln kuben metar	nasipen kuben metar	prostoren kuben meatr
Polish	metr sześcienny **m^3**	metr nasypowy **mn**	metr przestrzenny **mp**
Slovenian	Kubični meter **m^3**	Prostrni meter **prm**	Nasut kubični meter **Nm^3**

Table 26: Conversion of energy units (kilo joule, kilo calorie, kilo watt hour, ton of coal equivalent, cubic metre of natural gas, ton of oil equivalent, barrel, British Thermal Unit)

	kJ	kcal	kWh	TCE	m³ CH_4	toe	barrel
1 kJ	1	0.2388	0.000278	$3.4\ 10^{-8}$	0.000032	$2.4\ 10^{-8}$	$1.76{\cdot}10^{-7}$
1 kcal	4.1868	1	0.001163	$14.3\ 10^{-8}$	0.00013	$1\ 10^{-7}$	$7.35{\cdot}10^{-7}$
1 kWh	3.600	860	1	0.000123	0.113	0.000086	0.000063
1 TCE	29,308,000	7,000,000	8,140	1	924	0.70	52
1 m³ CH_4	31,736	7,580	8.816	0.001082	1	0.000758	0.0056
1 toe	41,868,000	10,000,000	11,630	1.428	1,319	1	7.4
1 barrel	5,694.048	1,360.000	1,582	0.19421	179.42	0.136	1
1 BTU	1.055						

Table 27: Conversion of power units (kilo calories per second, kilowatt, horse power, Pferdestärke = horse strength)

	kcal/s	kW	hp	PS
1 kcal/s	1	4,1868	5,614	5,692
1 kW	0,238846	1	1,34102	1,35962
1 hp	0,17811	0,745700	1	1,01387
1 PS	0,1757	0,735499	0,98632	1

Table 28: Conversion of temperature units

	Unit	Celsius	Kelvin	Fahrenheit
Celsius	°C	-	°C = K − 273.15	°C = (°F − 32) × 1.8
Kelvin	K	K = °C + 273.15	-	K = (°F + 459.67) × 1.8
Fahrenheit	°F	°F = °C × 1.8 + 32	°F = K × 1.8 – 459.67	-

Table 29: Conversion of pressure units (pascal, bar, technical atmosphere, standard atmosphere, torr, pound per square inch)

	Pa	bar	at	atm	Torr	psi
1 Pa		0.00001	0.000010197	9.8692×10^{-6}	0.0075006	0.0001450377
1 bar	100,000		1.0197	0.98692	750.06	14.50377
1 at	98,066.5	0.980665		0.9678411	735.5592	14.22334
1 atm	101,325	1.01325	1.0332		760	14.69595
1 Torr	133.3224	0.001333224	0.001359551	0.001315789		0.01933678
1 psi	6894.8	0.068948	0.0703069	0.068046	51.71493	

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