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## INDO-NORDEN – a consortium for developing holistic processes and land use practices for clean energy

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### Abstract

Intensive forest harvesting techniques are being used in Finland to enhance the share of bioenergy. However, there are no clear indications as to how environmentally safe are these practices. We address this issue in the INDO-NORDEN project through field studies addressing the climate impacts on the ecosystem carbon balance. Also, we will address several major issues relevant to Nordic agriculture under changing climatic conditions. INDO-NORDEN plans to develop biofuel production processes adopted in Estonia and India for enhancing biofuel yields. The effects of biomass raw material on ash characteristics, fine particle and gas emissions in combustion plants will be evaluated.

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## 1. Introduction

The EU and India share common objectives in enhancing energy security, promoting energy efficiency and energy safety, and the pursuit of sustainable development of clean and renewable energy source [1]. The EU's Renewable energy directive has set a binding target of at least 27% final energy consumption from renewable sources by 2030. Therefore, EU countries have committed to reaching their own national renewables. India, on the other hand, is emerging as one of the fastest growing countries in the world. Energy being the driver of this growth, its availability is of great importance to sustain a high level of growth. It is projected that the energy demand in India will be three to four times higher than the current level in the next 25 years [1]. Bio-based energy (produced from biomass and waste) is of particular interest for all of our consortium partners in meeting the common objective of replacing or complementing fossil fuels in the transport sector and in power (and heat) generation.

As a contribution to mitigation of climate change, the use of renewable energy is being promoted by international and national policies. Finland is expected to increase its share of renewable energy sources to more 50% by 2030 [2]. Currently, major share of the renewable energy supply in Finland is derived from forest resources. There is, however, a great scope for increasing the share of forestry based resources. Forest harvest residues are important raw materials for bioenergy in Finland. Removing these residues from a harvest site reduces the carbon stock of the forest compared with conventional stem-only harvest because less litter is left on the site. The indirect CO<sub>2</sub> emissions from producing bioenergy occur when carbon in the logging residues is emitted into the atmosphere at once through combustion, instead of being released little at a time as a result of decomposition at the harvest sites.

Another way of achieving intense harvesting is to extract the stumps that remain after final stem harvesting (whole tree harvesting). The stump harvesting technique is being increasingly practiced in Nordic countries. The biomass in the stumps and coarse roots corresponds to almost half of the biomass stored in stems in a mature forest [3]. However, little is known about the environmental consequences of intensive harvesting of logging residues and stumps and how such forest management practices affect the soil organic carbon (SOC) content, the overall ecosystem C balance and consequent energy conversion in combustion plants and fine particle emissions. Therefore, the substitution efficiency (the degree of emission reductions in relation to fossil fuel) of this intensive forest harvesting technique in Finland needs to be determined through continuous monitoring of ecosystem carbon balance measurements.

Biogas production is seen as a potential GHG mitigation measure in agriculture [4]. Currently most farm scale biogas plants in Northern Europe use animal manure as the basic substrate. The bio-methane production can be substantially increased by adding plant material into to the production chain [5-6]. Therefore, grass silage under Nordic climate is highly preferred as a co-substrate with manure or slurry. A further step is to include perennial legumes (e.g., red clover) and their symbiotic N fixing capacity in forage mixtures to produce biogas. This facilitates replacement of inorganic nitrogen fertilizers via nitrogen fixation by clovers thereby decreasing emissions and consumption of fossil fuels during fertilizer production. In order to evaluate the true potential of biogas production it is crucial to measure the total GHG balance originating from production of legume-grass silage used for biogas plant [7]. In addition, recycling leftover biogas substrates into the soil to produce biomass improves nutrient (N, P, K) cycle and increases the sustainability of the system. The consequences of applying recycled digestate on soil GHG emissions or C content are not clear but are relevant for soil quality management.

Estonia's target for 2020 is a 25 percent share of energy from renewable energy sources in its total energy consumption with at least 10 percent share of bio-fuels in the transport sector. Studies conducted on bioethanol production from different biomass types in Estonia have found that different agricultural waste biomasses are a perspective choices for lignocellulosic bioethanol production [8]. Lignocellulosic materials such as barley and rye residues are the most promising feedstock in Estonia for ethanol production considering their great availability, low cost, and sustainable supply [9-11]. However, the ethanol produced from lignocellulosic material is more expensive than that from sugars or starches [12]. In order to overcome this more efficient processes must be developed. Currently the most expensive part in lignocellulosic bioethanol production is pretreatment and therefore different pretreatment methods are widely studied. Since cellulose is embedded in the lignin matrix, the biomass needs to be pretreated to make cellulose accessible for enzymatic saccharification [13]. Several pretreatment techniques currently in practice include physical, chemical, biological and hybrid processes for effective hemicelluloses and lignin removal. The most perspective methods for this are physico-chemical methods which enable to gain highly

effective deconstruction of biomass while no chemicals are used which makes this more economical way. Further studies are also aiming to improve the hydrolysis and fermentation efficiencies to gain higher ethanol yields from lignocellulosic biomass. By reduction in the bioethanol production costs and more efficient processes, the commercial production of lignocellulosic ethanol can be made available and this will enable to meet the national binding targets by 2020.

India is one of the leading producers of sugarcane (*Saccharum officinarum* L.) and rice (*Oryza sativa* L.) in the world [14]. It is estimated that about 686 MT gross residue is available in India on an annual basis from the 39 crop residues generated by 26 crops. Out of this, 545 MT is contributed by cereals, oilseed, pulses and sugarcane crops together. Several papers have reported on the utilization of rice straw for the production of second generation biofuels [15]. Biogas can be produced from rice straw by anaerobic digestion [16]. Anaerobic digestion of rice straw is a green technology since it aids in better waste management as well as reducing greenhouse gas emissions [17]. As production of biofuels from rice straw is risky owing to its high silica content [18], sugarcane crop residues are gaining popularity in India owing to their large availability. Sugarcane harvesting leads to production of a large amount of post-harvest residues which could be an abundant, inexpensive and readily available source of lignocellulosic biomass (79.4 MMT) [19-21]. The residues are generally burnt in the field itself with serious consequences for the soil microbial diversity and environmental health. They can be used as substrates for the production of biobutanol, isobutene and other value added products. The utilization of these residual biomass will reduce the environmental pollution and provide energy security to the nation.

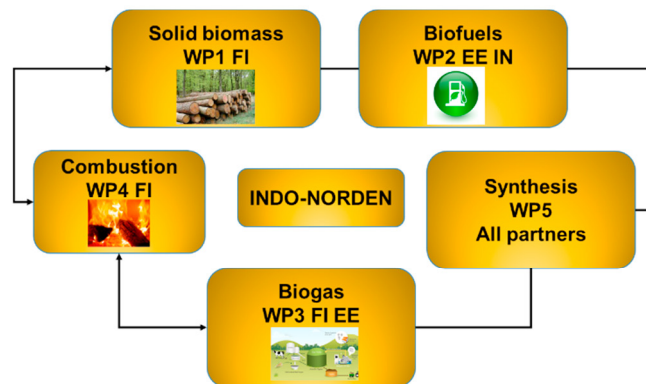


Fig. 1. The work package (WP) structure of INDO-NORDEN.

With the above in view, the INDO-NORDEN project proposal was drafted in response to the Science and Technology call of the INNO INDIGO Partnership Program (IPP) on Biobased Energy. Finland, India and Estonia have thus joined hands to work together in INDO-NORDEN to address the following broad objectives;

- Foster new, scientific collaboration among EU and Indian partners for long-term research activities with a focus on science and technological support to regional bio-based energy issues
- Investigate, evaluate and develop efficient processes and land use practices of transforming forest and agricultural biomass, agricultural residues and farm waste into clean fuels (solid, liquid or gas), by thermochemical or biochemical conversions as relevant to participating consortium partners.

## 2. INDO-NORDEN project methodology

Biobased energy is of particular interest for all partner countries, especially energy produced from biomass and waste, to replace or complement fossil fuels both in the transport sector and in power (and heat) generation. The methodology adopted involves specific tasks carried out in workwork packages (Fig. 1). There are in all five work packages (WPs) in the project. They are described below;

## 2.1 Solid Biomass

The specific objectives of this work package are the following:

- To review the availability of various solid biomass resources in each country – for direct combustion and production of heat and electricity in Finland and for liquid fuel generation in Estonia and India
- To assess the carbon balance of a clear cut forest site (with logging residues left on the ground) employing the eddy covariance technique and compare the C balance of an intact mature forest stand
- To perform a life cycle assessment of the intensive forest harvesting techniques in Finland and provide recommendations to the forestry sector on the environmentally safe practices

To achieve the above objectives, continuous field measurements of GHG exchange with eddy covariance technique will be carried out from June 2017 – April 2019 at the Hyytiälä Field station of the University of Helsinki (61° 50' N, 24° 17' E) in a forest site which has been recently exposed to clear-cutting. Supporting meteorological, soil and plant data will also be collected. These data will be used to assess how the Carbon balance is altered after removal of biomass for bioenergy and what environmental factors govern the carbon balance of these ecosystems (Fig. 2) and perform a complete life cycle analysis of the intensive forest harvesting technique.

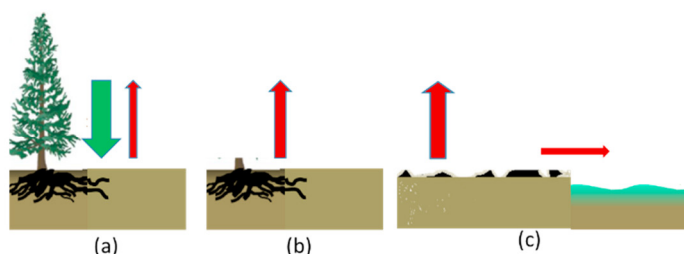


Fig. 2: Ecosystem carbon fluxes in a) an intact forest, b) clear-cut site and c) a site from where all biomass including stumps have been removed for bioenergy. We hypothesize that while an intact forest is a sink, clear-cut and stump harvested areas are increasingly greater sources of CO<sub>2</sub> to the atmosphere and nutrient losses to the adjacent waters.

## 2.2 Biofuels

The specific objectives of this work package are

- To review the current state of affairs with regard to liquid fuel generation potentials in Estonia and India (and Finland) vis-à-vis the global trends
- To develop efficient processes to transform e.g. agricultural lignocellulosic biomass (barley and rye) into different biofuels through thermochemical or biochemical conversion
- To improve technologies and biological tools for conversion of agricultural residues and wastes (sugarcane and rice residues) into fuels and fuel additives aiming at a complete life cycle assessment.

Handling of agricultural residues and wastes is a common problem across the globe. India, being one of the largest producers of sugarcane and rice, has huge amounts of residues generated each year. Similarly, barley and rye represent the dominant cereal crops in Estonia. Lack of a proper waste handling strategy leads to environmental problems and loss of opportunities to extract valuable resources from the waste. Therefore, WP2 offers solutions to a full utilisation of biomass in lignocellulosic biofuel production processes. In Estonia, different chemical-free biomass pretreatment methods will be evaluated and researched to achieve maximum sugar and ethanol yields (Fig. 3). To utilize whole of the biomass, the hemicellulose utilization by hydrolysing it to monomers and fermenting 5- and 6-C sugars will be studied. In order to gain high sugar and ethanol yields in bioethanol production process an effective pretreatment must be applied. In this project a new approach to existing physico-chemical biomass pretreatment methods - N<sub>2</sub> explosive decompression pretreatment of biomass - is proposed [12]. Proposed

$N_2$  explosive decompression pretreatment method is economically and environmentally attractive since no catalysts or chemicals are added in the process.

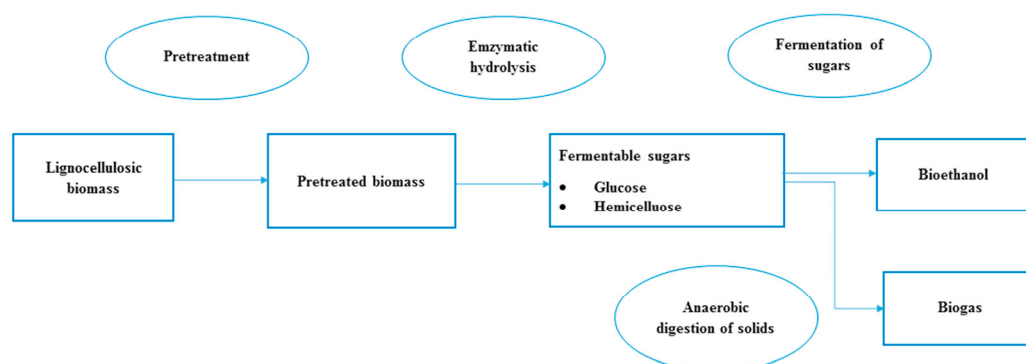


Fig. 3. Bio-ethanol production processes followed in Estonia.

In India, rice straw and sugarcane plant residues will be evaluated for the production of biobutanol and isobutene. The biomass will be pretreated and hydrolyzed as per the optimized condition developed in NIIST laboratory in earlier studies [18]. The biomass hydrolysate containing the fermentable sugars will be utilized as substrate for the production of biobutanol and isobutene. The anaerobic cultures will be isolated initially and physical fermentation conditions and media components will be optimized for improving the yield and productivity of isobutene and butanol from the potent strains. To improve the productivity of isobutene in natural microbial strains, heterologous expression of *ldhD*, *Isomerase* and *mva D* genes from *Lactobacillus acidophilus* into the isolated potent strain will be carried out to increase the yield of isobutene. Finally, we propose to develop the proof of concept by designing a prototype of anaerobic bioreactor up to 1 litre capacity for a continuous upstream and downstream process for the production of biobutanol and isobutene from biomass hydrolysate. As isobutene is a gaseous end product, a bioreactor will be designed, with a first module for gas sparging and second module for gas outlet from the working chamber.

### 2.3 Legume perennial agriculture and biogas production

The specific objectives of this work package are

- To promote soil nutrient recycling and farm-scale biogas production
- To improve the integrated production chain of perennial legume/grass mixtures and biogas by applying farming practices that aim at net reduction in GHG emissions from agricultural production
- To explore the possibilities of using residual waste (left over from the biofuel production described in WP2) in an anaerobic digestion process to produce biogas

In this WP, a farm-scale biogas plant will be used to digest cattle slurry and legume-grass mixture (*Phleum pratense* L; *Trifolium pratense* L.), a combination yielding more gas than slurry only. The grass will be produced using the resulting digestate as fertilizer. Total GHG balance of the grass-legume system will be continuously measured at field scale using the eddy covariance method [22–24]. A three-month biogas experiment with a farm-scale digester located at Luke Maaninka Finland will be used to determine the biogas production from dairy cattle slurry and mixed with grass-legume silage and annual biogas production ( $\text{kg CH}_4 \text{ ha}^{-1} \text{ year}^{-1}$ ) will be calculated. Surveillance of the biogas process with continuous biogas measurements and regular samples of feed and digestate will be done including the evaluation of the losses of stored biogas. A field-scale study on digestate use in production of grass/legume-mixture will be established (Natural Resources Institute Finland (Luke), Maaninka).

Grass-legume (mixture of timothy and red clover) silage will be produced on a 6.3 ha field that has eddy covariance and micrometeorological towers installed for year-round GHG and weather measurements. Silage will be harvested two times per season during 2017 and 2018. After this, the field will ploughed and the vegetation will be renovated. Digestate will be given with injection method after the first cut. Additional fertilizer will not be used. The yield (kg DM ha<sup>-1</sup>) will be determined by weighing the harvested bales. Relevant soil, plant and climate data will be collected. Additionally, as described in WP2, there will be residues left over from the bio-ethanol production. These residues will serve as substrates for biogas production. Estonian and Indian partners will generate knowledge on how the biofuel production processes can help produce biogas also as an integral part of the biofuel production system.

#### 2.4 Biomass combustion processes, emissions and ash characteristics

The specific objectives of this work package are

- Determine partitioning of ash species with the selected biomass raw materials during combustion representing typical grate boilers used e.g. in district heat power plants
- Determine emission factors of health and climate relevant emission components for the selected biomass fuels, including e.g. fine particles, black carbon, heavy metals, NO<sub>x</sub>, SO<sub>2</sub> and CH<sub>4</sub>.
- Evaluate the suitability of the alternative biomass fuels for various combustion plants, including considerations on the requirements of flue gas after-treatment techniques in various boiler sizes and possible slagging and fouling tendency in the boiler.
- Determine the composition of various ash fractions with special focus on environmentally hazardous metals, valuable metals for material industry and valuable soil nutrients
- Develop innovative methods for separating and recycling of ashes as nutrients and as raw materials for industry.

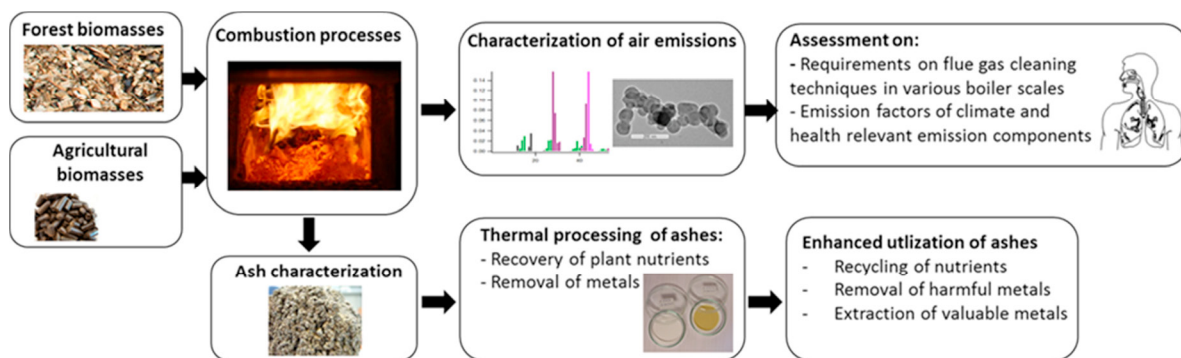


Fig. 4. Study on biomass combustion emissions and ash characteristics in INDO-NORDEN

The potential sources of new biomass raw materials include utilization of unused farmlands for growing of short-rotational plants as well as more efficient utilization of forest harvesting residues and stumps. However, this approach includes challenges which need to be evaluated. First, in both cases the soil nutrient balance needs to be considered and methods for recycling nutrients back to soil without environmentally harmful effects need to be developed [25]. While biomass ashes are concentrated with important nutrients, they also contain large amounts of toxic metals which need to be considered in ash recycling [26-27]. Second, the utilization of alternative biomasses in energy production has been shown to increase flue gas emissions with adverse health effects (Fig. 4), including fine particles, SO<sub>2</sub> and NO<sub>x</sub> [26-27].

In this WP, the combustion characteristics, ash behaviour and emission formation of the biomass raw materials selected (in Finland) will be studied at the combustion research facility of UEF ([www.uef.fi/ilmari](http://www.uef.fi/ilmari)). The facility is equipped with a 40 kW logic controlled grate combustion reactor for biomass combustion studies, and a wide range of measurement & analysis equipment to study combustion processes and their emissions. The reactor consists of a moving step-grate burner capable of burning various biomasses, a ceramic insulated combustion chamber followed

by a heat exchanger. The reactor is designed to have temperatures and residence time similar to larger boilers, and various combustion air staging possibilities, thus representing for example district heating boilers that commonly utilize various wood residues as fuel in Finland.

### 2.5 Synthesis of project results

The specific objectives of this work package are

- To integrate results on scientific/technological processes and practices employed in the study for utilization of bioresources for bio-based energy (solid biomass, biofuels and biogas) as relevant to consortium partners
- To summarize major results from INDO-NORDEN, discuss their main policy implications, and identify issues where further research seems most important and make recommendations, based on the knowledge gained in this project, for the primary bioenergy issues where science support is lacking.

The various work packages are expected to contribute a wealth of knowledge on the processes and land use practices in the utilization of bioresources in participating countries on the path of a bioeconomy society. This work package will synthesize this information and assess the overall performance of this project with regard to the following bioeconomy criteria;

- adding value to existing silvicultural and agricultural practices,
- bringing about technological innovation in forestry, agriculture, and waste management,
- improving soil nutrient management, productivity and/or hydrological conditions,
- sustainable land use management,
- the project's potential for reducing the cost and increasing the efficiency of lignocellulosic bioenergy technologies,
- assessing biogas production potentials in view of the fact that the current anaerobic digester systems face formidable barriers owing to relatively low energy content per unit of feedstock, high initial investment costs, and considerable logistical complexity,
- finally, reducing greenhouse gas emissions through the replacement of fossil fuels.

The project aims to address bioenergy issues in all three sectors – solid biomass, biofuels and biogas. Forestry is an important biomass contributor in both Finland and Estonia. The two partners will work together in exploring forestry biomass potentials in the Nordic countries. Estonian and Indian partners will work closely on developing biofuel production processes. This is an area of strong synergy in the project to highlight the state-of-the-art with respect to generation of transportation fuels in the two countries. Finland, although not involved in this project through liquid fuel production, will contribute current information on the issue in the country. All three partners are engaged in biogas production research – Finland through the use of energy crops and farm waste for biomethane production and Estonia and India through biogas production as an aftermath of biofuel extraction from agricultural residues. While addressing nation-specific bioeconomy issues, different partners will help explore commonalities and differences and pave the way for future scientific collaborations contributing to the solutions for the global energy crisis at hand.

### 3. Concluding remarks

- From the viewpoint of solid biomass, we will provide through INDO-NORDEN new information on how the ecosystem carbon balance changes with intensive forest harvesting techniques in a multi-year field experiment using novel GHG measurement techniques. There is a need for such information from different sites under varying climatic conditions.
- On the use of agricultural biomass for biogas production, we will conduct a field experiment to assess the impact of the cultivation of a mixture of legumes and grasses on the ecosystem GHG balance. We will examine the impact of the use of the legume-grass mixture as a co-digestate with farm waste (manure) on the yield of bio-methane gas in a biogas plant. The biogas digester residues left over after bio-methane extraction will be



recycled as an organic fertiliser on the grass mixture field. This novel concept will ensure that the resources are used in a sustainable way allowing proper soil nutrient management and avoidance of artificial fertilizers. Novel GHG balance measurements will be carried out at all stages of the experiment thus highlighting the system feedback mechanisms to a changing climate. The results are of high importance for organic and conventional grass based farming as well.

- The project will offer science based solutions to pretreatment inefficiency and high costs, full utilization of biomass, and fermentation of both, C6 and C5 sugars for lignocellulosic bioethanol and biobutanol production.
- The project will address the role of microorganisms that can hydrolyse hemicellulose resulting in additional sugar content thus, increasing the total ethanol yield. Bioethanol/biogas coproduction will ensure the complete utilization of biomass. INDO-NORDEN will pave the way for the design and construction of a pilot-scale instrument that employs the techniques developed here for large scale bioethanol production.
- The WP on combustion processes will evaluate flue gas emissions, including e.g. fine particles, SO<sub>2</sub> and NO<sub>x</sub> and ash properties from the utilization of alternative biomasses in energy production. The results are useful in assessing potential health and climate effects of biomass combustion, the requirements of flue gas cleaning systems, as well as in the development of methods for more efficient recycling of ashes as nutrients and other raw materials.
- Regarding the market sectors within the scope of this project – bioethanol, biobutanol and isobutene- this project will provide new bioproducts for a market in expansion with the advantages of positive environmental impact in relation to the currently existent products and lower cost.

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