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Biofficiency

Risk and socio-economic analysis

(D7.2)

Author:	D. Magiri – Skouloudi, K. Braimakis, D. Grimekis, S. Karellas (NTUA)
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Abbreviations and Acronyms

ALOP	Advance Loss of Profit
BREF	Best available techniques Reference document
CHP	Combined Heat and Power
DSU	Delay In Start Up
EED	Energy Efficiency Directive
EU	European Union
FAO	Food and Agriculture Organization
FGD	Flue Gas Desulphurization
GBEP	Global Bioenergy Partnership
GDP	Gross Domestic Product
GHG	Greenhouse gas(es)
GNI	Gross National Income
IEA	International Energy Association
IED	Industrial Emissions Directive
ILO	International Labor Organization
IRR	Internal Rate of Return
ISO	International Organization for Standardization
LCPD	Large Combustion Plant Directive
MCPD	Medium Combustion Plant Directive
NPV	Net Present Value
OHSAS	Occupational Health and Safety Assessment Series.
OM	Operation and Maintenance
OSH	Occupational Safety and Health
PPE	Personal Protective Equipment
PPE	Personal Protective Equipment
RED	Renewable Energy Directive
RIA	Research and Innovation Action
RSB	Roundtable on Sustainable Biomaterials
RWC	Residential Wood Combustion
SE	Steam Explosion
SEIA	Socio-economic Impact Assessment
UNDP	United Nations Development Programme
WBA	World Bioenergy Association

1. Introduction

1.1 General considerations

The transition from fossil-based products to renewable products is a prime necessity in future for the better environment, health, and socio-economic status of living beings on earth. Biomass resources are diverse and widely dispersed, thus the role of biomass as a local renewable energy source, as well as a factor of energy security, is critical. According to the German Council for Sustainable Development [1], sustainability means to equally consider environmental, social and economic aspects. The most important roles that bioenergy is expected to play are to significantly reduce GHG emissions (in comparison to fossil counterparts) and to help achieve both national and international sustainable development goals. The current rate of bioenergy deployment is well below the levels required within IEA long-term climate models. Acceleration is urgently needed to ramp up the contribution of bioenergy across all sectors [2]. This is a challenging task, given that power plant development projects in general are heavily capital intensive, therefore risk analysis and mitigation are crucial for all stages of project development.

In this spirit, Biofficiency project aims to reduce the impacts of biomass electricity and heat through the introduction of the next generation of highly efficient heat and power cogeneration systems, while simultaneously targeting corrosion and deposition issues, as well as ash utilization concepts.

One of the climate change mitigation measures stated in the Paris Agreement includes the use of renewable energies in substitution of fossil fuels as a way to meet the GHG emission reduction targets and to keep the increase in global temperature this century below 2 °C. For these objectives to be achieved, the implication of all parties, the necessary support to developing countries, the appropriate finance funding, and a new technological framework development are required [3]. Heat and power cogeneration systems, coupled with the combustion of renewable biomass fuels, represent a mature technology with a great emission reduction potential. A major problem for using 100% biomass in medium- to large-scale CHPs today is the *technological risk of failure, shutdown or increased maintenance and repair efforts*, mainly due to corrosion and ash deposition issues. Of course the *security and availability of fuel supply* is another main concern, especially for large scale installations.

The financial sector understands that there might be significant risk implications in investing in natural resources that are easily susceptible to environmental hazards and vulnerable to climatic changes. Huge financial losses owing to environmental hazards have occurred in the past even with very high profiled technologies that generated a lot of early optimism because certain risks were deemed too improbable or even overlooked in the initiating stages. It is important to bear in mind that several tested risks in the shelf life of bioenergy projects have been mentioned over time in various literatures and adequate steps taken to mitigate or transfer such risks to capable risk takers in the industry have been proffered. However, there are still risks that may currently have no bearing with the financial output of a biomass project but may later turn to be devastating obstacles that will obliterate all the earning capacity of the project [4] in subsequent years.

Sustainability assessments of bioenergy must cover the three sustainability pillars: social, environmental, and economic, so that their results can incline decision-makers towards those chains that are most beneficial for the environment, society, and the economy. Particularly for the integration of bioenergy in the circular economy, the major challenge lies in the selection of supply chains and economic models that generate the lowest environmental impacts while simultaneously offering the largest economic benefits, along with fostering positive social impacts. The scope of the present socio-economic analysis and risk assessment is to identify the main risks that might have significant bearings on the financial and social profitability of relevant bioenergy projects.

2. Risk assessment

2.1 Introduction - hazard identification

A *risk* is generally defined as the effect of a hazard (e.g. so many casualties per 100,000 at risk) multiplied by the probability of its occurrence. While there will be a margin of uncertainty attached to an assessed risk, that margin is statistical and reflects the sample size and the variance in the two key variables. The assessment itself is grounded in evidence already available and furnishes a ‘rational expectation’ that applies so long as the conditions on which our current knowledge rests remain unaltered.

When conducting a risk assessment as part of a feasibility study for innovative technologies, e.g. for an advanced construction project, the consequences lie in the future and may turn out to be quite different than expected. Therefore, the undertaken risk assessment will be used as a guideline for the formation of a contingency plan.

The overall approach envisaged by the Biofficiency consortium is to make sure each of the individual technological risks are sufficiently addressed at different levels to truly reduce the overall technological risk for the development steps, i.e. further innovation and demonstration activities, deployment steps and full-scale implementations in the EU and worldwide. In order to ensure the high impact of RIA projects, Biofficiency involves measurements in full-scale systems. This enables high-quality results and effective methods such as additive utilisation or fuel pre-treatment which can be directly used by CHP plant operator.

After Biofficiency, technological risks will be dramatically decreased by these measureable efforts. Through dissemination and exploitation measures, stakeholders will be actively involved in the development process and will be able to utilize the expertise collaboratively built up and gathered during this project. A solid business plan is the key to unlock further development of capital-intensive projects, such as the development of large-scale biomass power plants. A meticulous risk evaluation is one of the crucial components of successful biomass energy business plans, as it enhances the accountability of both the project developers and plant operators.

The hierarchy of measures for hazard control classified according to their effectiveness is presented, in Figure 1.

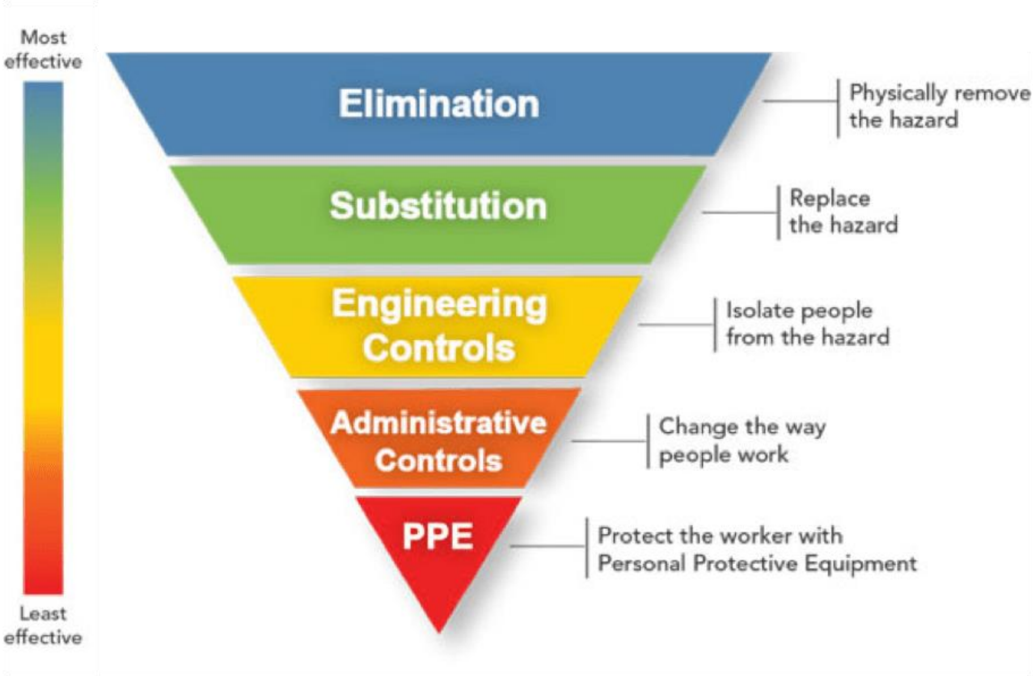

Figure 1. The hierarchy of protective measures for hazard control [5].

2.2 Relevant standards and regulations

The international standards, guidelines and regulations most commonly used for hazard evaluation and safety management are the following:

- **OHSAS 18001, Occupational Health and Safety Assessment Series.** This is an internationally applied British Standard for occupational health and safety management systems that helps all kinds of organizations put in place demonstrably sound occupational health and safety performance. It is a widely recognized occupational health and safety management system.
- **ISO 45001:2018 for Occupational health and management systems - Requirements.** This international standard was developed by a committee of occupational health and safety experts, and follows other generic management system approaches such as ISO 14001 and ISO 9001, providing a framework to improve employee safety, reduce workplace risks and create better, safer working conditions globally.
- **Guidelines on occupational safety and health management systems, ILO-OSH 2001.** Formulated by the International Labour Organization, this set of guidelines serves as a practical tool for assisting organizations in achieving continual improvement in occupational safety and health (OSH) performance. The guidelines have been developed according to internationally agreed principles defined by the ILO's tripartite constituents, while their main target is the call for formation of coherent policies to protect workers from occupational hazards and risks while improving productivity.
- **Large Combustion Plant Directive (LCPD) - Hazards & Risk Management.** To comply with EU emission limitations, it is necessary to install systems for the removal of NO_X from flue gases using catalytic systems. Aqueous ammonia or urea is usually used in this process, stored in bulk on site. Gaseous ammonia is flammable, toxic to humans, very toxic to aquatic organisms and is subject to international regulations for handling of chemicals. Emissions of dust, SO_x and other compounds must be limited as well.

- **Medium Combustion Plant Directive (MCPD).** The MCPD regulates emissions of SO_2, NO_X and dust to air. It aims to reduce those emissions and the resultant risks to human health and the environment. It also requires monitoring of carbon monoxide (CO) emissions. The emission limit values set in the MCPD apply from 20 December 2018 for new plants and 2025 or 2030 for existing plants, depending on their size. The flexibility provisions for district heating plants and biomass firing ensure that climate and air quality policies are consistent and their synergies are maximized.
- **Best available technique Reference document (BREF)-LCP**. BREF-LCP deals with combustion installations with a rated thermal input exceeding 50 MW. Plants with a thermal input lower than 50 MW are, however, discussed where technically relevant because smaller units can potentially be added to a plant to build one larger installation exceeding 50 MW.

2.3 Traditional risks

The main parameters that need to be taken into account when assessing risks in power plants are the plant size, the site characteristics (including whether the area is sufficiently developed or not), the power generation technology (that might infer additional technology-specific risks) and the project type (whether this is a greenfield construction, a capacity expansion or retrofitting project). Since this is a more general, pre-selection level study, specific site-related considerations are not included in the risk evaluation. A consistent risk analysis also needs to take into account the whole lifetime of the project, which can be divided into the following stages:

1) Planning,

2) Construction and commissioning,

3) Operation, and

4) Decommissioning.

Main risks often reported by previous studies are [5]:

- Fuel non-availability is perhaps the biggest risk the biomass power industry is facing
- Prices of fuel are volatile, however expected to stabilise in the near future
- Efficient procurement of fuel hinges on several smart sourcing strategies
- Technological barriers in using certain types of fuel
- Increased risk for corrosion and fouling of heat transfer surfaces
- Prices vary widely across regions and seasons
- Fixed tariffs for sale of power adversely impact feasibility when fuel prices go up
- Interruptions in operations as a result of non-availability/ high prices of fuel are normal
- Credit risks differ from state to state, depending on credit-worthiness and contracting
- Clear and cohesive policies are a pre-requisite to establishment and operation
- Few projects have contemplated insurance products for fuel and credit risks
- Insurance companies are often perceived to be non-responsive and risk-averse to cover new technologies

A breakdown into the most common risk categories follows.

Design, construction and commissioning risks

As highly complex construction projects, new biomass CHP plants bear the associated risks. The risks that are unique to biomass units are those related to the doubtful transferability of prototype (lab and pilot scale) results, the expensive retrofitting of older units, as well as the demanding equipment testing and commissioning stages. Thorough monitoring and recordkeeping during construction, commissioning and operation stages will minimize risks and assist in quantifying the achieved progress. Measures to mitigate exposure to this type of risk can be the selection of the design, management and construction teams based on their expertise and experience in similar projects. A thorough check on the construction site's ground condition and natural hazard assessment is another preventive measure suggested by professionals [6].

Operating & fuel supply risks

Fuel handling and storage is not free from safety hazards. Dust explosions are violent events, which can cause potentially extensive damage across a wide area and may result in personal injuries, as well as extensive domino effects caused by the blast overpressure and fragments. Apart from dust explosions, self-heating of biomass fuels can result in fires, which can occur due to several causes and are a major potential issue.

Regarding fatal incidents of bioenergy applications, Chatzimouratidis and Pilavachi [7] presented an overview of accident fatalities for different types of power plants based on global historic data. This overview is given in Table 1.

Table 1. Overview of accident fatalities for different types of power plants based on global historic data [7-9]

Type of power plant	Accident fatalities (deaths/TWyr)
Coal/lignite	342
Oil	385
Natural gas turbine	85
Natural gas combined cycle	85
Nuclear	8
Hydro	883
Wind	103
Photovoltaic	3
Biomass	**0**
Geothermal	0

It can be observed that biomass power plants have a null index of accident fatalities per TWyr of operation.

In addition to the emerging risks due to the new feedstocks and operational parameters, such as elevated pressures and temperatures, and market shifts, there are traditional operational risk aspects to be considered [10]. The main pieces of capital equipment in a coal-fired power plant that, in the event of a loss, can exceed the policy deductible for property damage or business interruption are:

1. Boiler
2. Steam Turbine / Generator
3. Generator Step-up transformer
4. Flue Gas Desulphurization (FGD)
5. Fuel Handling equipment

There is also a number of traditional operational risks in biomass-fired power plants with established methods of identifying and addressing the risk. These risks are present in the construction, start-up and operation phases of the plant. Property and Machinery Breakdown risk surveys, provided by construction companies, manufacturers and installers, will help identify and manage these traditional risks. These risks are:

1. Natural catastrophe – floods, hurricanes, wind and earthquakes
2. Fire – fuel and fuel handling, oil cooled equipment, FGD equipment
3. Equipment breakdown
4. Construction accidents
5. Operator Error

Financial / credit risks

As power plant construction and retrofitting projects are capital intensive, the associated financial and credit risks are generally high, although commonly covered by insurance companies. Capital cost inflation is a common risk in such projects. External assistance in the form of public subsidies, tax credits and other supports can assist in reducing the capital required and the overall risk of developing a new facility. Renewable energy grants and loan guarantees are increasingly available, as well as subsidies from governments and private investors.

A typical risk is related to financial business interruption for power plant construction projects; however, it can easily be managed through insurance. Advance Loss of Profit (ALOP) insurance cover requests are steadily rising, representing 27 % of the reported risks in industrial project development in the period 1998-2008 [11]. The main hazard is the loss of financiers' income. Financiers therefore often insist that Delay in Start-up (DSU) insurance be acquired to also secure future debt servicing after business operations have commenced. This trend is likely to continue to drive the emergence of this type of insurance.

Regulatory risks

Preliminary environmental permitting is another parameter that can be a challenge, due to strict regulations and public sensitization that can sometimes lead to opposition to the development of new projects, and special environmental protection requirements for a number of areas in the EU. The EU legislation related to power generation technologies from biomass is included in multiple documents, such as the Large and Medium Combustion Plant Directives, the BREF of Large Combustion Plants, the Industrial Emissions Directive (IED), the Energy Efficiency Directive (EED), the Directive 2005/89/EC concerning measures to safeguard security of electricity supply and infrastructure investment and the Directive 2008/50/EC on ambient air quality and cleaner air for Europe

Apart from the more general regulatory risks, additional risks inherent in the particular political situation of the countries may occur. However, due to the generalized approach that is followed in the present study, these risks are not examined.

2.4 Emerging technology risks

Apart from the traditional risks of power plant construction projects, emerging risks also need to be addressed. The main categories are discussed below.

Fuel supply, properties and storage

Direct combustion of biomass is a mature technology. However, in the case of biomass power plant construction projects, a major issue that comes up repeatedly when seeking investors / financiers is the security of fuel supply and fuel price volatility, preventing projects from reaching financial close. Within the European Union, the seasonal fluctuation in the availability of key biomass feedstocks can be regarded as moderate; however, this risk can be minimized through seasonal storage. In the Biofficiency project, a large number of residual biomass feedstocks, readily available in the European Union, was evaluated regarding combustion properties, gaseous emissions, deposition and corrosion impacts, as well as biomass ash properties. A comparative environmental impact assessment of selected biomass supply chains, assuming the operational parameters and fuel requirements of a highly efficient large-scale biomass CHP plant to be constructed in Germany, was also performed.

Solid biomass storage itself can incur self-heating, dust explosion and self-ignition hazards, however this risk can be mitigated by selecting densified, upgraded biomass fuels with improved physical properties, resulting in higher pellet durability, which implies less dust emissions and a decreased self-heating hazard [12]. This issue is also investigated in the Biofficiency project. The selected biomass fuels must not pose a threat to currently established local biomass utilization scenarios. Specific risks related to the quality and properties of biomass feedstocks used are not taken into account, since there is a large variety of available options in the European continent.

Controls Systems and Cyber Security

These risk categories are not studied in the context of the Biofficiency project, however they are drawing increased attention due to their nature and therefore are worth mentioning.

- Alarm management is difficult to assess, but may have an important impact on losses. Surveys should address the question, how the alarms are managed. International standards and protocols should be followed whenever applicable.
- While not yet a source of large losses in the power generation industry, cyber risks are now an area of concern. Risk surveys and underwriting should address these issues by verifying that plant management has established procedures for security following the latest standards [10].

Besides the aforementioned risks, the Biofficiency project significantly increased technology performance by improved equipment and process design. The key parameters are reduced emissions, increased power plant efficiency, increased resource efficiency (feedstock and ash utilisation) and increased plant availability.

2.5 Evaluation criteria

The identified risks are evaluated according to their estimated probability and severity, using the 5x5 level evaluation color coding table presented below in Figure 2. The relevant scores for the assessment of each risk were taken as average values from past studies [4-6, 10, 11, 13] and expert estimations by the NTUA personnel.

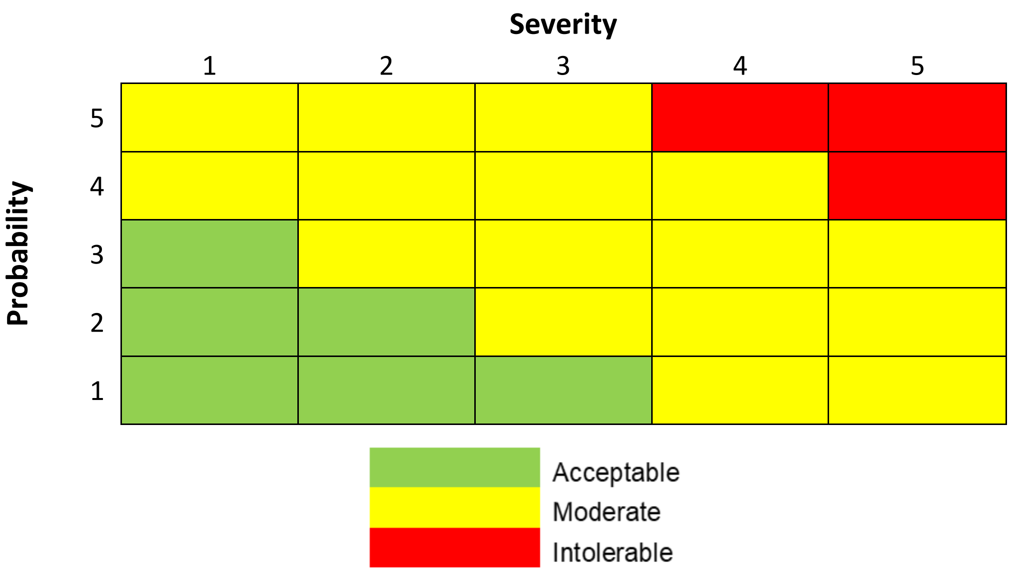

Figure 2. Risk evaluation matrix used for the quantitative assessment

2.6 Overall risk assessment

The risk assessment matrices are presented below. First, a brief quantitative assessment of traditional operational risks is presented in Table 1. Naturally, the main priority for the prevention of most types of safety incidents is the proper use and maintenance of personal protective equipment (PPE). Afterwards, a qualitative presentation of the possible technological risks associated with the innovative concepts introduced by the Biofficiency project, along with the proposed measures for risk mitigation is summarized in Table 2.

Table 2. Main traditional operational risks – quantitative evaluation matrix

No.	Activity	Probability (1-5)	Impact (1-5)	Risk (1-25)	Mitigation measures
1	Fire at fuel storage / conveyor belts	3	5	15	• Storage away from ignition sources • nitrogen injection in pellet silos • Spark proof electrical equipment • Firefighting facility provided • Use of PPEs • First aid box • Personnel training for proper fuel handling
2	Dust explosion at fuel storage / conveyor belts	3	5	15	• Constant monitoring of temperature, proper ventilation • dust formation prevention by means of proper storage and handling operations, fuel pretreatment •Spark proof electrical equipment • Pressure proof housings / explosion suppression systems where applicable • efficient equipment cleaning • Firefighting facility provided • Personnel training for proper handling • Use of PPEs • First aid box
3	Spillage / fire at chemicals storage	2	5	10	• Personnel training for proper handling • Use of PPEs • Proper loading operation • Proper ventilation • First aid box • Firefighting facility provided
4	Burst / outage of equipment body due to over-pressure and over-temperature	2	4	8	• Regular maintenance & inspection of equipment • Proper personnel training • First aid box
5	Electric shock, short circuits in power room	2	5	10	• Regular checking and maintenance of equipment • Use of PPEs • First aid box • Personnel training
6	Workers' injury (slipping, tripping and falling, burns, hearing damage)	3	2	6	• Regular personnel training • Use of PPEs • First aid box
7	Respiratory problems / eye irritation from exposure to dust or chemicals	2	2	4	• Use of PPEs • Proper maintenance • Regular personnel training • First aid box, safety shower stations nearby

Regarding the scale-up of the Biofficiency concepts, the main identified risks are presented in Table 3. Since the uncertainty for these future risks is larger, a precise quantitative assessment is not included. A qualitative prediction regarding the likelihood and severity of each risk is provided instead.

Table 3. Emerging technological risks for Biofficiency concepts and measures taken for next development stages

Technological risk	Measure to reduce risk	Impact
Fluctuating fuel quality due to environment effects or harvesting season Likelihood: low / Severity: low	Focus on widely abundant European waste biomass species and cost-effective pretreatment technologies. Widened spectrum of feedstocks for selection according to site-specific needs (location, plant size) for supply chain optimization. Flexible boiler technologies (e.g. FB) and fuel blends (homogenization) are considered.	Improved fuel quality and year-round security of supply. Increased economic performance by using cheaper feedstock and optimizing supply chain design. Collaboration towards integration of experimental findings from D2.1, D2.2 in existing databases to assist in standardization of fuel properties, emissions and combustion quality performance.
Transferability of lab-scale results to full-scale plants Likelihood: low / Severity: medium	Constant verification and comparison of investigations at three different scales (including large-scale) and evaluation of transferability at each step.	Increased security and validity of results for fast utilization of findings from stakeholders. Future deployment can directly be built upon knowledge created by Biofficiency.
Technical challenges in pre-treatment of biomass storage, milling. Missing experience for use of challenging fuels (straw, bark etc.) Likelihood: low / Severity: medium	Improve pre-treatment technologies for challenging fuels (agricultural residues, recovered feedstocks), widening biomass spectrum. Case-specific selection criteria for optimized design of appropriate pre-treatment method.	Better fuel quality through pre-treatment. Improved grindability and energy density. Widened biomass spectrum. Improved ash quality.
Costly disposal of ash Due to lack of possible utilization route because of chemical and physical properties of some ashes Likelihood: medium / Severity: medium	Evaluation of all applicable ash utilization options and influence of pretreatment methods on ash quality. Suggestions of ash utilization oriented plant operation.	Improved ash quality through pretreatment processes. Definition of sufficient number of alternatives for ash utilization according to site-specific criteria and EU regulations.
Material / equipment failure due to corrosion caused by biomass composition, unpredictable increase of costs Likelihood: low / Severity: high	Development and investigation of materials in long-term tests. Improvements measureable by material loss tests. Strong suggestion for strict inspection & maintenance schedule in developed operating guideline based on partner experience and results from experiments.	Increased security and planning reliability through guidelines based on real-scale expertise, as well as advanced materials selection with high resistance against corrosive environment. Enhanced plant availability due to improved equipment design. In-depth understanding of corrosion and deposition mechanisms for a variety of biogenic fuels.
Low CHP plant availability due to lack of real-time furnace diagnostics (FB boilers) Likelihood: low / Severity: high	Development and optimization of diagnostic tools for use in biomass-fired CFB boiler-equipped CHP plants (sensor technology, evaluation criteria).	Increased availability > 95% of service lifetime. Lowered operational costs.

High emissions from biomass combustion (CO_2, NOx, SO_2, particulate matter) Likelihood: low / Severity: high	Investigation of primary measures through fuel staging and additive utilisation. Reduction of N_2O and NO under (circulating) FB conditions simultaneously. Reduction of particulate matter through pre-treatment and improved equipment design, removal of alkali metals.	Improved air quality through lowered particulate matter emissions. Achievement of EU goals on carbon emission savings verified through D5.2. Comparison of emissions from different scales and firing systems (D7.3) as basis for the technology roadmap for future CHP.
Too conservative plant design Likelihood: low / Severity: high	New design of next generation power plant with focus on the fuel and its composition, such as ash and chlorine content.	Significant know-how generated through Biofficiency project. Widened fuel portfolio. Improved plant economics through slim design (especially regarding the flue gas cleaning section).
Seasonal shortage of supply Likelihood: high / Severity: high	Investigation of a number of fuel pretreatment technologies to broaden the portfolio of suitable feedstocks towards improved operation, identification of advanced corrosion-resistant materials to facilitate combustion of challenging feedstocks	Improved fuel storability, widened feedstock range due to application of fuel pretreatment technologies and meticulous material selection

For the project development stage, fuel supply risk, along with the volatility of solid biofuel prices, was found to be the most critical risk factor for biomass fuelled CHP plants in Europe, according to the reviewed literature. Regarding the operational hazards, fuel self-heating and dust explosions are the most critical risks currently faced by the bioenergy industry.

In general, however, due to the high safety standards implemented in modern biomass CHP plant design and operation, as well as the advanced fuel pretreatment technologies, innovative construction materials and design principles proposed by the Biofficiency project, the overall quantitative risk assessment results are relatively low for traditional operational hazards, as shown in Table 2. The standardization of biomass fuels, with the assistance of the emerging solid biofuel certification schemes, will further lower the operational hazards, as well as the equipment failure risk.

Social perception of bioenergy and the financial incentives provided are also major risk factors, as discussed in the present study. Stakeholders from the fields of energy and environment, involved in policy recommendations and decision making, need to further stress the need for clear, concise legislation which will aid in transparently fostering the most beneficial investments for both the environment and the EU societies, and at the same time effectively communicating the problems and mitigation strategies to the EU citizens.

3. Socio-economic evaluation

3.1 Introduction

Worldwide production and trade in bioenergy has increased exponentially during the last few years. Biodiesel production rose from less than 30 PJ in 2000 to 572 PJ in 2009 and ethanol production from 340 PJ in 2000 to 1,540 PJ in 2009 [14]. Meanwhile, the global wood pellet consumption in 2017 was equal to 29.8 Mt (23.0 Mt in Europe, 2.5 Mt in North America and 3.8 Mt in Asia). However, a strong public debate on sustainability aspects for bioenergy emerged in the last few years and, as a consequence, several initiatives are set up that are engaged in developing methodologies and tools to ensure the sustainability of biomass. One of these is the conduction of socio-economic evaluation studies along with the application of certification systems that use indicators which can be useful to share and compare information [15]. There is globally an increased focus on the development of sustainability certification schemes [16, 17]. However, most of these are not yet fully operational, although sustainable bioenergy production is required, e.g., by the European Renewable Energy Directive (RED) [18].

The biomass conversion chain (its inputs, outputs and activities) has various socio-economic impacts, which can take place at various levels, such as production, community, regional, national and international. Moreover, the impacts can be categorized into direct, indirect and cumulative. Direct impacts include the direct consequences of a proposed project's location, construction or operation on the socio-economic environment. The direct socio-economic impacts of a large-scale development are often manifested as changes in socio-economic structures (e.g. increased employment opportunities, increased income levels, new or expanded social services, etc.). Indirect impacts are the secondary consequences of direct impacts (e.g. altered consumption patterns, increased business opportunities and an increased need for particular services. The types of indirect impacts that the proposed development may cause, depend largely on an individual and community's priorities, and their ability to adapt to changes. Lastly, cumulative impacts are repeated impacts on a valued component. In fact, the accumulation of insignificant impacts happening over time can eventually lead to significant impacts. In the case of biomass-firing, a cumulative impact is the potential gradual reduction of forestry volume over a long period of time.

The socio-economic impact assessment (SEIA) is one of the methodologies that have been developed to assess and quantify the impacts of planned interventions (policies, programs, plans, projects). More specifically, SEIA is the systematic analysis that aims at identifying and evaluating the potential socio-economic and cultural impacts of a proposed development on the lives and circumstances of people, their families and their communities [13].

The following main steps are included in the SEIA process:

1. Scoping and issues identification: The proposed project must be well-defined. Social and economic issues must be identified as well as the geographic and temporal study boundaries.

2. Determining the social and economic baseline: There must be a good understanding of the impacted community or communities and the general socio-economic conditions in the project area.

3. Predicting and analyzing impacts: The assessment must be able to project what the social and economic impacts may be, including the effect of potential interactions between factors and over the lifetime of the development.

4. Determining significance: There must be an assessment of the importance of the social and economic impacts of the project.

5. Mitigation, management and monitoring: Once impacts and their significance are understood, decisions must be made about whether the project should proceed. If so, measures must be identified to avoid or lessen negative impacts (mitigation) and maximize positive impacts. Management of the mitigation needs to occur and on-going

monitoring of the projects effects must be carried out to ensure thresholds are not crossed.

3.2 Socio-economic impacts and indicators

When the socio-economic performance of a project is investigated, economic and societal impacts on both regional and global scale need to be considered. An overview of the economic impact pathways of biofuels use is presented in Figure 3. Bioeconomy-related innovations provide the opportunity for new production processes. Besides these innovations as a key driver for impacts, the changing demand for products leads to several impacts. A growing bioeconomy leads to a rising demand for bioeconomy-related feedstock and products, while the demand for fossil fuel based products might potentially decrease. However, this effect also depends on the fossil-fuel dependency of feedstock production. An increasing demand for bioeconomy-related feedstock and products can lead to changes of the respective commodity prices (such as food, fibre etc.). At the same time, new bioeconomy processes also potentially alter production methods, biomass productivity and processing. An increased demand for feedstock and input for the bioeconomy potentially provides significant economic perspectives for producers of these commodities in terms of new sources of income. At the same time, increasing commodity prices could enhance pressure on other consumers of these commodities. Changing demand and prices for bioeconomy-related products and processes could also have a significant influence on regional and national trade balances. New markets and changing trade balances then have an effect on the overall gross domestic product (GDP) and gross national income (GNI).

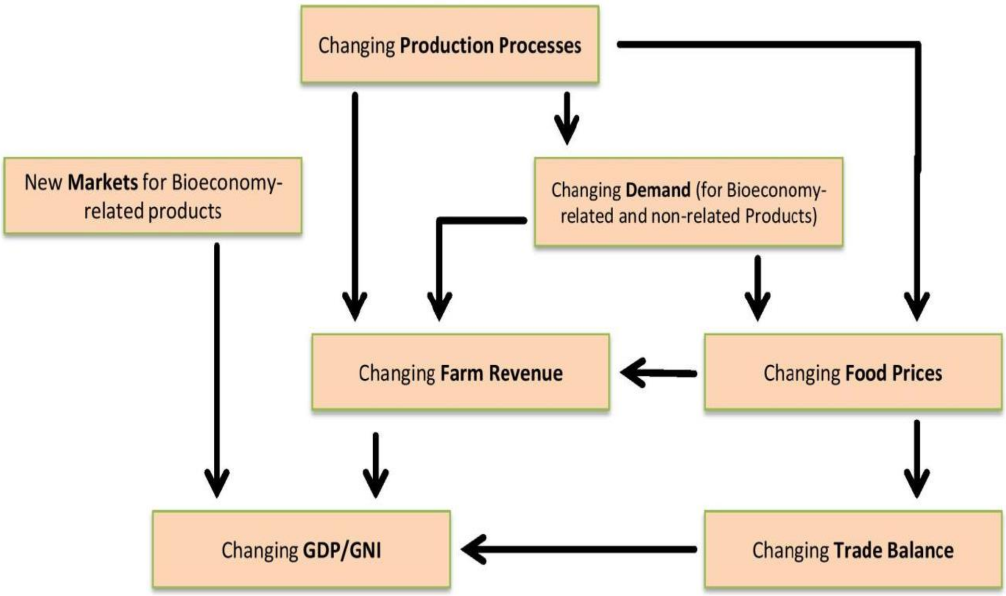

Figure 3. Overview of economic impacts of biofuels use [19]

An overview of the social impact pathways of biomass use is presented in Figure 4.

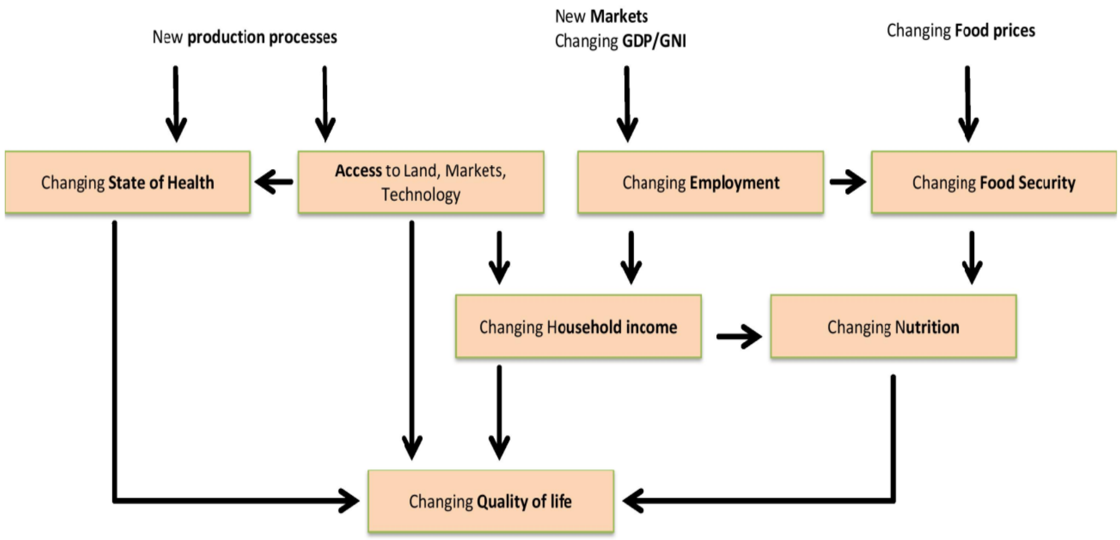

Figure 4. Overview of social impacts of biofuels use [19]

Many drivers of social impacts have an economic background. A big part of these impacts is based on questions of distribution. Changing income levels, new markets and production processes, for example, have potentially positive effects on employment, health and food security. At the same time, questions about the distribution of income and economic possibilities are relevant to assess social impacts. These concerns are very much linked to access to land, markets, seed capital and technology. Limitations in access can potentially indicate which communities or individuals are not benefitting from the bioeconomy.

At the same time, changing prices on bioeconomy-related commodities can directly or indirectly affect food security. All these changes, like changing household income, consumer prices, health, but also access issues have an impact on people's quality of life.

More than 100 socio-economic indicators (social, economic, and environmental) have already been identified in the studies of Lewandowski and Faaij [20] van Dam et al. [17]. Nevertheless, there is a lack of unity and consensus on the exact definitions of socio-economic indicators and their related measurement and certification schemes. In fact, socio-economic criteria and indicators may sometimes be too general, vague, and leave room for different interpretations [20]. Furthermore, most of the existent certification schemes mainly considered environmental principles, even though there are serious concerns about socio-economic impacts of bioenergy production activities. More recently, certification schemes have been developed that also include socio-economic aspects. Examples of sustainability certification systems that include socio-economic aspects are the Sustainability Indicators for Bioenergy, developed by the Global Bioenergy Partnership [21], the Principles and Criteria for Sustainable Biofuel Production, developed by the Roundtable of Sustainable Biofuels [22], and the NTA8080 [23], developed by the Nederlands Normalisatie-institute.

An overview of typically considered social impact indicators is provided in Table 4.

Table 4. Overview of typically considered social indicators grouped based on their associated impacts

Impact	Indicators
Demographic and health	Birth rate Demographic increase rate Child mortality rate Life expectancy at birth Rate of death per causes Morbidity and health attendance Under nutrition Malnutrition rate
Educational and cultural	Illiteracy rate Average schooling Information and culture access
Employment (Labor market)	Unemployment rate Average income
Income and poverty	GDP per capita Average familiar income Gini Index Theil Index Poverty rate
House and urban infrastructure	House condition Urban services accessibility Transport infrastructure
Quality of life and environment	Satisfaction with house, neighborhood, city and basic infrastructure Crime and homicides Environment (air condition, water, waste treatment, garbage collection)

A number of socio-economic sustainability criteria and indicators were identified in the EU funded project Global-Bio-Pact [12]. A core activity of Global-Bio-Pact was the description of socio-economic impacts in different countries and continents in order to collect practical experience about socio-economic impacts of bio-products and biofuels under different environmental, legal, social, and economical framework conditions. The results of these surveys are described in different case studies. The set of indicators proposed by the Global-Bio-Pact project is balanced and includes the main topics of impacts selected by a clear process with the aid of expert partners of the project. Furthermore, the topics reflect the main identified socio-economic and environmental areas which can be measured in order to monitor and if possible to eliminate negative impacts and to promote the benefits if a sustainable production is in place.

A discussion on the different types of indicators follows.

3.2.1 Economic and employment impacts

Within the economic indicators, macro, regional, and local indicators are differentiated. Furthermore, a large difference exists between background indicators that describe the general background of the nation or region and impact indicators that are directed specifically towards the impact of the biofuel activity. All economic indicators are quantitative indicators. The macro and regional economic indicators rely on statistical analysis or input/output analysis and require statistical data availability. Usually most of the indicators are collected by national bodies. The methodology that is applied to the majority of local indicators is by means of interviews or company records, which means data collection partly depends on information provided by companies. Only the net present value (NPV), which can be calculated on project level, is more objective, although even this methodology relies on data that is obtained from companies or projects.

- National (Macro) Level

The majority of the macroeconomic background indicators are used and collected by global organizations such as Food and Agriculture Organization (FAO), United Nations Development Programme (UNDP), and the World Bank. Statistical data that are presented by sector such as the sector-GDP contribution, number of jobs per sector, etc., is normally collected by national bodies, but since the bioenergy sector is relatively new, this sector is often not disaggregated. Therefore, some indicators such as investment in the bioenergy sector and number of jobs in the bioenergy sector are currently difficult to gather in some countries.

- Regional Level

The regional impact of the biofuel sector in the case study countries is difficult to assess. General regional differences, such as the per capita income in a region compared to the national average give an idea of the relative level of development of a region compared to the national average, but this does not give information about the impact of biofuels. Two indicators seem to give a good overview of the regional impact by the biofuel sector. These are the percentage bioenergy contribution to GRDP (if statistical data is available), as well as the total number of jobs generated in the region by the biofuel sector.

- Local (Micro) Level

As the impacts on a local scale are project specific, the microeconomic indicators have to be assessed for each project. If a business plan is publicly made available, acquiring the internal rate of return (IRR) or the net present value (NPV) of a project is relatively easy. However, in reality the exact cost figures might be different from the planned ones, and obtaining this type of data is very time consuming.

An overview of selected economic indicators identified by the Global-Bio-Pact project is given in Table 5.

Table 5. Overview of selected employment indicators identified by the Global-Bio-Pact project

Economic indicator
<u>Macroeconomic</u> Sector contribution to GDP/agricultural GDP (%) Value of the sector generated by the sector Exported products Investments in sector Value of industrial inputs
<u>Regional</u> Bioenergy sector contribution to GRDP (%) Contribution of bioenergy product exports to total exports (%) Regional turnover of the sector Regional investments in sector Regional employment in sector as part of total employment Total number of jobs generated in the region by bioenergy sector
<u>Local</u> Net present value (NPV) Internal rate of return (IRR) Contribution of feedstock sales to household income (%) of absolute value Total project investments Labor requirements and costs Wage levels Feedstock and product prices Total profit generated by project

Bioenergy investments have also a particular impact on employment generation as well as the compensation rates. Direct employment results from operation, construction and production. In case of bioenergy systems, this refers to total labor necessary for crop production/residue collection and transport as well as the construction, operation and maintenance of conversion/power generation plant. Indirect employment results from all activities connected, but not directly related, like supporting industries, services and similar. The higher purchasing power, due to increased earnings from direct and indirect jobs may also create opportunities for new secondary jobs, which may attract people to stay or even to move in. These latter effects are referred to as induced employment. In principle, the number of jobs created is very location-specific and varies considerably with plant size, the degree of feedstock production mechanization and the contribution of imports to meeting demand. Estimates of the employment creation potential of bioenergy options differ substantially

An overview of selected employment indicators identified by the Global-Bio-Pact project is given in Table 6.

Table 6 Overview of selected employment indicators identified by the Global-Bio-Pact project

Employment indicator	**Measurement method**
Employment generation on regional and local levels	Statistical data
Ratio of fixed contract: casual/daily workers	Company records and interviews
Wage levels (inc. casual workers compared to minimum wages)	Company records and interviews
Income earned by smallholders	Interviews, literature
Educational level required	Company records and interviews
Job growth rate	Statistics
Average age of employees	Sector level labor statistics
Participation of different races	Sector level labor statistics

The Irish Bioenergy Association published a report entitled “The Economic Benefits of the Development of Bioenergy in Ireland”, in which the economic impacts of bioenergy in the country are presented, among others. The data corresponding to employment generation from different bioenergy concepts are summarized in Table 7.

Table 7. Employment generation per ktoe of annual output in construction employment and installation (temporary work years) and operation and maintenance (permanent work years) in Ireland [24]

	Investment	O & M
Biomass (heat)	0.6	1.7
CHP	16.2	4.9
WtE	29.3	12.3
Biomethane	32.8	9.8
LFG	5.4	11.3
MSG	-	11.0
Biofuels	8.5	2.2

In other studies, Domac et al. [25] report employment generation of between 25 (Croatia) and 81 (Bosnia and Herzegovina) total jobs per PJ annual fuel consumption for CHP (combined heat and power) and wood heat projects in Central Europe (ranging in capacity from 6.8 to 15 MW_{th}), between 44% and 64% of which were classified direct employment. Panoutsou [26] calculated a potential employment of 13 to 22 additional jobs per MW_{th} capacity of installed district heating fed by locally sourced cardoon and giant reed.

In recent detailed studies, job creation in the feedstock production system is estimated based on labor requirements for each part of the system as summarized in Table 8. The cropland acreage requirements for each feedstock in the various supply chain clusters (a given cluster provides feedstock to a single, unique biorefinery) are given in the US Billion-Ton Update [17]. Job creation due to crop residue feedstock (e.g. corn stover, wheat straw) is associated only with collecting and baling crop residues, while job creation based on other types of cellulosic feedstock (i.e., annual energy crops, perennial grasses, coppiced and non-coppiced woody crops) is associated with all farm level operations from seeding to harvesting.

Table 8. Labor requirement and job per hectare for cellulosic biomass production [27]

Biomass type	Labor requirement (hour per ha)	Full time equivalent jobs per ha
Crop residues	0.62	0.0003
Perennial grasses	2.91	0.0014
Annual energy crops	5.57	0.0027
Coppiced and non-coppiced woody crops	5	0.0024

The number of full time jobs required per ton-mile in the transportation sector for truck, railroad and water is presented in Table 9.

Table 9. Labor requirement and job per hectare for cellulosic biomass transportation by truck, railroad and water [27]

Means of transportation	Full time equivalent jobs per ton mile
Truck	1.35×10^{-6}
Railroad	7.70×10^{-8}
Water	4.50×10^{-7}

Job creation in the local biomass storage facilities and the biorefineries are obtained by taking into account the generation of jobs in the construction industry which encompasses direct labor and construction related services (e.g. engineering, design, and other professional services) per million dollars of investment (Table 10).

Table 10. Full time equivalent jobs per million dollar in construction [27]

	Construction direct labor	Construction related services
	6.48	7.22

Chatzimouratidis and Pilavachi [7] presented an overview of job creation and compensation rates for different types of power plants based on global data. This overview is given in Table 11.

Table 11. Overview of job creation and compensation rates [7]

Type of power plant	Job creation (new employees/500 MW_e [28-30]	Compensation rates (c/kWh_e) [31]
Coal/lignite	2500	8.40
Oil	2500	6.75
Natural gas turbine	2460	2.00
Natural gas combined cycle	2460	1.33
Nuclear	2500	0.49
Hydro	2500	0.56
Wind	5635	0.16
Photovoltaic	5370	0.24
Biomass	36055	2.65
Geothermal	27050	0.20

Additional data on the employment generation and income from biomass activities for different countries has been compiled by Domac et al. [32]. The data is given in Table 12.

Table 12. Overview of job creation and labor earnings for biomass activities per PJ of annual fuel consumption for different countries [32]

Project	MW_{th}	Direct jobs	Indirect jobs	Induced jobs	Total jobs	Labor earnings in k€	Country
Forest residues CHP	8.9	12	7	8	27	348	Croatia
Wood residues CHP	6.8	16	4	5	25	974	Slovenia
Wood residues CHP	15	40	9	14	65	932	Croatia
Wood residues heat	10	52	2	27	81	698	Bosnia and Hercegovina

The average paid wages for agricultural workers in the year 2015 are depicted in Figure 5.

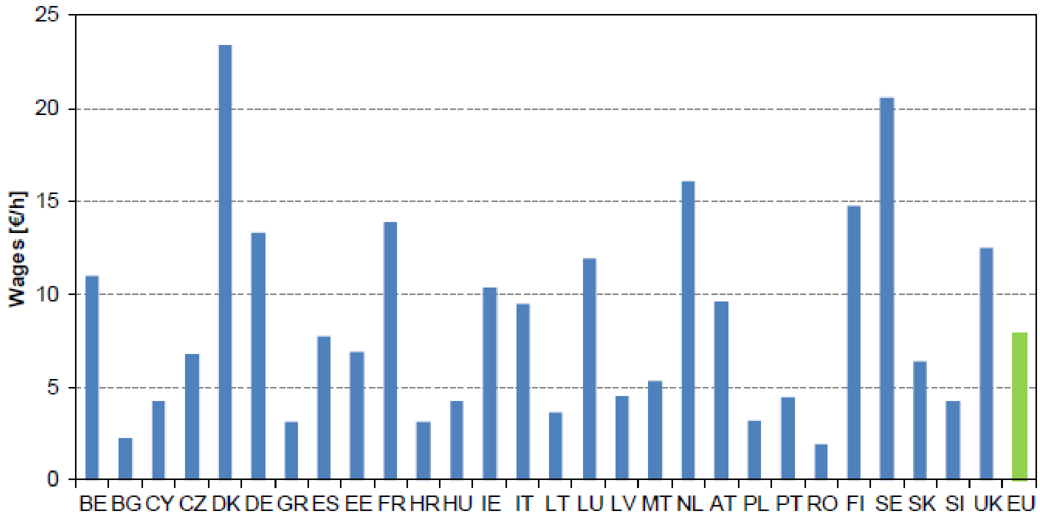

Figure 5. Average paid wages for agricultural workers in the year 2015 in the EU [33]

In Table 13, the annual spending in investment and operation and maintenance corresponding to specific energy output of different types of plants and operations is presented.

Table 13. Annual k€ of spending per ktoe of annual output in investments and operation and maintenance in Ireland [24]

	Investment	O & M
Biomass (heat)	1,099	384
CHP	2,347	592
WtE	8.972	296
Biomethane	4.433	311
LFG	4.348	203
MSG	2.308	15
Biofuels	1.337	848

In Figure 6, the biomass production costs without interest, taxes and subsidies for case study scenarios (marginal and very marginal land) of the SEEMLA (Sustainable exploitation of biomass for bioenergy from marginal lands in Europe) project [33] are depicted. The goal of the SEEMLA project (2016-2018) was the reliable and sustainable exploitation of biomass from marginal lands, which are used neither for food nor feed production and are not posing an environmental threat.

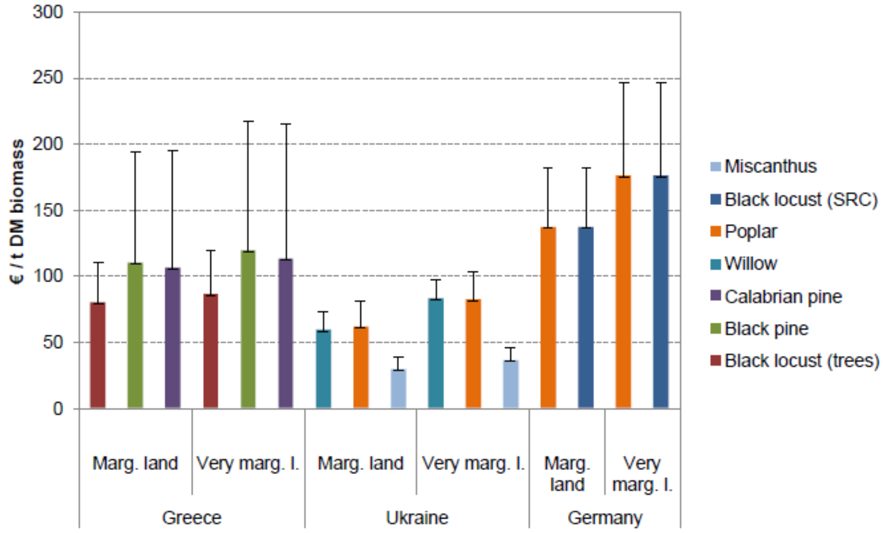

Figure 6. Biomass production costs without interest, taxes and subsidies for case study scenarios (marginal and very marginal land) of the SEEMLA project [33]. Solid bars and thin lines indicate results of more optimistic and more conservative calculations, respectively.

A series of estimates on the potential job creation of different renewable energy source utilization schemes was carried out by Kis et al. [34]. These estimates are presented in Figure 7.

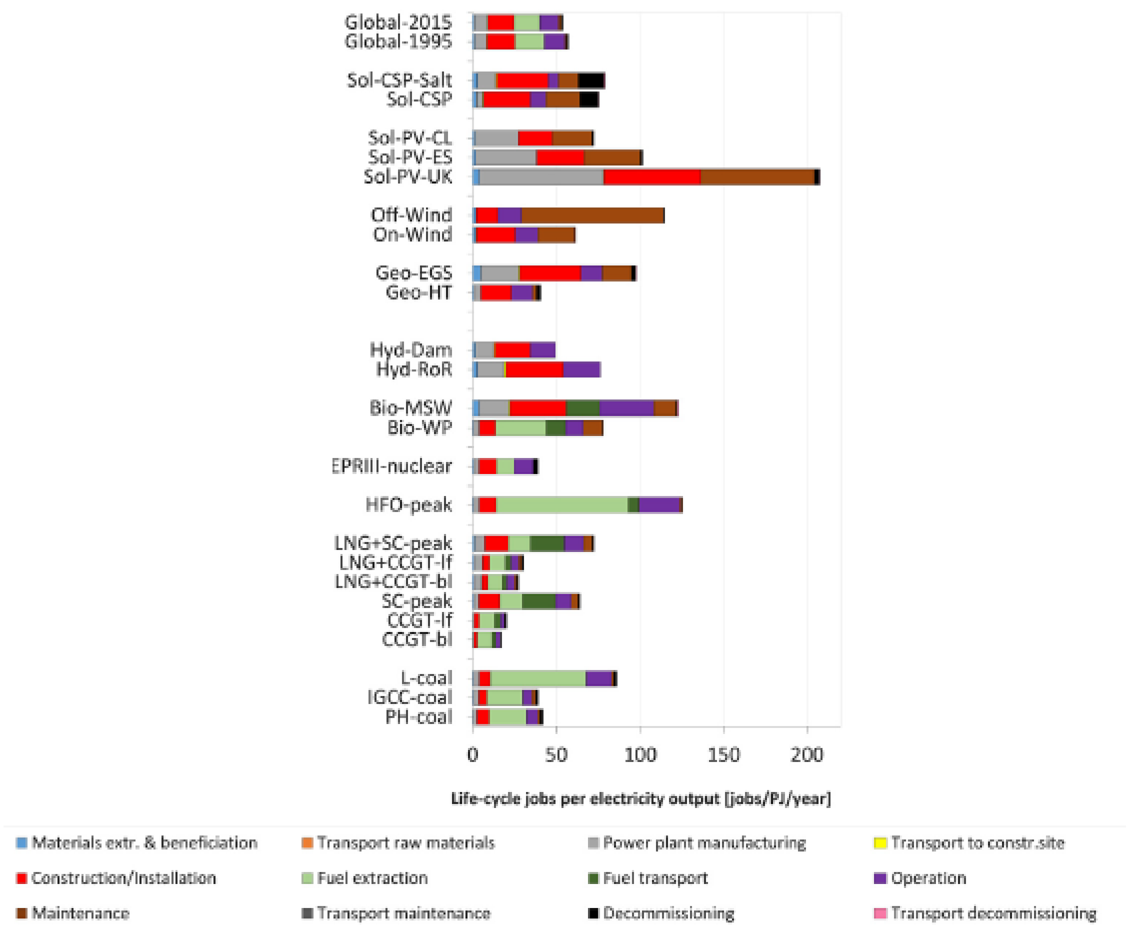

Figure 7. Job creation potential of different renewable energy sources [34]

In forecasted impact assessments employment generation is often an important parameter; while in certification systems there is usually no criterion for the number of jobs to be created; the working conditions and (minimum) wage levels have to be considered (discussed in other sections). It can be a challenge to measure minimum wage levels, e.g. for contract workers that are paid by unit.

3.2.2 Food security impacts

As the area globally available for agriculture is restricted, an expansion of biomass cultivation for electricity generation or for the production of biofuels inevitably leads to an increased competition – above all with food production. The basic mechanism through which this new linkage is established is by competition for arable land; if agricultural land resources where unlimited, increased demand for biofuels would have little effect on food prices. In the biofuels debate it is sometimes argued that the problem is that we use food (e.g. corn or wheat) to produce biofuels, and not non-food feedstock such as cellulose. However, as long as the production of feedstock requires agricultural land higher demand for biofuels will tend to drive up food prices, whether the actual feedstock can be eaten or not [35].

However, within the scope of the Biofficiency project, biomass derived from agricultural/industrial process residues is to be used. Therefore, the described conflict of use between fuel and food, which is common in the case of energy crops, is not relevant.

3.2.3 Land use impacts

The increased global demand for bioenergy (primarily biofuels) has contributed to a boom of land acquisition in the past few years, both directly and indirectly, as it can be observed in Figure 8. Directly, as the production of biofuel feedstocks accounts for the largest share of land acquisitions - 40% of the area for deals where the purpose of the land use is known. Indirectly, as the underlying driver of the land rush has been an expectation that a tightening global market for agricultural commodities, driven by increasing populations, incomes, and biofuels demand, will drive up future returns from arable land. As a matter of fact, between October 2008 and August 2009 alone - in the wake of the global food crisis - close to 50 Mha of large-scale land acquisition deals were struck [36].

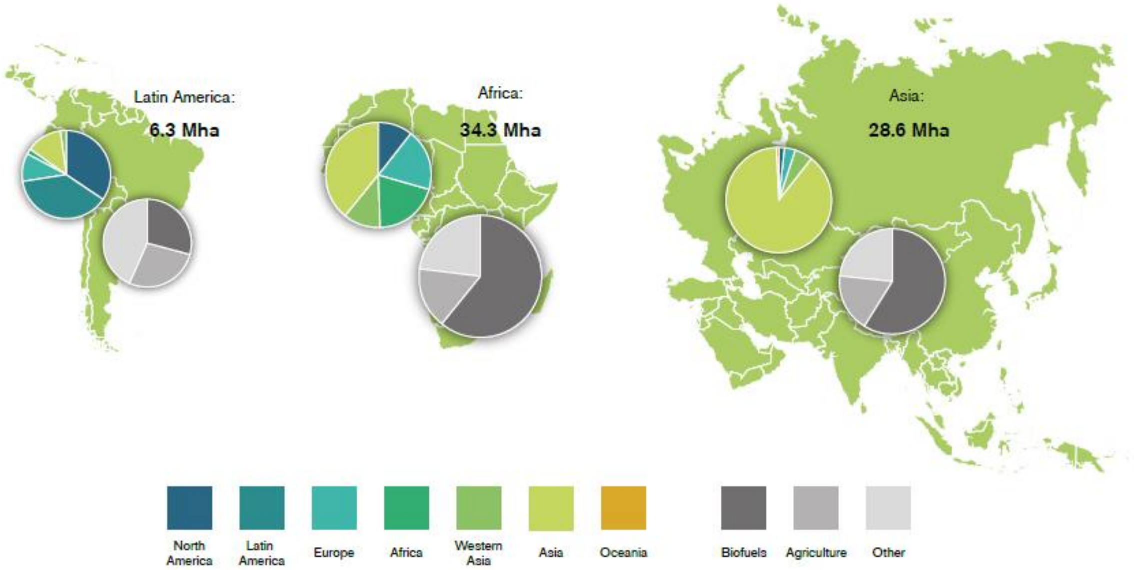

Figure 8. Distribution of land acquisitions between different investor regions and between different planned uses of the land (other includes forestry, industry, mining, tourism and other) [35, 37]

The production of biofuels and bio-products requires large amounts of feedstock, which is related to land use. This is obvious for dedicated energy crops; but also feedstock that is currently categorized as “residues” or “wastes” may have impacts on land use in the long term, as the general competition on carbon-based renewable sources is increasing. This is heavily influenced by prices for biofuels and biomass, as well as by prices and availability of fossil based sources. However, considering that in the case of biomass residues (which are utilized within the scope of the Biofficiency project) these impacts are less significant and more difficult to predict in the long run, they are left out of the present study.

Of course, the EU has introduced via the Renewable Energy Directive (RED) a series of minimum requirements to ensure the sustainability of harvesting biomass fuels from forests. These include the following:

1. Legality of harvesting operations
2. Forest regeneration of harvested areas
3. Areas designated by international or national law or by the relevant competent authority for nature protection purposes, including in wetlands and peatlands, are protected
4. Harvesting is carried out considering maintenance of soil quality and biodiversity with the aim of minimising negative impacts
5. Harvesting maintains or improves the long-term production capacity of the forest

Furthermore, as mentioned in the Directive, *“special attention is given to areas explicitly designated for the protection of biodiversity, landscapes and specific natural elements, that biodiversity resources are preserved and that carbon stocks are tracked, woody raw material should emanate only from forests that are harvested in accordance with the principles of sustainable forest management that are developed under international forest processes such as Forest Europe and that are implemented through national law or the best management practices at sourcing area level. Operators should take the appropriate steps in order to minimise the risk of using unsustainable forest biomass for the production of bioenergy. To that end, operators should put in place a risk-based approach.”*

It should be also noted that the above criteria apply to electricity and heating from biomass fuels produced in installations with a total rated thermal input equal to or exceeding 20 MW.

3.2.4 Health and safety issues impacts

An overview of selected health indicators identified by the Global-Bio-Pact project is given in Table 14.

Table 14. Overview of selected health indicators identified by the Global-Bio-Pact project

Health and safety indicator
Number of workers reporting health concerns related to agrochemical use
Level of compliance with standards for waste treatment and disposal
Workplace accidents
Number of deaths during work
Number of retirements due to workplace accidents
Benefits for disability and fatalities
Noise above legal threshold
Risk of fire outbreak
Risk of gas emissions
Number of staff with medical insurance

The main health issues relevant to the operation of biomass power plants are accidents and occupational diseases. The most severe indicators are deaths and retirement due to labor accidents or labor related diseases. Other indicators are related to potential causes of long term health effects: like noise and dust emission levels etc. However, whether preventive health policies are in place or not could be checked and can be regarded as an important verifier. National labor laws normally also cover these aspects, but monitoring and control are often neglected. On company level, it can be difficult to obtain correct information from the involved companies, as the number of accidents of work related health issues is clearly not good advertisement. It is also difficult to define a threshold for the number of accidents. The observation whether a company has a record system for accidents in place, is a (compliance) indicator of the companies' awareness and attention for this issue and can be included in a certification system. Another observation is that company records of accidents are sometimes absent. Furthermore, it is observed that health risks are mainly focused on company level impacts. Health impacts related to environmental impacts, for instance by air, soil, and water pollution could be included as well.

3.2.5 Social perception of bioenergy

In 2015, Radics et al. [38] carried out a systematic review of studies on the bioenergy perception across the world by retrieving data from 44 peer-reviewed publications from 2000 to 2013. The authors noted that in the last decade the research community has been increasingly interested on the societal and public perceptions of the bioenergy industry compared. Among the reviewed studies, a large majority (84%) focused in the US and Europe, while only a few have focused on stakeholders in Asia and other parts of the world. Moreover, among stakeholder groups, the majority of studies focused on the public or the consumer's opinion about bioenergy (79% of studies). The specific bioenergy topics addressed by the studies are presented in Table 15. It can be seen that the most commonly addressed topic are transportation biofuels (especially in the USA), forest bioenergy (especially in Asia), while bio-power has attracted relatively more interest in Europe.

Social acceptance varies greatly, especially after the lawsuit against the revised RED filed by European plaintiffs [39]. This incident is part of an ongoing discussion of sustainability related aspects and the CO_2 neutrality of biomass fuels, as also included in the revised Renewable Energy Directive.

Table 15. Distribution of social perception studies compiled by Radics et al. [38] based on the addressed bioenergy topic

Product/Application on Focus in Publications	**USA (n=16)**	**Europe (n=25)**	**Asia (n=7)**	**% Total Publications* (n=44)**
Biofuels for transportation	36%	20%	14%	25%
Forest Bioenergy	18%	8%	43%	18%
Bio-power (electricity production)	13%	20%	0%	16%
Bioenergy for heat/power	0%	20%	0%	14%
Biofuels (unspecified and for heat/power)	25%	4%	14%	11%
Bioenergy (in general, unspecified)	0%	24%	29%	11%
Renewable energy in general (solar, wind, *etc*., including bio-mass-based energy)	6%	4%	0%	4.5%
Total	100%	100%	100%	100%

Public

Based on the analyzed data the authors concluded that public support is moderate to low toward bioenergy and the biofuel industry. However, greater enthusiasm is shown for second-generation biofuels (from cellulosic feedstock) when the public is informed about them. The public is relatively unfamiliar with biomass energy, which explains their lack or lukewarm support to bioenergy, as is indicated by various publications [8, 40-44]. In fact, most articles reported that a large majority of stakeholders was not aware of and knowledgeable about the technologies used for production of bioenergy and, even when aware, respondents indicated that bioenergy technology was relatively weak and was not mature enough to warrant their support towards renewable energy projects.

The main factors governing support or opposition to bioenergy was found to depend on many aspects including respondent knowledge and opinion of various attributes, demography, stakeholders past experience with renewable energy, as well as media exposure. Additionally, respondents across almost all articles indicated having low knowledge and awareness of bioenergy. However, the most critical attributes driving consumer opinion were found to be the purchase price of bioenergy products and the biofuel impact on vehicle functionality, as respondents have the perception that bioenergy may cost them more than alternative products and indicate their unwillingness to pay a premium. Meanwhile, they additionally indicated they are likely to use biofuels (bio-based transportation fuels) on the precondition that it does not have an adverse impact on their vehicle performance or damage their car. Lastly, according to the meta-analysis, people are concerned about bioenergy systems competing with food systems and that increasing bioenergy production will increase the price of food, and hence support to bioenergy was based on the precondition that it does not compete with existing food supply and prices. Considering this, the Biofficiency concept which aims at the exploitation of solely on biomass residues is expected to be unaffected by such concerns in terms of its social acceptance.

On the other hand, most people are in favor of small-scale local facilities to large bioenergy facilities, and their perception was guided by whether jobs will be created. Policy measures such as government regulations that mandate the use or production of biofuels was not ranked highly, and in fact, some studies in Europe show that government interference in this market is not well liked by the consumer groups. Additionally, government subsidies along the supply chain are not favored by the consumers.

The key findings of the study by Radics et al. [38] are summarized in Table 16.

Table 16. Key findings of meta-analysis carried out by Radics et al. [38] on the public perception of bioenergy

Focus Areas	Key Findings
Bioenergy general support/opposition	• Moderate to low support towards bioenergy • Public is relatively unfamiliar with the bioenergy industry and associated impacts • Greater enthusiasm for second generation biofuels • Support/Opposition depends on respondent awareness and knowledge, opinion on various attributes of product use, experience with renewable energy projects, and media exposure, among others • Support is preconditioned on many factors/attributes around the application

Attributes driving opinion about bioenergy (purchase/use)	• Economic attributes: Price is the primary driving factor
	    ○ Low willingness to pay (WTP) any premium for bioenergy use
	    ○ WTP depends on prevailing fuel/energy price
	• Market attributes: Low cost, consistent availability, performance of biofuels (on vehicles), effect on food availability and food price important
	• Technology and policy attributes: Biofuel and biopower technology is perceived as relatively immature; citizens do not favor subsidies along the supply chain and oppose regulations for green energy use
	• Environmental attributes: Environmental attributes are important only when compared to fossil fuels, odor or air pollution more important than other environmental factors
	• Social attributes: Jobs and national security not as important as market factors; societal subjective norms important; local generation at small scale is perceived positively; institutional support (local authorities) is perceived positively

Demographic effects	• Females more likely to support bioenergy • Younger generation more likely to support bioenergy • Inconsistent relationship between education and support and perceptions of risk associated with bioenergy
Feedstock preference	• Prefer feedstocks that have least impact on natural resources • Prefer other renewable sources (solar, wind) over biomass • Disagreement over importance of grass and wood including wood residues for bioenergy
Information channels Other issues	• Mass media preferred by public • Utility companies ranked second • Siting issues are a challenge • Not informed or no knowledge of bioenergy effects on environment

Landowners

The perceptions of landowners towards bioenergy are summarized in Table 17.

Table 17. Key findings of meta-analysis by Radics et al. [38] on the landowners' perception of bioenergy

Focus Areas	Key Findings
Bioenergy general support/opposition	• Moderate support for bioenergy • Concern about long-term viability of the industry • Positive opinion on employment, rural economic development • Concern over environmental impacts of bioenergy
Factors affecting barriers to supply	• Lack of market structure • Available land to dedicate to energy crops • No commercially successful examples • Barriers to adoption of forest management plans (forest) • Depressed prices for wood (forest) • Loss of soil fertility
Factors driving supply/harvest	• Higher price of energy crops vs. food or pulpwood prices • Low investment cost • Long term guaranteed contracts with fuel suppliers (farm)
Demographic effects	• Those with large land area more likely to supply • Older landowners are more skeptical of the viability
Other	• Low awareness of benefits and bioenergy policies affecting landowners (forest) • Tax exemption not as important as price (forest) • US independence from imports of foreign oil not important

Landowners were supportive of bioenergy primarily due to their perception of its positive impact on employment and rural economic development, while they indicated support for the bioenergy industry if it created rural employment and economic development. However, almost all landowner respondents indicated concerns about the long-term viability of the bioenergy industry. Furthermore, both farm and forest landowners were concerned about the impacts such as loss of soil fertility if energy crops are grown or if thinned materials are removed from forest floors. As stated previously, the Biofficiency concept aims at the use of agricultural and forestry residues, and thus it is not related to the aforementioned concerns of the landowners.

Forest landowners reported limited awareness of the government programs that provided benefits for producing biomass and bioenergy, and were interested in learning more about bioenergy policies affecting them.

The main factors that are more likely to promote the successful implementation of bioenergy technologies from the perspective of different stakeholder groups according to the findings of the study are summarized in Table 18.

Table 18.Main factors that could promote the success of bioenergy investments from the perspective of different stakeholder groups [38]

Key Stakeholders	Factors Likely to Promote Success
Public	• Need for consistent and simple messages across channels from trusted sources • Collaborative planning process that includes integration of local information into project design and consulting from local experts (enhancing security at local level- energy, health, safety)
Farm/Forest Landowners	• A model showing successful deployment at a small-scale (with network of collaboration) essential • Development of certification standards and labeling (Qu *et al.* 2012) • Institutional support (local government, local landowner associations) • Education about production and economics (from extension agents)
Others	• Education is key • Proper management of land

Some of the key areas of focus for the public to mitigate the risk perceptions and promote success are the following:

- Education and information dissemination: The meta-analysis showed a limited public understanding of bioenergy and biomass technologies. This finding emphasizes the need for raising awareness for all stakeholders concerned with renewable energy sources and their link to general issues such as climate change and to local issues, e.g. rural income and community stability.
- A collaborative approach to decision-making: Stakeholders expect to be included in truly collaborative planning, interactive communication, public participation, and collective learning processes. Siting decisions for plants require situation analysis, e.g. what are the expected benefits and concerns, who are influential decision makers, how they see the proposed development, how can local interests be effectively represented, etc. for a local community. Institutional support from local authorities is also important for community- based renewable energy projects to be successful.

Based on the results and discussions, several gaps and limitations in bioenergy perception research were identified by the authors, which included the following:

- Lack of surveys of all stakeholder groups in the same study;
- Lack of pre-biofuel implementation surveys and dynamic analysis based on measures and evaluation of the projects;
- Lack of focus on social impacts;
- Focus on bioenergy in general but less focus on specific product groups such as bioenergy for pellets or biofuels for transportation.

3.2.6 Overview

The socio-economic aspects related to biofuels, bioenergy, and bioeconomy have been investigated mainly in developing countries; much of them associated to the negative social impacts they produce, associated to food security, local livelihoods and reduction of poverty, land tenure, and large-scale production. So far different methodologies have been developed to assess biomass, bioenergy, and biorefineries, which are expected to play a key role in the large-scale implementation of bioeconomy worldwide as the main infrastructure with chemical paths and processes that can produce the bio-products desired for the market. Currently there is no tool, method, or framework generally accepted for measuring biomass socio-economic sustainability [45]. Naturally, the deployment of bioenergy projects needs to be designed in an integrated way in order to enhance community collaboration and participation, assure the active engagement of all potentially relevant societal groups, encourage gender inclusion if needed, and avoid the exclusion of minorities.

Pelkmans at al. [29] assessed the input of different stakeholders (including representatives from industry, biomass producers, certificators/auditors, regulators/administrators, NGOs, consultants, and researchers) through focus-group discussions and a global survey, focusing on the following aspects: key principles of sustainable biomass trade, risks and opportunities of biomass trade, both for import regions (EU countries) and for sourcing regions, and practical barriers for trade. The research was carried out within the BioTrade2020plus project, supported by the Intelligent Energy for Europe program of the European Commission. Statements were provided to the respondents concerning the following topics: economic development, job creation, synergies with local sectors, improved productivity, sustainable practices, building up supply chains, and capacity building.

In Table 19, an overview of how many respondents indicated an opportunity as important or very important, in relation to a certain sourcing region is shown.

Table 19. Global survey – opportunities for different sourcing regions; percentage (%) rated important or very important [29]

Region (#respondents)	**North America**	**South America**	**East Europe (non-EU) and Russia**	**Southeast Asia**	**Africa**	**No specific region**
Economic development	73	80	77	100	64	78
Job creation	56	80	77	83	91	74
Synergies with local sectors	63	80	70	83	73	48
Improved productivity	60	67	53	100	64	39
Sustainable practices	68	80	63	83	91	61
Building up supply chains	58	73	79	100	64	68
Capacity building	53	67	57	100	82	57

Table 20 provides an overview of the percentage of respondents that indicated a risk as important or very important in relation to a certain sourcing region.

Table 20. Global survey – risks for different sourcing regions; percentage (%) rated important or very important [29]

Region (#respondents)	North America	South America	East Europe (non-EU) and Russia	Southeast Asia	Africa	No specific region
Overexploitation (biodiversity loss and carbon loss in forests and soils)	38	67	69	80	85	67
Displacement of local biomass/land use	23	40	62	80	62	57
Reduced access to land	11	60	38	100	69	48
Lower local renewable energy opportunities	23	20	42	60	69	43
Mainly opportunity for large players, less for smallholders	26	73	65	100	85	43
Low value-added exports	21	53	54	80	62	50

In conclusion, biomass fuelled electricity production is an emerging sector of the EU bioeconomy, resulting in an average of more than 1000 new job position openings between 2005 – 2018, with an average increase rate of slightly above 12% [46]. Hence, strongly positive impacts are expected in both regional and international level from the deployment of highly efficient biomass fuelled cogeneration plants based on the Biofficiency project outcomes across the EU.

3.3 Studied scenarios, main assumptions and results

In the present study, the socio-economic impacts of the deployment of the Biofficiency concept in Europe are evaluated in terms of two aspects: job creation and human health impacts.

The first approach to evaluate the job creation potential is by considering the deployment of large-scale CHP plants in order to cover the heating demands of major European cities across different climate zones in Europe via district heating is considered. The second approach involves the deployment of CHP plants throughout the whole Europe by taking into account the total EU potential of forest and agricultural biomass residues.

The main assumptions taken for calculating the biomass CHP deployment needed to cover the annual heat demands, as well as the job positions created for each scenario are subsequently described. For biomass fuelled CHP plants, the average construction time is taken as 2 years. During the construction and installation stage, 15.5 jobs are created per MW [47]. However, these are not permanent job positions, therefore they are not considered in the context of this study.

The operational lifetime of the considered CHP plants is taken as 40 years. For the operation and maintenance stage, 1.5 jobs are created per MW, while 32.3 jobs per PJ for the fuel supply chains are generated [47]. The selected fuels were raw wood pellets from Canada (case A) and steam exploded bark pellets from Finland (case B). Fuel properties were retrieved from Phyllis2 database, as well as experimental measurements conducted in TUM, as specified in Biofficiency deliverables D2.1, D2.2 and D5.2. By considering a standard single electrical (35%) and thermal efficiency (55%), the number of plants that must be deployed in each case is subsequently calculated. Additionally, the number of jobs created was further multiplied by a factor of 1.08 (after personal communication with K. Kemppainen, Metsä Fibre) in the case of steam exploded fuel for each scenario, in order to account for the additional job positions expected to be generated for the fuel pretreatment plants' operation.

As far as human health is considered, the particulate matter (PM) and NO_x emissions reduction that can be achieved via supplying domestic heat via a district heating network from a large scale, highly efficient biomass CHP plant, as compared to the emissions of small domestic log and pellet stoves, taking the annual heat demand of a typical residence (flat) in the city of Hamburg as reference, is assessed.

3.3.1 Job creation

1st approach: Major European cities

The job creation potential by the deployment of large scale biomass CHP plants in order to cover the heating demands of 5 European metropolitan areas is herewith evaluated. The 5 cities with their surrounding areas were selected as being representative of different climate zones, having a large population density, as well as being in close proximity to major EU logistics hubs. The selected cities are Copenhagen, Prague, Hamburg, Thessaloniki and London.

In each case, the inputs to the calculation procedure are the metropolitan area population (taken from Eurostat [33]), the total annual heat demand of the cities, the peak annual load and number of annual heating hours. The above data were offered by plant operators (B. Sander, Ørsted, year: 2016) in the case of Copenhagen, calculated by extrapolation based on data provided by the Ptolemaida district heating operators (Municipal District Heating Company of Ptolemaida, year: 2017) in the case of Thessaloniki (since the two cities are in the exact same climate zone) and from relevant reports for the remaining cities ([48], [49]), while assumptions were made for any missing information. In the case of Hamburg, yearly demand was extrapolated from data for Berlin, since the two cities are in the same climate zone. Existing data on specific heat sold per inhabitant display large variance between the studied cities, as in many cases the entire metropolitan area is not considered. In the case of Prague, for example, the current heat sales were multiplied by a factor of 1.5 in order to estimate the expected heat sales to cover the entire metropolitan area. Of course, the condition of the building stock in each studied city is a major cause of discrepancies.

The total nominal capacity of the CHP plants deployed is calculated by considering a coverage of **80%** of the peak heating demand. Meanwhile, it is assumed that the minimum heat demand covered by the CHP plants is **20%** of the peak value. The overall CHP installed capacity is calculated using the aforementioned electrical and heating efficiencies. Furthermore, in each instance the total fuel consumption and the total number of jobs created for plant operation and maintenance, as well as fuel supply for raw and pretreated biomass fuels is determined.

2nd approach: Residual forest and agricultural biomass throughout Europe

Regarding the location of future full-scale biomass-fired CHP plants, an investigation of the available options on feedstock potential and the realistic fuel volumes that can be mobilized in the surrounding areas needs to be conducted. A recent analysis [50] concluded that **Germany, France, Sweden, Finland and Poland** present the largest unexploited potentials in the EU towards 2030 for forest biomass, collectively representing almost 58% of the total EU supply, while **Spain, France, Poland and Germany** present the highest potentials in agricultural biomass, with more than 51% of the overall EU supply when combined.

Naturally, nearby ports and other logistic centers or transport hubs in neighboring countries are also worth examining as possible locations for the CHP concepts developed in the Biofficiency project, as they can be easily connected to one or more of the available surplus biomass streams through cost-effective fuel supply chains. In this context, large CHP units of 200 MW fuel input and 8000 hours of annual operation are considered, in order to exploit the economic and technical benefits of providing high temperature and pressure steam to nearby industrial consumers, apart from district heating and cooling networks. The jobs created for this scenario were again estimated from a recent report [47].

1st approach: results

The main results from the scenarios of highly efficient biomass CHP deployment in 5 European cities are subsequently presented in *Table* 21. In the cases of Prague, Hamburg and London, the operating hours were based on educated guesses. The number of job positions created refers to the generation of both direct and indirect jobs.

Table 21. Results of the case studies for the deployment of Biofficiency concepts in 5 European cities

City	Copenhagen	Prague	Hamburg	London	Thessaloniki
Annual heat consumption (TWh)	8.8	4.2	6.7	66	5.8
Annual operating hours	5170	4200	4204	4600	4266
Considered plant capacity (MWth)	170	130	130	200	100
No of CHP plants	10	6	18	50	14
Total no. of jobs created (raw fuel pellets)	6500	2885	8442	37060	4919
Total no. of jobs created (SE-treated fuel pellets)	6648	2942	8607	37839	5016

As derived from *Table* 21, the operation of one large scale, highly efficient biomass-fuelled CHP plant can result in the generation of between **360** (for raw wood pellets in Thessaloniki) and **754** (for SE-treated bark pellets in London) new job positions. This is estimated without taking the construction and installation phase into account. In order to translate these employment benefits into economic growth, values for average annual wage in the region, as well as national and regional GDP are needed. For instance, for the Hamburg scenario, assuming an average wage of 42 500 €, the expected regional income raise – considering that all jobs are created in Germany - can reach **20,3 million €**, roughly around **0.6% of the German GDP**.

2nd approach: results

Considering the the EU-wide deployment of the Biofficiency proposed concepts, while also taking into account the revised RED biomass criteria for heat and power for achieving a minimum 70% GHG emissions, the technical potential of EU-sourced biomass includes 53.9 Mtoe of agricultural waste and 102.7 Mtoe of forest residual biomass [50]. These residues can serve as fuel for large scale, highly efficient CHP plants that can be operated for almost all year long for the supply of hot water and process steam to nearby industries, apart from district heating and cooling, thus benefiting from the robust, corrosion-resistant design to allow for higher profits from the year-long sales of elevated properties steam.

Assuming 30% fuel energy losses due to fuel pre-treatment and densification processes, the overall potential of residual biomass in the EU can fuel up to **797** large CHP units of 200 MW fuel input and 8000 hours of annual operation. It should be noted here once more that the geographic location of each plant plays a decisive role in determining the installed capacity of each unit. Regarding the pretreated fuels, the energy yield of each fuel pre-treatment process varies, and therefore the actual number of CHP plants to be fuelled by a feedstock pre-treated following a specific technology shall vary accordingly. However, any surplus fuel demand can be swiftly and effectively covered through the growing extra-EU pellet market.

The anticipated construction of 797 large scale biomass CHP units across the EU can lead to the creation of **more than 580 000 job positions** (both direct and indirect) in the EU biopower sector. Naturally, as already discussed, in the case that the fuel is sourced outside the EU, the majority of these job positions will be subsequently located outside the EU, therefore a large percentage of the expected benefits at EU regional level will be lost.

3.3.2 Health impacts

Residential wood combustion (RWC) is one of the main sources of fine particle ($PM_{2.5}$) emissions in many parts of the world, with Europe being one of the most heavily affected areas [51]. NO_x emissions are also a major health hazard for urban areas. Large-scale biomass fired CHP units can greatly assist in minimizing this hazard due to their lower emissions arising from the implementation of highly advanced combustion technologies. These are not cost effective in small-scale applications; however, they are proven feasible in large-scale installations due to economies of scale. Therefore, a comparison between small and large-scale biomass firing emissions was performed as a useful addition to the present study.

To assess the emission reduction potential for centralized district heating networks, as compared to domestic heating stoves, a district heating network was considered as described in Biofficiency Deliverable D7.1, assuming typical hot water properties (85 °C, 2 bar). An average heating demand of **13800 kWh_{th}/year** for a typical household located in Hamburg, Germany was selected as a typical value from a relevant study [52]. Assuming an overall heat transmission and distribution efficiency of 80% due to grid morphology and distance losses, the maximum number of households that can be covered by the operation of the district heating network was calculated. Considering that these households are at present heated using 6 kW domestic wood stoves, a comparative assessment of the emission savings for different capacity factors was undertaken.

Representative values for emissions of PM_1 and NO_x of hybrid domestic wood log and pellet stoves were taken from a recent study [23]. These were compared to the limit values for large combustion plants adapted from the Industrial Emissions Directive (IED) [25]. It is noted here that future biomass CHP plants based on the advanced concepts introduced by the Biofficiency project will achieve specific emission values well below the IED limits. The calculated emission savings responding to a range of annual hours of operation are presented in Figure 9. As presented, an annual reduction of up to 130 tons of PM and up to 70 tons of NO_x emissions are expected from the construction of only one highly efficient large CHP installation.

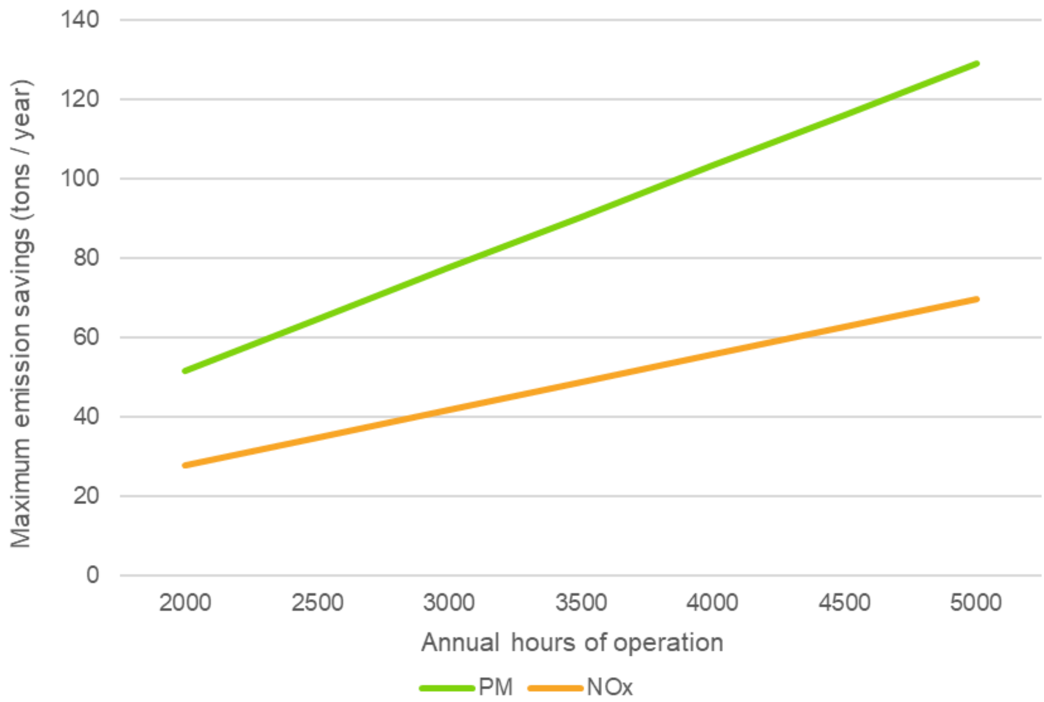

Figure 9. the estimated potential for emission savings when switching from individual domestic log stoves to large CHP - based district heating network

4. Conclusions

The results for the studied scenarios, along with their interpretation, are presented below.

4.1 Risk analysis results

For the project development stage, fuel supply risk, along with the volatility of solid biofuel prices, was found to be the most critical risk factor for biomass fueled CHP plants in Europe, according to the reviewed literature. Regarding the operational hazards, fuel self-heating and dust explosions are the most critical risks currently faced by the bioenergy industry.

In general, however, due to the high safety standards implemented in modern biomass CHP plant design and operation, as well as the advanced fuel pretreatment technologies, innovative construction materials and design principles proposed by the Biofficiency project, the overall quantitative risk assessment results are relatively low for traditional operational hazards, as shown in Table 1. The standardization of biomass fuels, with the assistance of the emerging solid biofuel certification schemes, will further lower the operational hazards, as well as the equipment failure risk.

Of course the social perception of bioenergy and the financial incentives provided are also major risk factors, as discussed in the present study. Stakeholders from the fields of energy and environment, involved in policy recommendations and decision making, need to further stress the need for clear, concise legislation which will aid in transparently fostering the most beneficial investments for both the environment and the EU societies, and at the same time effectively communicating the problems and mitigation strategies to the EU citizens.

4.2 Socio-economic assessment results

The European-wide deployment of CHP units based on the Biofficiency concepts can facilitate the realization of the targeted creation of up to 1 million new job positions in bio-based sectors by 2030, especially in rural and coastal areas [53], providing the grounds for the creation of **more than 580 000 new job positions** across the EU. At city level, 5 case studies based on the major EU metropolitan areas of Copenhagen, Prague, Hamburg, London and Thessaloniki were evaluated, resulting in the expected generation of between **3000** and **38000** new job positions in each scenario. Fuel pretreatment was also included in the evaluation of the scenarios, as an emerging sector for job creation. The main advantage is that, in the case that EU-sourced biomass residues are utilized as fuel, the job creation will take place entirely inside the EU, thus strengthening the European bioeconomy and supporting the development of EU rural and semi-rural areas that were recently impacted by the worldwide financial crisis.

Regarding the health impacts of the examined scenarios, the PM_{10} and NO_X emission limits for large combustion plants according to the IED were compared to the equivalent emissions of small-scale domestic wood stoves fuelled by log wood for heating to assess the environmental benefits of centralised district heating installations based on highly efficient biomass CHP plants. The future highly efficient CHP plants based on the Biofficiency project concepts will perform well below these limits. However, even when following current legislation limits, an annual reduction of up to **130 tons of PM_1 and up to 70 tons of NO_x emissions** is expected. Of course, apart from lowering emissions and providing improved biomass combustion quality, district heating grids also offer the benefit of minimizing domestic fire risks due to stoves and fireplaces.

Other environmental impacts (both for gaseous emissions and ash), along with the land use change impacts of the examined scenarios, were assessed in the Biofficiency LCA study available in Deliverable D5.2. Finally, compliance with the current and future EU and international guidelines and regulations on sustainable development (RED I & II, UN Sustainable Development Goals), along with existing certification frameworks (such as ENplus, World Bioenergy Association - WBA, International Organization for Standardization - ISO, Roundtable on Sustainable Biomaterials - RSB and Global Bioenergy Partnership - GBEP) will assist in promoting and further expanding sustainable forestry and agriculture both inside and outside the EU.

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