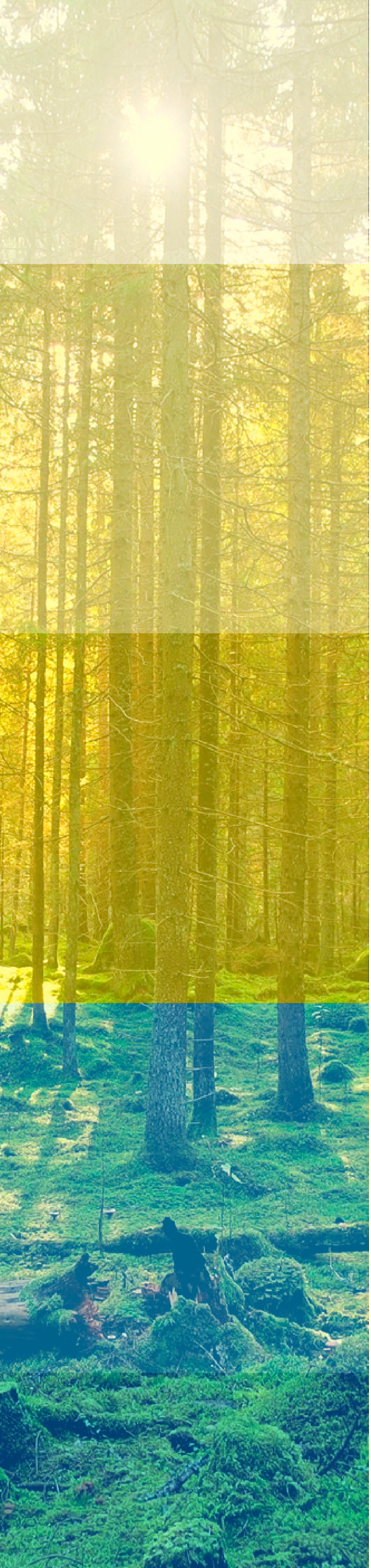

MISTRA
The Swedish Foundation for
Strategic Environmental Research

Background paper

Bioeconomy and digitalisation

November 1, 2017

Authors:
Antje Klitkou (Chairman)
Joe Bozell
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Contents

Background

Mistra continuously strives to invest in research programmes with great relevance for developments in society and industry and with strong pertinence for solving environmental problems. In response to a number of contacts with various representatives from industry and forestry owners associations together with studies of current trends in research literature, the bioeconomy was identified as an area of particular interest. Concurrent rapid development of the IT sector and the digitalisation of society opens new opportunities for the future, often termed the next industrial revolution. The coupling of these two areas, the bioeconomy and digitalisation, seems a logical step forwards.

A workshop arranged by Mistra together with the Swedish Forest Industries Federation further confirmed the relevance of conjoining bioeconomy and digitalisation. Mistra's board of trustees, therefore, commissioned a background paper covering the relevant topics with a view to publishing a call for research proposals. This background paper has been written by a group of experts representing disciplines expected to be covered by the proposals.

Mistra envisages a programme which covers a wide range of topics at different levels. Topics could vary widely and range from the source and processing of biomass, increasing the value of the bio-base through the introduction of new classes of products, to digitalisation of the biomass processing industry, which is already ongoing, to attitudes of consumers and market partners. It is clear that researchers preparing proposals in response to a call have greater knowledge of the particular details to be addressed. The background paper should, therefore, be read as an opener to the potential field of research rather than a limitation thereof.

The assignment

A working group comprising international experts has drawn up this background report as documentation for Mistra's Board of trustees, ahead of a forthcoming decision on whether to call for proposals for research funds for a programme in the area described above.

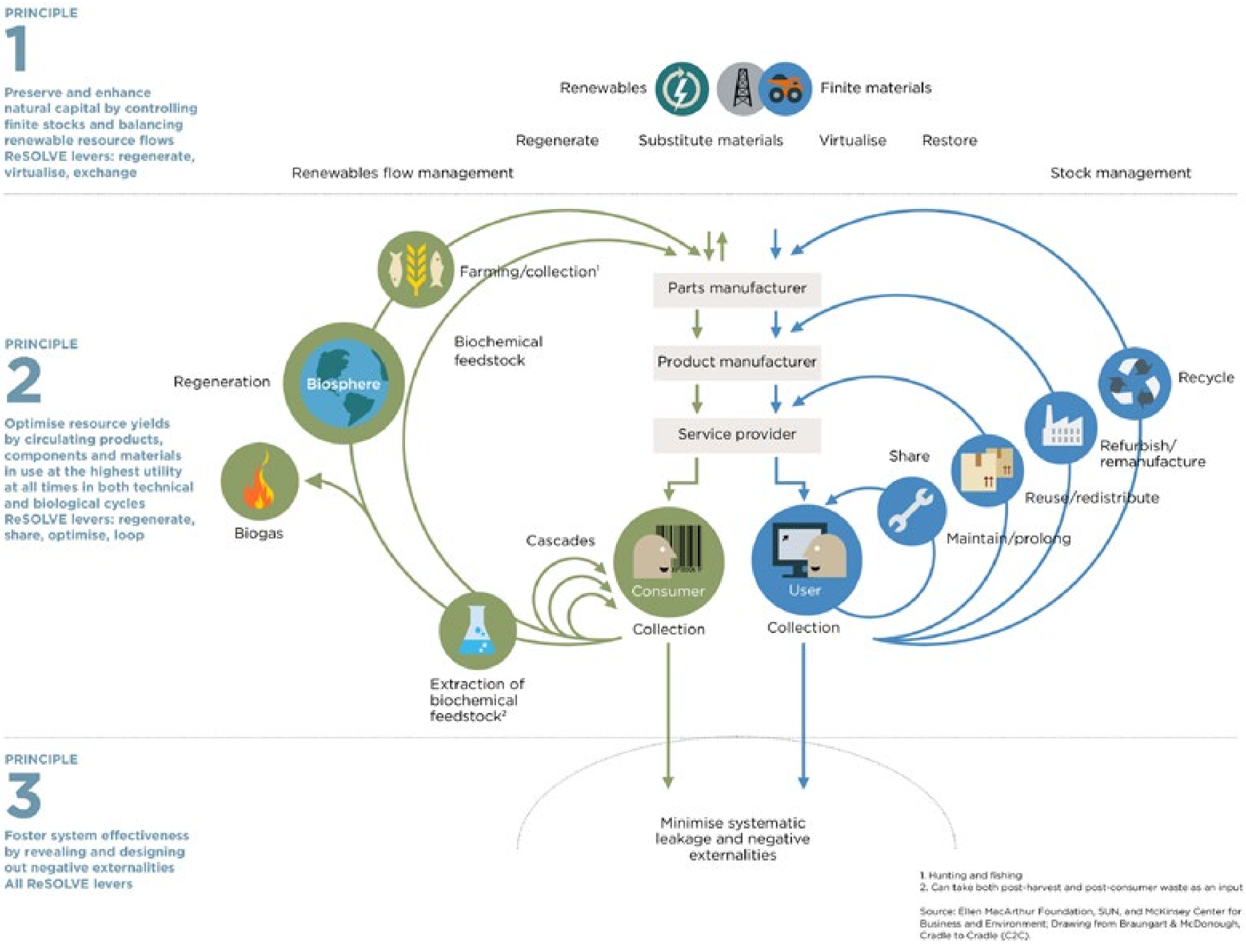
The group's tasks were:

- to describe the challenges of developing a future sustainable bio-based economy where digitalisation plays a central role
- to provide an overview of the current state of the art within potentially relevant areas, both for Swedish research and in an international perspective
- to provide some guidelines as to the possible orientation of a new research programme.

Introduction

FIGURE 1. The circular economy as depicted by the Ellen MacArthur Foundation. Finite resources, represented in blue, should be conserved within the system as long as possible. Renewable resources, shown in green, are also conserved within the system while new inputs are available through various regeneration processes for biomass and, in the case of energy, from solar, wind, and hydroelectric systems.

The development of our modern industrialised society seems to be coupled to greater access to consumer products at lower relative cost. This has, in turn, led to a higher standard of living with benefits to health and well-being. The resources needed to drive this development have traditionally been extracted from a pool of natural resources through processes such as mining or petrochemical refining. The general attitude towards these resources has been that they are, from a human perspective, inexhaustible. However, during the latter half of the 20th century it has become apparent that human activities have depleted the available resource base. At the same time, human activities, especially the burning of fossil based fuels, have been shown to be the main cause of ongoing climate change. There appears to be a growing consensus that society needs to manage resources much more efficiently in the future, especially with regards to fossil fuels and feedstocks, which should be replaced by renewable resources. The consequences of this will be a change from the traditional fossil economy to a more sustainable bioeconomy which should also be resource conservative and circular, as illustrated in figure 1 (Ellen MacArthur Foundation, *www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram/*).



Both industry and individuals have gained greater access to the exchange of information through the advent of greater computer capacity and the connectivity between systems. This has been facilitated by the internet, which couples objects, information and services. There is every reason to believe that the development of a circular economy based predominantly on the use of sustainable and renewable resources, a bioeconomy, should also be completely connected through the internet giving open exchange of information and services.

Mistra's intentions are to facilitate the development of a digitalised bioeconomy contributing to a sustainable society through investment in a research programme. The research topics and questions to be addressed are the domain of the researchers seeking to participate in the programme, as is the approach to solving them. The aim of this report is to identify some topics which may be relevant for a research investment and which may be of interest for investigators seeing the potential in coupling the digitalisation of society with a sustainable bioeconomy.

Scope

The focus of the proposed research programme should be on the role of digitalisation in the development of a circular and sustainable Swedish bioeconomy. The programme should address this topic in a comprehensive way, covering technological, socio-economic and political aspects of this development.

This is a multidisciplinary call and requires collaboration between academic research teams, experts from different industries in Sweden, such as ICT-firms and the chemical, forest-based and consumer goods industries. We invite the participation of experts from the public sector, incumbent firms, and also new entrants.

The core industry for this proposed programme is forestry and the forest-based industry in Sweden. This industry is one of the corner stones of the Swedish economy. It is estimated that Sweden's bioeconomy constitutes 7.1 percent of Sweden's total value added and 22.9 percent of the total goods exported in 2014. Forest-based industries comprise a broad range of manufacturing: beside the forestry sector the pulp and paper, construction, furniture, textile and other consumer goods manufacturing industries use forest resources. There is also potential for introducing wood-based feedstocks in other industries to replace fossil resources, for example, in the chemical industry. As this new bioeconomy evolves, it will be enabled through biorefineries, which will have access to an even wider range of different raw materials: wood, agricultural residues, municipal solid waste, aquaculture residues, etc. The ability to use an increasingly large proportion of *all* lignocellulosic materials will significantly improve Sweden's efforts toward greater sustainability and incorporation of renewable feedstocks into the nation's overall raw material stream.

The suggested programme should analyse how the Swedish bioeconomy can meet digitalisation as a mutual catalysing process resulting in a kind of industrial revolution. However, one should not limit this industrial revolution to robotics and automation in the production process, but consider that the whole business cycle has to be digitalised. This includes the extraction and procurement of materials, including the planning of these processes, logistics, as well as the distribution of intermediate goods and the retail of finalised products to the consumers, including the reuse, repair and recycling of products and materials. Equally important will be the connection of this process with human resources: (1) improving competencies of the employees, (2) positively affecting the required levels and scope of skills, and (3) increasing the number of jobs.

Digitalisation is progressing in different complementary perspectives and at varying speeds in different industry segments. The perspectives range from evolution to revolution and can proceed in parallel. Within this non-hierarchical structure, we can distinguish between four main perspectives of digitalisation:

Digitalising business processes, by applying digital technologies and solutions, including automation, digital process control, measuring, scanning, image recognition, robotics, IoT, etc.

1. **Digitalising customer experience**, by engaging the customers and transforming their experience in the interaction with digital solutions which can also be integrated with physical solutions. This can be done e.g. through on-line, real-time,

customised service experience applying self-service elements and providing immersive experience through virtual or augmented reality.

2. **Digitalising products and services**, which has already been done in various industries (banking and music industry as examples) could also find various ways of emerging in bio-based industries. Examples include embedding digital and electronic functionality into the forest industry products (e.g. intelligent packaging) to even providing fully digital products that get their physical form through additive manufacturing (3D printing) using wood-based raw materials.
3. **Re-innovating business models**, by rethinking the intended value of a product or service, reshaping the business for creating this, and re-defining the value network around it. Such business models are typically digitally enhanced and also open doors for new market entrants. Examples include packaging-as-a-service or mobility-as-a-service.

General concept of integrating biorefinery operation and chemical conversion into a digitalisation context

There is a need and opportunity for converting the outputs of the forest industry (and other biological raw materials) into higher value chemical products as a means to improve the industry's profitability. However, conversion research has generally not incorporated digitalisation as a standard approach to overcoming barriers. One part of this solicitation will address how digitalisation can be integrated with laboratory research to improve such processes. Mistra seeks descriptions from researchers that propose how their processes would be improved by digitalisation. Mistra expects that a successful proposal will partner experts in different branches of technology, life cycle assessment, policy analysis, market development etc. Moreover, a successful proposal to Mistra will address the question: *Can the proposer envision means to incorporate digitalisation into their research in a way that will enable and improve the ability to convert renewable process streams into high value bioproducts and biomaterials?*

One example would be the valorisation of lignin, a concept that has seen significant increase in interest in the last 5 years. Lignin's structural heterogeneity remains as a significant barrier to its use beyond boiler fuel. Can the researcher couple novel conversion processes with modern and emerging digitalisation concepts that would afford significantly improved technology when compared to a standard laboratory research program? A unique and creative application of modern digitalisation to lignin conversion would ultimately cascade into value for all stakeholders in the process: researchers, industry, consumers, etc.

The digitalisation of the bioeconomy can be an endeavour associated with certain risks. The Mistra programme asks how such risks will be addressed by the proposers. Risks could be limited access to necessary skills and competencies, de-skilling of parts of the work force, employment effects, safety and vulnerability risks, and risks to social acceptance and sustainability. There is a need for robust solutions which increase the reliability of the digitalised bioeconomy.

Mistra encourages that the proposal, as much as is practical, uses or develops open source software solutions which allow better communication, sharing and development of standardised solutions. However, Mistra acknowledges that portions of software development may end up as proprietary information for a single commercial partner. To open up possibilities for commercial use, social innovations and new business models, for example, crowd sourcing, should be encouraged.

The Mistra programme assumes that proposals will take sustainability as a starting point. Sustainability covers ecological, environmental and social aspects.

The UN Sustainability Development Goals define 17 primary and secondary targets. Some are more relevant than others with respect to the Swedish bioeconomy depending on the respective value chains and markets involved. Digitalisation is an enabler for sustainability. First of all, digitalisation enables transparency across value chains and thereby helps to identify sustainability hot spots as well as to monitor corrective actions. For continuous improvement, compliance with given rules and standards – including those which have to be developed – digitalisation works as a means for keeping track and providing documentation. In doing so, digitalisation can contribute to social acceptance as well as explain societal and economic benefits of a future-oriented Swedish bioeconomy involving all actors, including individuals and also taking into account non-industrial usages of forests and nature in general.

The Mistra programme acknowledges that the development of a digitalised bioeconomy requires also addressing political challenges. Policy strategies have to *give directions* for the future transformation of the Swedish bioeconomy. A Mistra programme should build on two of the main government strategies: the national research and innovation strategy for a bio-based economy and the digitalisation strategy.

In Sweden, a national research and innovation strategy for a bio-based economy was launched in 2012. This strategy was developed in dialogue with industrial participants, public agencies and academia. Their work gave rise to the innovation programme "BioInnovation", with the overall aim of maintaining Sweden's leading roll and transforming Sweden to a bioeconomy by 2050. Other research programmes have also been aimed at a circular bioeconomy. The forest industry and the Forest Industries Federation have been central in several of these programmes and have played critical roles in their development. The federation launched their vision for a wood-based bioeconomy in the early 2000s. Lately, other industrial federations have defined the forest as the cornerstone of the Swedish bioeconomy, and several cross-sectoral efforts have been made to exploit forest resources, such as in the chemical industry, the construction industry, and in the production of textiles and biofuels.

The Swedish digitalisation strategy was launched in 2017. The strategy outlines the focus of the Swedish Government's digital policy and vision for a sustainable digital transformation in Sweden. The overall objective is for Sweden to become the world leader in harnessing the opportunities of digital transformation. The strategy has set five goals to achieve this objective: digital skills, digital security, digital innovation, digital leadership and digital infrastructure.[1]

When aiming for a transformation of an incumbent system, a broad range of policy instruments can be useful. These include both incremental and more radical policy instruments, as well as a need for discouraging the old ways of economic affairs, i.e. by withdrawing subsidies, reducing tax benefits, etc. A successful Mistra proposal should address how policy can support the digital transformation of the Swedish bioeconomy.

1 *http://www.government.se/49c292/contentassets/117aec2b9bf44d758564506c2d99e825/2017_digitaliseringsstrategin_faktablad_eng_webb-2.pdf*

Digitalisation, disruption and Bio-based economy

Introduction to digitalisation and the fourth industrial revolution

The digitalisation of the economy is an issue related to the fourth industrial revolution. The concept of the fourth industrial revolution has been coined to capture processes related to a combination of cyber-technical systems, the Internet of things (IoT), the Internet of services, direct Internet-based communication between humans, between humans and machines, and between machines (M2M). There are two types of driving forces for this new industrial revolution: on one side, due to changes in the socio-economic framework, there is a demand for shorter development periods, more individualised demand, more flexible product development, decentralisation and less hierarchic business organisations and more resource efficiency. On the other side, in industrial praxis is demanding more technological solutions for increased mechanisation, automation, digitalisation and miniaturisation. Hence, research on digitalisation should consider both possible technical developments as well as the socio-economic context of this development. This is not just a technological fix.

"Digitalisation" as a concept is, on one hand, connected to the application of digital technologies and digitalised data as the name implies, but has even more to do with new and changing business models and revolution in consumer behaviour.

Business and information systems engineering have to address several integration processes, such as the integration of the basic physical and software systems, the interaction with other branches and sectors, and with other industries and industry types, and the integration in dynamic value networks.

The circularity of the economy is emerging as particularly critical. Circularity means that the lifetime of a product has to be extended through maintenance, adding new elements while replacing those that no longer function, returning and re-using the products by other consumers, remanufacturing and finally recycling to capture the material streams.

Research challenge: *How can the processes central for a sustainable circular bioeconomy be supported by digitalisation?*

Several industry actors have analysed the most disruptive technologies which will enable and drive the digitalisation of the bioeconomy, such as Gartner, Accenture and Schneider.[2] Aiming for *sustainable* value creation requires that the circularity of the bioeconomy has to be in focus as well.

2 *https://www.gartner.com/technology/research/top-10-technology-trends/*

The transition to the sustainable bioeconomy in general

What has this background to do with the bioeconomy? The bioeconomy encompasses many pathways, but common to all of them is that the bioeconomy is based on sustainable value creation through utilisation of renewable biological resources. And due to the high specialisation of the Swedish bioeconomy the envisioned Mistra Bioeconomy programme is focusing on a specific sector of the bioeconomy – forestry and forest-based industries.

Research challenge: How can digitalisation be used to achieve a prosperous and sustainable bioeconomy?

It has been pointed out that the transition to a sustainable bioeconomy does not mean that the traditional facilities will be instantly replaced by new ones, but rather that new technologies will be integrated into existing facilities. Turning towards biorefining could be a promising solution for pulp and paper companies currently struggling with value creation, and a means to overcome their image as very conservative and focused only on protecting their existing businesses.

Lately many leading forest industry companies have made significant investments in the production of new types of bioproducts and in understanding consumer behaviour, and are strongly linking these efforts to digitalisation as a main strategic theme. Examples for such trends are the Metsä Group, which recently opened its next-generation bioproduct mill in Äänekoski, Finland[3], UPM Plywood, which started using a new sustainable lignin based WISA BioBond gluing technology in plywood manufacturing[4], Borregaard's effort to produce microfibrillated cellulose in the EXILVA project[5], or BillerudKorsnäs, a company specialised in sustainable packaging solutions[6].

As mentioned earlier, the new industrial revolution is based on an increasing integration of dynamic supply chains, and the interaction of different branches, industries and sectors. This will also impact the bioeconomy, and therefore the bioeconomy has to be prepared for these changes. The term often used today is "ecosystem" (not to be confused with biological ecosystems). As an example, the forestry and wood supply ecosystem involves thousands of – often very small – business partners that together form the ecosystem. This includes hundreds of thousands of forest owners, entrepreneurs, and companies specialising in forest service, harvesting, transport and logistics, and the production of forest products or energy. Transparency through this ecosystem is the key, and ecosystem services called "hubs" are one possible means to achieve that.

At the same time, new business concepts are being brought to the market, such as products as a service, sharing platforms, peer-to-peer interactions, or industrial symbiosis. These types of innovations rely on social and technological innovations and will become mainstream solutions as part of the circular economy. Usage requires IT tools such as apps, websites, consumer platforms, or databases. Several IT tools are being used by consumers, and thus become tools not only to steer demand but also to extend the influence of the consumers throughout the value chain. This is leading to greater customisation needs at early stages of the value chain depending on individual preferences.

3 *https://newsclient.omxgroup.com/cdsPublic/viewDisclosure.action?disclosureId=805664&lang=en*

4 *http://www.upm.com/About-us/Newsroom/Releases/Pages/UPM-Plywood-starts-using-a-new-sustainable-WISA-BioBond-gluing-technology-001-Mon-02-Oct-2017-13-03.aspx*

5 *http://www.exilva.com/*

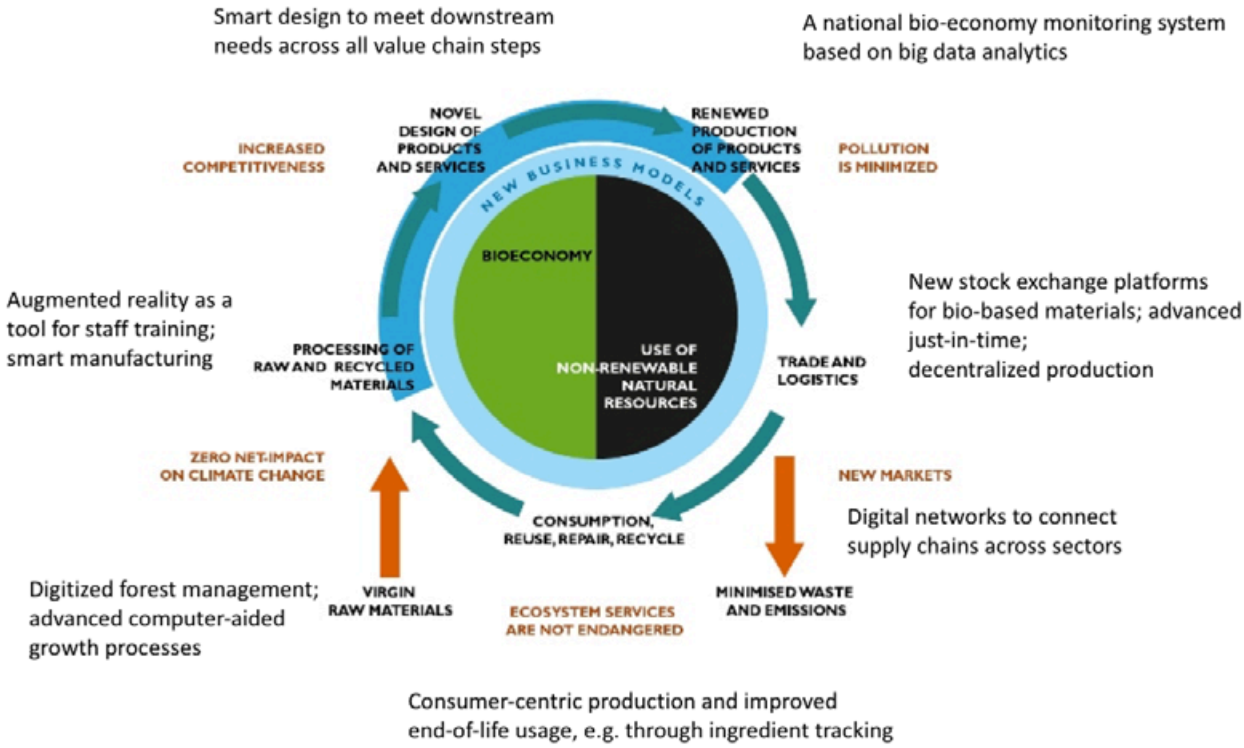
6 *http://www.billerudkorsnas.com/*

Examples for digital accelerators for a circular and sustainable bioeconomy

Given these emerging digitalisation developments, Mistra seeks to identify those specific fields where application of digital solutions become value adding factors to the bioeconomy. The following figure, illustrating a circular bioeconomy concept, shows examples of such technologies applied to the bioeconomy.

The following examples describe how digitalisation may be applied in the bioeconomy context, but are far from being an exhaustive list.

FIGURE 2: Adaptation of the Concept of sustainable circular bioeconomy, applied in the RECIBI project.
(ANTIKAINEN ET AL. 2017, P. 14)



Smart Design

Smart design can extend a product's lifetime or favour the recycling of parts of the product, for example by using appropriate (renewable) matter as an ingredient of the final product adequately qualified for recycling and cascade usage of the materials at the end of life of the original product. Life and (renewable) material science technology can provide guidance on the choice of appropriate materials. Ingredient tracking systems can provide information on the composition and quality of the product at the end of life allowing for more effective recycling of materials.

Bioeconomy monitoring system

A national bioeconomy monitoring system could be based on automatic data flows for assessing trends and therefore the potential of different renewed production processes or calculation of saved emissions. If needed, real-time assessments are possible due to digitally connected entities such as databases or machines and quick data processing.

New stock exchange platforms for bio-based materials

Digital market places for bio-based materials increase their availability and provide higher volumes. Ingredient tracking systems allow an improved availability of complex datasets (purity, composition, etc.) on materials, hence, a better assessment of their quality.

Advanced just-in-time

Improved and advanced just-in-time delivery processes based on Internet of Things principles or M2M communication will result in optimised delivery routes through navigation systems.

Decentralised production

Decentralised production can be ensured through 3D printing (e.g. printing of Wood-Plastic Composites on demand) which will enable establishment of small modular manufacturing companies, possibly using small scale intelligent manufacturing systems (SIIMS).

Digital networks to connect supply chains across sectors

New digital networks will provide comprehensive bio-based product availability and information on their nature to serve untapped demand of newly connected markets and branches, based on horizontal and vertical integration through digital networks.

Consumer-centric and improved end-of-life usage through ingredient tracking

Consumer-centric production based on intelligent order systems will enable a greater choice of product features, including consumer guidance towards sustainability.

Bringing together complementary goods based on end-of-life data flows will enable better compostability or feeding appropriate products to bio-gas plants (Smart Design). More generally, better recycling options will result because of improved assessment of product composition and quality through digital tracking or robotics to enhance waste separation.

Advanced computer-aided growth processes

Digitalisation will enable steering and tracking of growth processes according to specific target group needs, also based on the linkage of information and operation technology. Steering of growth input factors such as light and water in greenhouse processes accordingly or automatic orders of tailor-made supplies (e.g. fertilizers of specific, tailored compositions) will be monitored according to changing production process circumstances.

Augmented reality as a tool for staff training

Augmented reality will demonstrate and enable new ways to teach and learn, for example, through training on the handling of machinery in virtual production environments.

Smart manufacturing

Digitalisation enables automatic control and steering of (bio-) chemical processes as well as communication between production entities; e.g. in biorefineries to initiate a chemical reaction in the right moment. Data on the quality of outcome materials (e.g. purity degree) can be tracked and fed to all downstream actors in the value chain.

In addition to these opportunities, two of the central elements of a forestry based bioeconomy which are less visible in the above graph are digitalisation of forest management and forest harvesting.

Digitalisation of forest management

Digitalisation for this part of the bioeconomy can come about in different ways. Let us start with the raw material, the forest resources. Sustainable forestry management has to balance the ecological, economic and social functions of the forests. This means that forestry management cannot just take economic objectives as guiding principle, but have to ensure biodiversity and the quality of the soil, and to provide eco services like recreation to the citizens. These different demands can conflict with each other. Thus, fulfilling such multiple tasks and minimising conflict requires that forest management be based on the newest data on the qualities of the soil, the development of the local climate, and the status of the trees, all combined in geographic information systems providing spatial information for forecasting the development of forestry resources and planning planting, conservation, and harvesting. To get such data, remote sensing of forest resources can be used, including the use of satellites or airborne systems such as drones. These data have to be analysed in light of the parallel ecological and social functions of the forests. Analysis of these complex data streams requires a combination of competences from traditional forest management to ICT and semantic analysis of amounts of data. While almost every industry now is trying to exploit big data, it is timely to ask what types of data are available for forestry management and how can they be accessed and integrated into sustainable forest management. One of the main challenges for the digitalisation of the bioeconomy is that there is a need for a more open and collaborative culture of data acquisition and data sharing between the research, business and government sectors.

Research challenge: *How can the conflict between proprietary knowledge and open access to forest data be solved and enable advancement of the forestry sector?*

Examples for big forestry databases which provide free downloading of data are the International Tree-Ring Data Bank, the TreeGenes and Dendrome Project, Global Forest Watch, Soil Grid, FAO Stat Forestry, The European Forest Institute, and the TRY-Plant Traits Database.

Information about biomass stocks and flows from the supply chain, including existing international trade data, and data from potential new suppliers is needed to reduce supply costs, to improve transport logistics and to improve collaboration between suppliers. Databases with such information can also contribute in identifying other applications for products and bi-products. The data acquisition methods are diverse and will greatly expand in the future. A digital forest asset database, when containing accurate enough information about species, ages, volumes, growth models, conditions and circumstances can be called a “digital twin” of the forest.

A certain challenge for the forest-based bioeconomy is not only that forests have to serve different objectives, but also that the ownership of the forests is often dispersed. In Sweden about fifty percent of the forest resources are privately owned. To meet the targets for more biomass production and climate services it has been proposed to implement adaptive management in Swedish silviculture. However, there are many obstacles to tackle, including fast communication, monitoring, modelling and simulation of experiments in forestry management. This requires fast and continuous knowledge acquisition, effective information flows and developing a shared understanding. Internet-based platforms can provide such open-ended methodology which allows different actors to participate and to maintain control over their own information, but sharing the platform.

Private forest owners are very much consumer-like actors even though they are raw material suppliers in this value chain (or ecosystem). There are over 300.000 owners in Sweden, providing 50% of the wood-based raw material for the industry. For comparison, In Finland the numbers are even higher: over 600.000 owners provide close to 60% of the raw material. Through generation change forest estates are sometimes split resulting in growing numbers of private estates. Also new forest owners are often urban and may have no experience (nor interest sometimes) in forestry. There are also many passive forest owners who never sell forest. Digital engagement is a way to activate forest owners by making wood trade a simple and easily approachable activity.[7] Urban (as well as traditional) forest owners have formed a new market for digital services, ranging from wood trade to various forest-related services as well as financial asset management services by banks and financial institutions.

Harvesting of forest resources and levels of automation

Harvesting forest resources from a dispersed ownership pool requires long-term logistical planning from access to the transport system (forest road standardisation, access to larger roads, rail road, harbour quays etc.), to developing plans for logging timber from the forest owners. The motivation of the forest owner will be governed by several aspects: (1) the importance of the income from the forest for the economy of the forest owner, i.e., whether ownership a hobby or the main economic activity, (2) the prices achievable by the forest owner on the different markets in both the short and long term, (3) whether there been any changes to the forest due to external events (weather, fire, flooding, diseases etc.) which have an impact on the quality of the timber and on the need to harvest, and (4) identifying efficiency gains by combining harvesting of forest resources in co-located places. Such types of information should be gathered and updated continuously to allow planning of such operations. Digital devices, can contribute to updated data on the quality of the forests, the status of the forest roads, etc. Long-term planning of logging activities can be a precondition for attracting investors for new innovative projects.

Research challenge: *How can digitalisation help forest owners to achieve more economic value out of their limited ownership of forest resources?*

Tree harvesting combines five work steps: accessing the tree, felling, debranching, stem cross-cutting, and transporting the stem to a roadside landing. Lindroos et al. distinguish between different levels of automation in engineering in general, which require different levels of human involvement: (0) human operator only, (1) human operator with some assistance for control functions (cruise-control, anti-sliding control etc.), (2) partial automation for specific functions (self-parking or automatic braking), (3) conditional automation under supervision of a person, (4) high automation for a defined use, without supervision but which requests help if data do not give an explanation, and (5) full automation for all situations, without supervision, with the system making its own decisions through use of machine learning. In modern engineering, level 3 is the highest available level at the moment. Lindroos et al. point out that level 4 will probably not be achieved earlier than in 2025, while level 5 is in the distant future. When discussing higher levels of automation for forestry machinery it must be ensured that such machines are able to use advanced localisation and to deploy decision-making algorithms. By using existing information and their own data gathering the machines must understand their surroundings, the placement and qualities of the work objects and must be able to plan how to carry out the work. Following Lindroos, Westerberg and Hellström it can be assessed that semi-automated solutions and improved decision support can be expected before higher levels of automation. At the moment, many projects try to simulate advanced automated forest machines.

7 See e.g. "Kuutio" *www.kuutio.fi* (in Finnish only) or Virkesbörsen *www.virkesborsen.se* (in Swedish only).

Usage of automated forestry machines, such as planting machines, autonomous vehicles and robotic logging machines have made work in the forests much easier, but also contribute to soil disturbances and damages. Such potential damages have to be addressed via regulations and new technology.

In addition to making the machines more intelligent and independent, one key application, or opportunity, for digitalisation is dynamic end-to-end optimisation. This means that we dynamically pass information through the chain affecting operations in (typically) the upstream stages based on activity or analysis somewhere downstream. As an example, if we had transparency throughout we could dynamically optimise the bucking process (i.e., cutting the trees to specific lengths) in harvesting based on the latest up-to-date production plan at the sawmill. Today harvesting and bucking is being done according to a more static plan. There are other examples, like being able to better optimise the raw material mix of pulp production if we had accurate traceability of the pulpwood and fibre through the chain.

Bioeconomy clusters, industrial symbiosis and digitalisation

Over the last decades the development of specialised business clusters has been a certain issue for industrial and regional policy. Several theoretical approaches have been developed to analyse such clusters. Such clusters are based on cooperation and competition in a regional setting, but can also be open for actors outside the region. Important for the competitiveness of the cluster is the cooperation with knowledge institutions, the access to infrastructure and skilled labour and raw materials. And of course, the companies in the cluster need a market for their products, either as intermediate goods for collocated firms or external firms (via trade), or as final goods for consumers inside the region or outside via trade. An important characteristic of business clusters is the development of an environment characterised by mutual trust and cooperation. This might facilitate experimenting with processes related to the digitalisation of the economy, which still are rather uncertain and risky.

The exploitation of by-products and energy flows inside a cluster can improve the circularity of the industry cluster. Local agglomerations of firms which are based on such cooperation have been characterised as industrial symbiosis, a term especially used in industrial ecology. In industrial symbiosis, traditionally separate industry plants collocate to achieve more efficient utilisation of resources, reduction of waste streams and increased profits for all participants in the industrial symbiosis. There exist a number of case studies about industrial symbiosis. In the Nordic context case studies about Kalundborg in Denmark should be highlighted being of the key cases of industrial symbiosis in a global context.

Achieving industrial symbiosis is mostly the result of spontaneous action of economic actors to gain economic benefit, but such systems can also be designed and promoted via policy instruments. National programmes for eco-industrial parks can be found in different parts of the world. However, few studies exist on the overall impact of policy instruments promoting design of industrial symbiosis. In a recently published report on the potential of industrial symbiosis for green growth in Nordic regions barriers and drivers for industrial symbiosis and key policy measures in support for such developments have been identified for each Nordic country. They highlighted that there still do not exist systematic policy programmes for industrial symbiosis in Sweden and that existing examples are more the result of bottom-up initiatives.

Why have we mentioned industrial symbiosis in the context of digitalisation? The possibilities of digitalisation will allow to achieve more sustainability and resource efficiency if it is on the agenda of the development.

Redefining refining – research opportunities in new processes and new products in a Forest Biorefinery

Establishing effective and symbiotic bioeconomy clusters within the context of the Swedish pulp and paper industry suggests that co-locating key operating units will ultimately afford a working model of a forest industry biorefinery. An operating cluster could be envisioned to include a pulp and paper mill, individual biorefining operations, different chemical conversion facilities or an integrated biorefinery. Co-location in this manner would also improve the economic performance of the whole, and might also result to a smaller environmental footprint in contrast to each unit operating individually. The cluster's outputs would include conventional pulp and paper products, biofuels, and high value chemicals. Under this umbrella, a wide range of research opportunities and challenges exist for the conversion of the various process streams available from biomass fractionation and isolation.

Feedstock supply to the bioeconomy cluster

Feedstock supply to this cluster would be available from a number of different sources. In Sweden, as in most Western countries, potential sources of renewable carbon will include agriculture, aquaculture and forestry. Agriculture in Sweden, however, is based on small farms of 20–30 ha, and provides a relatively small portion of its renewable raw material output. Nonetheless, agricultural crops in Sweden have been evaluated as biorefinery feedstocks, to include the use of wheat straw (produced at a level of about 2.4 million tonnes annually in Sweden) for ethanol production, and the cultivation of industrial hemp, reed canary grass, and other agricultural grasses.

In contrast, the forest products and pulp and paper industry in Sweden is the third largest in the world, behind only Canada and the US, and is a significant contributor to the Swedish economy. The industry is sustainable, with an annual harvest that is roughly 1% of the forested area in Sweden, and boasts a continuing increase in the amount of forested land over time. Recent research has studied the potential of growing dedicated bioenergy crops, such as hybrid poplar or willow, in Sweden. The industry also provides an excellent model for biorefinery operation, as it already has infrastructure in place for growth and harvest of the raw material, as well as a robust delivery infrastructure for supplying large scale separation and conversion operations.

Much like its counterparts in Canada and the US, the industry could benefit by new outlets for its raw material. An increase in the level of R&D investment, potentially seeded by Mistra, could help to support these opportunities. The impact could be significant as the connection between R&D investment and the potential for real breakthrough and innovation within the industry are directly correlated. Transitioning the pulp and paper industry from commodity production to operation as a biorefinery offers an important opportunity to improve their bottom line while simultaneously contributing to bioeconomy development in Sweden.

Research challenge: *defining the optimal feedstock or feedstock mix to supply bioeconomy clusters.*

Research opportunities and challenges within the cluster

Within a bioeconomy cluster, fostering an evolution of the pulp and paper industry from a commodity producer to an integrated biorefinery has gained significant traction in recent years, and is exemplified by the “Forest Biorefinery” concept. This construct envisions the continued production of conventional forest products, supplemented in parallel with high value chemicals as a means to improve the operation’s bottom line. Recent reviews present multiple options for converting the process streams of the Pulp and paper industry into higher value materials to complement their primary output of cellulose pulp. If implemented within a bioeconomy cluster, this model becomes analogous to that employed with great success in the petrochemical industry. The petrochemical industry has developed a highly integrated value chain based on non-renewable carbon, from raw material collection and processing to fuel and chemical production. Even though chemicals account for only 7-8% of crude oil use in the US, they provide the key economic driver for overall profitability of the petrochemical industry. Chemicals provide 50% or more of the value-added for the industry despite their low comparative consumption of crude oil. Using a similar portion of the process streams to generate high value products is at the core of the forest biorefinery concept, which targets a wide range of products available from a kraft mill after its transition to biorefinery operation.

Forest biorefinery development in Scandinavia has seen different research activities in recent years. The AFORE project, coordinated by VTT in Finland and including 21 partners, demonstrated an integration of separation, fractionation and upgrading in the pulp and paper industry, and representative of a potential bioeconomy cluster. More recently, Stora Enso examined the attachment of biorefineries to their existing mills to generate xylose and xylitol from hemicellulose and carbon fibres and adhesives from lignin. Parallel life cycle and technoeconomic analyses have looked at supply chains for biofuel and bioenergy production, tools for selection of biomass and processing technology and evaluation of integrated biorefinery models.

In most scenarios for forest biorefinery operation, value to support the primary production of cellulose pulp is provided by converting hemicellulose and lignin to higher value chemical products. Hemicellulose is removed from the wood during an initial pre-treatment step, with the pre-treated chips then being subjected to conventional kraft pulping. A portion of the kraft lignin can be isolated via standard procedures, through CO2 precipitation and drying. Within a bioeconomy cluster, these various process streams would be distributed as necessary to the different operations that comprise the cluster.

Conversion of forest biorefinery hemicellulose.

Multiple techniques have been used for pre-extracting hemicellulose from wood chips prior to pulping, including pre-treatment with kraft green liquor aqueous alkaline solutions or low cost hot water. As hemicelluloses are normally carried through the kraft pulping process, life cycle and technoeconomic analyses have evaluated the impact of their removal on the overall process and paper properties. Research and technoeconomic analysis has looked at methodology being developed for lignocellulosic biorefineries, including steam explosion and dilute acid pre-treatments, followed by kraft pulping of the remaining wood chips. More exotic treatments have also been employed, such as ionic liquid extraction of kraft pulps.

Research challenge: *effective, high yield separation of hemicellulose from the lignocellulosic matrix.*

Technology has been developed for converting the isolated hemicellulose, or hemicellulose-rich fractions, into a number of products. Biofuels have received considerable attention, with fermentation ethanol and butanol as primary targets. Parallel life cycle and technoeconomic analyses have been carried out for these processes. Integrated processes have combined extraction with fermentation to give pulp and hemicellulose conversion to Ethanol. Hemicelluloses have been treated with hydrogen to generate alkanes and for the production of diesel grade fuels. Isolated hemicellulose has also been gasified to produce synthesis gas.

High value chemical products have been made from hemicellulose-rich solutions. Lactic acid has been produced via an SSF process, while furfural and gamma-valerolactone have been made via catalytic dehydration. The forest biorefinery in Sweden could take advantage of the extensive work carried out on conversion of hemicellulose from agricultural feedstocks as well, for example, the production of xylitol from corncob hemicellulose. Since the primary monomeric sugar in hemicellulose is xylose, the forest biorefinery will also be able to draw on related activities for the converting xylose into high value chemicals. Xylose has been converted to Ethanol or biodiesel precursors. The design of more efficient chemical catalysts to carry out these transformations is a significant opportunity for the forest biorefinery. Furfural, formed via xylose dehydration, remains as a primary target for sugar conversion, and multiple reports describe effort to design new and more efficient catalysts to carry out this transformation, including processes studying the dehydration in the presence of kraft lignin. Related to this process is the ongoing investigation of processes for the conversion of xylose to gamma-valerolactone. Catalytic reduction of xylose, both chemical and biochemical, to give furfuryl alcohol and xylitol continues to be of interest as a key biorefinery process. More selective reduction to 1,2,4-butanetriol has also been examined. Catalytic oxidation processes have also been developed, and target the production of xylonic, formic, or threonic acids. Xylose has also been examined as a component of sugar-based surfactancts and as a precursor to adipic acid.

Research challenge: *developing selective, high yield and economically viable processes for converting hemicellulose to biobased fuels and chemicals.*

Conversion of forest biorefinery lignin.

Only about 2% of the annual production of lignin from the pulp and paper industry is used for manufacture of high value products. As part of a biorefinery cluster, however, a portion of the lignin could be diverted for conversion to higher value, as has been practiced for years by WestRock (formerly MeadWestvaco) in the US. In the kraft industry, lignin combustion is fully integrated with a mill's energy balance. Mill operators will be wary of any process that has the potential of adversely affecting this balance, and will require clear and credible analyses of the risks and benefits associated with biorefinery operation. Lignin's use in any application must align with the huge amount of captive lignin burned for process heat and fuel in the kraft process.

Research challenge: *providing credible and robust economic analysis of the bioeconomy cluster concept.*

Some initial efforts to provide this information have appeared. Decision making tools and analyses of the impact on kraft process operation as a result of converting a portion of the lignin stream, and evaluations on repurposing existing industrial facilities as biorefineries are also available. Alternatively, technoeconomic and environmental evaluation of the cost of replacing black liquor as a fuel (with, for example, cheap natural gas) would provide a baseline for determining the potential of kraft lignin as a source of renewable carbon. Although new fractionation strategies may be considered for a forest biorefinery (steam explosion, organosolv, dilute acid pre-treatment), the huge capital investment already in place for kraft pulping suggests that lignin conversion research in Sweden may retain a focus on kraft lignin.

Assuming that economically viable scenarios for kraft lignin diversion in the mill are found, a number of research opportunities exist to improve catalytic processes for lignin conversion. Nonetheless, overcoming lignin's structural heterogeneity remains as the primary challenge for the biorefining industry. It is particularly striking that the types of targets still commonly suggested as lignin derivatives have changed relatively little over the last 30 years. Reducing lignin valorisation to practice is still fraught with the now well-recognised challenges of multiple feedstock sources, structures that change depending on both the source of the lignin and the methods used to isolate it from a lignocellulosic matrix, and a lack of simple, selective transformations tailored for its unique structure. Lignin will play a key role in the evolution of the forest biorefinery, but lignin's utility as a source of chemicals is poorly developed.

Catalysis has been widely examined as a means to deconstruct and convert lignin, and a number of studies have examined transformation of kraft lignin specifically. Methodology for its depolymerisation and deconstruction or hydrogenation are available. Significant effort has been expended on thermochemical processes to generate a bio-oil enriched in low molecular weight aromatic compounds Catalytic oxidation processes have been developed for the production of quinones and related aromatics.

Lignin has been widely suggested as a new, biobased source of high performance carbon fibre, and its preparation has been carried out using yellow poplar as a feedstock. New carbon materials from lignin include fibres from kraft lignin/polyacrylonitrile blends, kraft lignin/kraft pulp blends, or kraft lignin itself. Lignin has been converted into porous nanocarbons and graphene. The oxidative conversion of lignin into vanillin and syringaldehyde continues to be studied, and still presents a considerable research challenge to achieve high selectivity and yields. Lignin also remains as a potential component in polymer blends and composites.

Research challenge: *developing selective methodology for converting lignin into high value chemical products*

A particularly promising approach for improving lignin's utility in the biorefinery is the rapidly developing ability to tailor lignin's heterogeneous structure through genetic engineering of plants. The primary barrier to selective lignin valorisation is the heterogeneity of the lignin polymer, introduced both during biosynthesis and during isolation processes in the biorefinery. Extensive research has identified the enzymes and structural intermediates used during lignification and has enabled modification of the structure of the lignin polymer itself. Demonstration of chemical production from transgenic lignocellulosic material is still in its infancy, as is an understanding of the structural changes that will occur in the transgenic lignin upon its isolation. Moreover, little is known about the structure of engineered lignin after isolation during kraft pulping. This approach may offer significant new opportunities for producing lignin based chemicals through biosynthetic modification of lignin composition and designing of the lignin polymer from the ground up. Various operating units within the cluster could take advantage of different designer lignin structures, tailored for optimal conversion using their unique technologies. Lignification appears to be highly adaptable, allowing construction of a wide variety of different lignin structures depending on the intermediates available within the plant. Indeed, more than 150 different, naturally occurring building blocks have been identified that could conceivably be incorporated during lignification. By regulation of proper enzymes, lignin enriched in, or almost exclusively composed of H, G, or S units can be prepared and lead to lignocellulosic materials with significantly altered properties. Lignin may also be designed for effective deconstruction. Lignin biosynthesis offers the opportunity to construct a lignin polymer that retains function necessary for healthy plant growth while simultaneously containing interunit linkages that afford simpler deconstruction and utility of the resulting intermediates for conversion to high value chemicals.

Research challenge: *integrating and aligning genetic engineering of biosynthetic lignification pathways with conversion pathways used in the bioeconomy cluster.*

Despite these opportunities for transforming hemicellulose and lignin into biobased products, it is clear that large scale forest biorefining and bioeconomy clusters do not yet exist. The experience of the pulp and paper industry has revealed that the transition from commodity production to biorefinery operation can have a negative impact on pulp quality, or gives poor operational economics. The challenges to be overcome by research likely include a low yield of hemicellulose after wood extraction, accommodating the structure of isolated kraft lignin, which undergoes significant chemical changes from its native form as a result of the conditions used in kraft pulping. Thus, a successful proposal would demonstrate how coupling of chemical conversion technology with modern concepts in digitalisation affords better and more efficient access to the high value products able to improve economic performance of the Pulp and paper industry. Examples could include, but would not be limited to, computational process modelling of conversion processes and the structure of the lignocellulosic matrix, improved life cycle and technoeconomic analysis tools, or inclusion of robotics for large scale parallel testing within the research program. Addressing past problems in forest biorefinery operation would demonstrate integration of digitalisation and research to identify those products most suitable given the raw materials available in the mill, the barriers to their production, and a viable path to overcome these barriers. Robust economic analysis would help identify reasonable targets for production within an integrated paper/chemical forest biorefinery.

Sustainability – biomass-based value chains and the consumer perspective

Sustainability is the overarching guiding principle in the bioeconomy strategies for supply and use of biomass. However, operational sustainability schemes are designed only for a few application fields (e.g. biofuels).

Given the Sustainability Development Goals of the UN and its sub-targets, the question arises as to which targets are of greatest importance. One approach can be to answer the question by identifying both sustainability hot spots as well as the potential for positive contributions to the SDGs on a case by case basis depending on respective value chains and markets involved. Digitalisation can help here by enabling transparency across value chains and to shed light on ecological, economic and social challenges and opportunities. Furthermore, digitalisation can help to monitor corrective actions by tracking and communication. For continuous improvement, compliance with given rules and standards – including those which have yet to be developed – digitalisation works as a means for keeping track and providing evidence on it.

Differences in the sustainability performance of bio-based value chains largely depends on the respective product and its life cycle. The sustainability performance of each step of the (circular) value chain depends on connected or embedded factors such as biomass sourcing (e.g. use of fertilisers for cultivation, water usage, land-usage conflicts), the nature of input factors (e.g. materials, energy) for the processing of precursors, the design of and information provided on the final product, consumer behaviour, information availability and the allocation of biowaste streams.

Better material collection and recovery, improving recycling and reuse of materials (e.g. through product design or acquiring information on the potential of biowaste streams), increasing resource efficiency (e.g. through cascade usage, use of by-products or higher scale effects), raising awareness on sustainability risks and opportunities of the bioeconomy as well as taking advantage of favouring consumption trends are a few of the approaches for making value chains and hence the bioeconomy as a whole more sustainable.

Nowadays, personal lifestyles in Europe are unsustainable. At the same time there are trends and practices in consumer behaviour, which lead towards sustainable lifestyles. To enable large-scale transitions towards sustainable lifestyles, current promising practices point to two important factors: understanding and supporting individual behaviour change as well as creating enabling environments and infrastructure that stimulate and support more sustainable ways of living.

Digitalisation can foster transition by supporting new business concepts such as products as a service, sharing platforms or collaborative actions. Usage requires IT tools such as apps, websites, consumer platforms or databases. Several IT tools are being used by consumers, and become tools not only to steer demand but also to extend the influence of the consumers throughout the value chain, leading to greater customisation needs at early stages depending on individual sustainability-related preferences.

Furthermore, it has to be taken into account from a sustainability point of that there are non-industrial uses of landscapes such as forests that can provide value besides industrial usage by serving different purposes. These include recreation use, tourism, lifestyle aspects and preservation.

Lifestyle aspects could comprise social activities such as collaborative action on privately owned forest areas in order to contribute to natural preservation. In a wider perspective areas consisting of primeval forests or areas comprising endangered or endemic species or historical sites are worth being preserved for safeguarding natural and social heritage. Digitalisation can support these opportunities, for example, through modelling various ways of experiencing the forest, to include virtual experiences or a real word experience augmented with digital tools or collaborative experiences shared with peers. In doing so, digitalisation can assure social acceptance as well as explain societal and economic benefits of a future-oriented Swedish bioeconomy involving all actors, including individuals.

Research challenges:

- *What does it take to ensure sustainable action? How can sustainability opportunities in representative business cases be identified and realised?*
- *Which positive consumer trends towards sustainability can be met best through bioeconomic business models supported by digitalisation?*
- *Consumers experiencing the bioeconomy through digitalisation – which cases are most suitable to both increase social acceptance, raise awareness and contribute to education?*
- *How could the development of a digitalised bioeconomy be supported through a stakeholder process in order to safeguard the right direction of development?*

Policies for a circular and sustainable bioeconomy

Rationale for bioeconomy policies

Bioeconomy policies are not just sector policies, limited to the domain of agriculture, forestry, fishery and aquaculture. The transition to a sustainable bioeconomy is an essential element of sustainability for the whole of society, requiring transformation processes across the entire economy: on the supply side through investments in innovation infrastructure and demonstration activities, and on the demand side through public procurement policies and policies that change consumption and investment patterns. In particular a Sustainable Public Procurement can be major lever to steer the development of bio-based products as it accounts for 17% of Sweden's GDP. Policy is therefore the key lever that should set the direction for this transition process, going much further than traditional policy of market failure fixing, and smart specialisation strategies.

Regarding market failures, Weber and Rohracher distinguish between the *traditional market failures* such as information asymmetries, knowledge spill-overs, externalisation of costs, and over-exploitation of commons. Klein Woolthuis et al. identified *structural system failures* such as infrastructural failures, institutional failures, interaction of network failures, and capability failures, and *transformational system failures* such as directionality failure, demand articulation failure, policy coordination failure and reflexivity failure. Directionality failure refers to the inability to steer innovation towards a certain direction to meet societal challenges. Demand-articulation failure refers to a lack of capacity to understand user needs, which hinders the uptake of innovation. Policy coordination failure refers to a lacking coherence between policies at international, national, regional and municipal levels (vertical coordination failure), or across different sectors and ministries (horizontal coordination failure). Reflexivity failure refers to missing learning feedback loops and the lacking ability to monitor and adjust the transformational change.

What can be said about today's policies when reflecting these different rationales of policy for the bioeconomy? There exist clear differences between countries which depends also on a different understanding of what the bioeconomy is. Are these policies envisioning a broad application and commercialisation of bio-technology in different industry sectors (bio-technology vision)? Or are they aiming for processing of bio-based resources as the primary driver and objective for innovation and economic growth (bio-resource vision)? Or do they highlight the importance of ecological processes that optimise the use of energy and nutrients, promote biodiversity and avoid monocultures and soil degradation (bio-ecology vision).

Sweden has passed a strategy for sustainable consumption to give more attention to environmental and social aspects in consumption by supporting the private consumer to make sustainable choices. The strategy encompasses the state, municipalities, the business sector and civil society. Envisaged activities include increasing knowledge about impacts of consumption, deepening cooperation within society, tackling behaviour change also considering social circumstances of consumers, improving waste management and phasing out harmful chemicals.

Concerning digitalisation Sweden has developed a digital strategy following the vision for a sustainable digital transformation. The overall objective is to "become the world leader in harnessing the opportunities of digital transformation". The strategy covers the promotion of necessary skills throughout society, safeguarding digital security and governmental support in general, and in particular on investments in infrastructure and fostering digital innovation.

Policy mix for the transition to a sustainable bioeconomy

The technological innovation system (TIS) approach has been demonstrated in many empirical studies. In recent years there has been a stronger focus on the dynamics taking place within an emerging TIS. To address these dynamics, key activities have been identified and the concept of "functions of innovation systems" developed and applied to renewable energy technology systems. As described by Hekkert et al., the approach "focuses on the most important processes that need to take place in the innovation systems to lead successfully to technology development and diffusion". These seven functions are: entrepreneurial activities; knowledge development and learning processes; knowledge diffusion through networks; guidance of the search; market formation; resource mobilisation; and creation of legitimacy and counteracting resistance to change.

There exist attempts to combine the technological innovation framework and the regime destabilisation framework with the policy mix approach to analyse policy mixes for system change. The innovative part is here the integration with the regime destabilisation. They distinguish between control policies to put pressure on the existent regime, significant changes in the regime rules, such as deeper going systemic policy reforms which might accelerate destabilisation, reduced support for incumbent technologies, such as withdrawing subsidies for fossil fuels, and changes in social networks including the replacement of key actors to overcome institutional lock-ins.

The following main groups of policy instruments can be distinguished:[8]

- Economic instruments, including direct investments (infrastructure, procurement rules, RD&D funding etc.), financial incentives (grants and subsidies, loans, tax measures, etc.), market-based instruments (certificates for biofuels);
- Information and Education, including advice for implementation, information provision, performance labels, professional training and qualification;
- Regulatory instruments, including auditing, codes and standards (standards for roads, products, sectors and vehicles), monitoring, and obligation schemes;
- Policy support (creation of institutions, strategic planning, public procurement strategy)
- Research, development and demonstration; and
- Voluntary approaches, including negotiated agreements, public voluntary schemes, and unilateral commitments of the private sector.

Research challenges:

- *How do these different policy mechanisms operate across the value chain steps of the bioeconomy sectors, how are they related to the different rationales of bio-*

8 IEA. (2017). IEA /IRENA Joint Policies and Measures database. *https://www.iea.org/policiesandmeasures/*

economy policies, and how can their interlinkages be improved and their complementarity be strengthened?

- *How do the policy mixes change over time? Is it possible to trace changes and in which direction go they, how are they related to changed policy rationales?*
- *How can policy mixes support the digitalisation of the Swedish bioeconomy?*
- *What are strategies to promote bio-based products to public procurement?*
- *How to align the policy mix to the Swedish strategy for sustainable consumption in order to join forces towards a sustainable and prosperous bioeconomy and take advantage of synergies at the same time?*

Bioeconomy policies in a value chain perspective

This section presents the findings of recent research, which has reviewed and analysed existing bioeconomy policies per value chain step they address and impact, i.e. biomass supply, logistics and biobased products. Recommended actions for future policy development are presented in the Annex.

In order to ensure sustainable use of biomass and highest economic value as possible it is necessary that policy is addressing conflicting objectives for exploiting such resources (i.e., cascading usage of bioresources). Unintended consequences of administrative regulations should be addressed.

Biomass supply from forests

Key in the mobilisation of forest biomass for bioeconomy is to consider their multi-functionality and stimulate further deployment of sustainable forest management (rules, guidelines, certification), also extending it to currently unmanaged forests. The following focus points can be mentioned:

- Increase the share of forests managed through SFM (sustainable forest management) principles;
- Afforestation/reforestation;
- Improve access to forests through infrastructure deployment;
- Restrictions can be placed on the types of forest biomass which are entitled for renewable energy support.

Biomass supply from agriculture

The main actions to further mobilise biomass supply from agriculture for bioeconomy purposes are to:

- Utilise agricultural residues, i.e. field residues (like straw) and on-farm residues (like manure). In terms of field residues, attention should be given to soil carbon and ecosystem services;
- Further support agricultural productivity, also with attention for soil carbon & ecosystem services; with increased productivity, less land will be needed to supply food and feed demand.
- Mobilise unutilised potentials, including marginal/abandoned lands. Some could be dedicated to non-food crops.

As mentioned before, for the EU Member States, policies related to agriculture should fit in the framework of the Common Agricultural Policy, which provides several instruments, but also conditions for good agricultural practice. Within this framework, the obligation of keeping land in good agricultural and environmental condition refers to a range of standards related to soil protection, maintenance of soil organic matter and structure, avoiding the deterioration of habitats, and water management.

Biomass supply from biowastes

The EU Circular Economy strategy, adopted in December 2015, includes clear targets for reduction of waste and establishment of a long-term path for waste management and recycling. Key elements include[9]:

- A common EU target for recycling 65% of municipal waste by 2030;
- A common EU target for recycling 75% of packaging waste by 2030;
- A binding landfill target to reduce landfill to maximum of 10% of municipal waste by 2030;
- A ban on landfilling of separately collected waste;
- Promotion of economic instruments to discourage landfilling;
- Simplified and improved definitions and harmonised calculation methods for recycling rates throughout the EU;
- Concrete measures to promote re-use and stimulate industrial symbiosis – turning one industry's by-product into another industry's raw material;
- Economic incentives for producers to put greener products on the market and support recovery and recycling schemes (e.g. for packaging, batteries, electric and electronic equipment, vehicles).

According to the Waste Framework Directive, the following waste management hierarchy should be applied in policy for waste prevention and management:

a) prevention;

b) preparing for re-use;

c) recycling;

d) other recovery, e.g. energy recovery and

f) disposal.

Given the different stages in waste management in each country, these priorities vary among EU Member States. Countries with high landfill shares focus on shifting from landfill to mixed waste treatment (taking out recyclable components and combusting the remaining fraction with energy valorisation), and capture landfill gas. Other countries with more developed waste management systems, focus more on separate collection of waste stream types, and further processing them to products (e.g. as input for biobased products).

Logistics

Logistics play an important role in the mobilisation of biomass resources. Biomass is typically a dispersed resource (opposed to fossil fuels), sometimes at remote and difficult to reach locations. Technical standards would be needed and preferably agreed at international level (ISO), including trade codes to monitor trade. Commodities are fully tradable and compatible with storage facilities, shipping and conversion processes. This facilitates contracting, opens markets and provides easier access to finance.

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9 *http://ec.europa.eu/environment/circular-economy/index_en.htm*

Biobased products and the demand side

Biobased products offer outlets to replace fossil resources and lead to considerable GHG savings. Next to support for industries themselves, several measures can be taken having influence on the production process and on the demand side.

Based on the European Ecodesign Directive national action plans could promote the development of bio-based products focussing on environmental advantages on a general level. In order to also align to the improvement of Sweden's waste management system according to the national strategy in sustainable consumption, actions can be taken such as recycling-oriented eco-design strategies.

Based on the national strategy on sustainable consumption, labels can help to inform about the nature of biobased products and give orientation to both private consumers and public procurers hence strengthening a pull from end-use markets. Further measures could include creation of environmental awards, knowledge centres on sustainable products, exchange hubs between public procurers and company procurers.

In orientation to German Agency on Renewable Resources measures can be taken to give guidance and promote bio-based products to public procurement, such as information campaigns, training of procurers, targeted development of networks comprising key actors, leading by examples (pilot projects).

Research challenges:

- *How to align given initiatives and strategies in regard to private consumers in neighbouring fields in order to serve best the development of a sustainable and prosperous bio-based economy in an efficient way?*
- *What are key learnings from bio-based oriented public procurement endeavours throughout Europe and how to adopt best to Sweden's goals?*

Challenges & Opportunities

Policy for support for different levels of technology maturity

There are different policy instruments required for the different levels of maturity of different technologies. Mature technologies need other instruments than new emerging niche technologies. And governments must consider policy support for incumbent technologies to get resources for the new technologies, i.e. for biorefineries, and to discourage the demand for the old technologies.

Public procurement rules for advanced bio-based products can stimulate the demand for such products. Advances in biorefineries require a broad range of policy interventions, beside economic instruments, systematic programmes for funding of research and development, but also more specifically of pilots and demonstration projects must be funded.

Figure 3 (next page) provides an example of energy and biofuel related policy interventions per market development stage for forest biomass.

In regard to the policy implementation towards sustainable production and consumption, it has to be considered that SCP policies are highly cross-cutting. Thus, formulation, implementation and monitoring requires a high degree of inter-agency collaboration within government. Integrating SCP policies into key policies, strategies and plans should be the preferred approach, rather than formulating them as stand-alone policy areas. Adequate communication and education to all parties, including the community increases the likelihood of successful implementation. Multi stakeholder engagement and partnerships are needed.

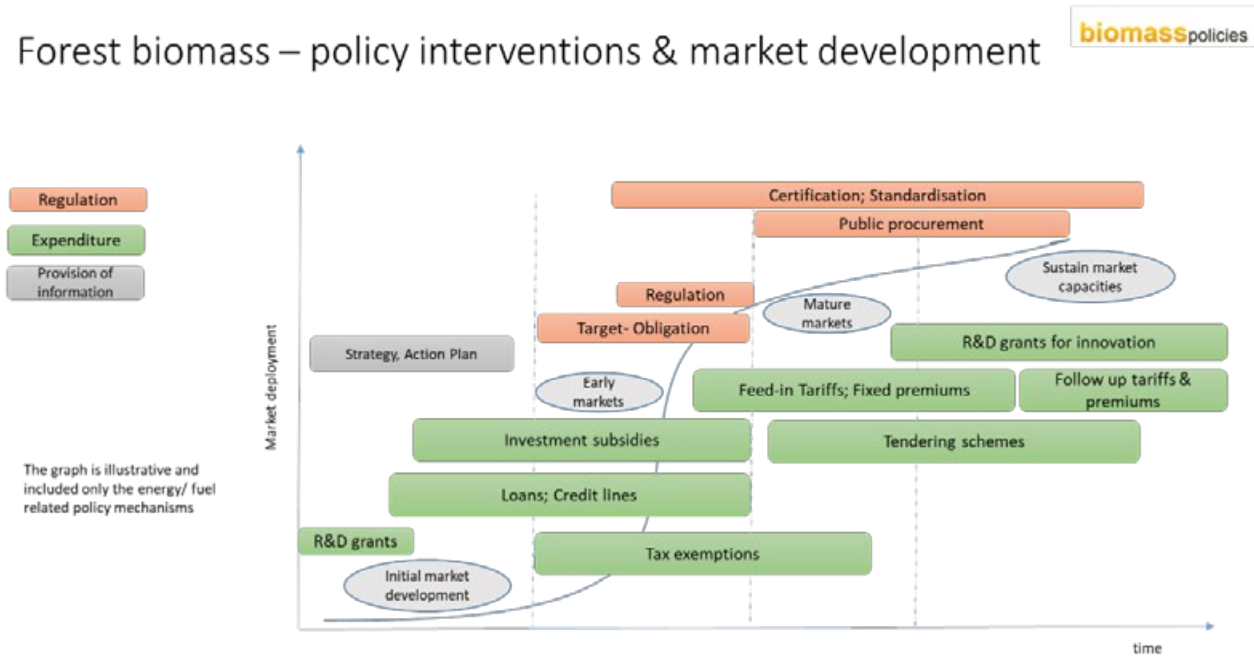

FIGURE 3 Energy and fuel related policy mechanisms per market development stage for forest biomass.

Recommendations for further research and innovation in bioeconomy policies

Considering the cross sectoral and value chain nature of bioeconomy, future research in policy actions should aim to create and maintain a level playing field among feedstocks, market sectors and products. The focus should be on developing synergies between sectors to make maximum use of the biomass and integrating policies towards both bioenergy and bioproducts, thereby creating a level playing field to reach maximum resource efficiency.

Distinction should be made between measures to support early markets, mature markets, or to sustain markets. R&D grants and investment subsidies are clearly linked to early markets; tax exemptions, tendering schemes and obligations are more directed towards mature markets.

Solutions depend on the local situation and the specific (interacting) goals for that region (e.g. biomass supply, energy demand). Many good examples exist where mutually reinforcing linkages among different policy options are applied.

Research funded so far in policy formation for biomass and bioeconomy, falls in the following categories:

- National and regional planning and strategy development for bioeconomy and mobilising biomass from agriculture and forestry in a resources efficient way;
- Sustainability;
- Standardisation and certification issues;
- Market uptake for biomass;
- Public procurement;
- Public perception & consumer awareness.

Based on these, important gaps in knowledge for informing policy formation and updates at European, national, regional and local level can be summarised as follows:

- Optimise supply system tools considering various land use, resource efficiency, displacement effects, market interdependencies, etc.;

- Demonstration of a portfolio of systems (subject to regional ecology and climate) with high potential for feedstock supply in relation to availability, infrastructure and supportive policy framework;
- Supply and demand analysis and impacts for policy and financing mechanisms (local, regional level);
- Best practices, mobilisation, benchmarking;
- Analysis and estimation of direct and indirect impacts over employment, economy and the environment at regional and national scale from specific value chains and the use/promotion of biofuels.

In order to keep track of and to manage the development of a sustainable bioeconomy, the set up of a monitoring program could be object to a research challenge.

Conclusion and recommendation

Mistra's expert panel believes that a significant opportunity for breakthrough and innovation exists at the interface between digitalisation and the bioeconomy. At the centre of this interface is the bioeconomy cluster, able to incorporate the diverse components comprising this research and ultimately leading to an important opportunity to enhance the Swedish economy and to develop sustainability further. The current interest in Sweden related to sustainability, reduction of environmental impact, and development of a circular economy in Swedish society offers important infrastructural support for activities that enhance integration of digitalisation and the bioeconomy. Many of these concepts are still in their infancy, but can draw on existing efforts in the different applications of digitalisation technology and biorefinery development. Nonetheless, there remains a clear need for developing new fundamental and applied knowledge to transition these concepts from the laboratory to industrial and societal utility through development of innovative solutions to the research challenges identified by Mistra's expert panel. Successful realisation of these opportunities will result from expanded collaboration between industry, academia, research institutes and other key stakeholders within Sweden. Success in these activities will provide a tangible economic and societal benefit to Sweden.

We strongly recommend that Mistra initiate an interdisciplinary research programme with the following characteristics:

- Development of collaborative programmes that effectively integrate the diversity of talent needed to address the many moving parts associated with digitalisation of the modern bioeconomy. The successful team will include IT professionals, software developers, chemists, engineers, forestry experts, and stakeholders both within the Swedish forest-based industries and other relevant industries, and from academic institutions.
- The research team will provide a clear description of how the four perspectives on digitalisation integrate with feedstock growth and forest management, harvest and delivery of raw material, biorefinery operation, and new approaches for converting process streams to biobased products and materials.
- The successful programme has to address the demand side in order to ensure and strengthen market uptake and safeguard alignment with sustainable consumption. The different nature of both private consumer and public procurement will be taken into account as well as consumer behaviour change through social innovation and new business models.
- The successful programme will afford results that can be widely distributed and will be of benefit to the entire current and emerging industry.

Long-term outcomes that characterise a successful programme will include:

- Establishing a next generation bio-based industry within Sweden that takes advantage of all aspects of the next industrial revolution.
- Projects and collaboration will find new means to strengthen academic/industrial collaboration, as well as with digitalisation experts, leading to a new means of expanding the bioeconomy.
- Expansion of bioeconomy concepts within universities to train the next generation of experts in sustainability and minimised environmental impact.
- It will provide benefits to the whole society.
- Policies which consistently support the interface between digitalisation, sustainability and the bioeconomy.

Finally, Mistra's expert group recognises that a single solicitation will not meet all the needs, or address all opportunities described in this document. We conclude, however, that Mistra's establishment of an integrated team to investigate these opportunities will likely serve as a critical starting point for expanded research in this field. The combination of both basic and applied knowledge that will be generated will take advantage of the strengths inherent in both academic and industrial institutions and other societal representative organisations. In parallel, the team approach necessary to meet these challenges will lead to results that might be difficult to obtain within smaller, individual investigator-type projects.

Annex

Recommended policy actions

TABLE 1 Recommended policy actions for forest biomass mobilisation

Policy typology	Recommended actions
Regulatory instruments	▶ Adopt measures to prevent forest damage, forest fires or diseases; ▶ Restrictions can be placed on the types of forest biomass which are entitled for renewable energy support, to reduce the risk of competition with wood processing industries.
Economic instruments & financial incentives	▶ Stimulate harvesting of non-commercial thinnings in the frame of sustainable forest management and to obtain healthy and well-growing forests; ▶ Afforestation/reforestation; ▶ Building roads, tracks and other infrastructure to improve access to forests and assist the extraction of timber from woodland.
Information & education, Policy support	▶ Establish grouping of (small) forest owners to facilitate joint management plans; ▶ Facilitate the preparation of forest management plans; ▶ Provide guidelines and training for sustainable forest management; increased information provision measures towards private forest owners by means of capacity building and awareness campaigns at national and regional level.
Research & demonstration	▶ Demonstrate enabling technologies (digitalisation, big data, sensor technology) to promote radical innovations to lower the supply costs; ▶ Integrate biomass value chains with other value chains (e.g. integrated harvesting of residues & the main product(s), new alternatives for backhauling, multiple-use machines to alleviate seasonal fluctuations).

TABLE 2 Recommended policy actions for agricultural biomass mobilisation

Policy typology	Recommended actions
Regulatory instruments	▶ Ensure CAP cross-compliance rules of good agricultural practices as a requirement for Pillar I and Pillar II payments are followed.
Economic instruments & financial incentives	▶ CAP P1 Direct Payments: Ensure that budget from 'Green Direct Payments' includes appropriate crop diversification activities matched to local ecosystems and practices which can lead to optimised biomass mobilisation, including sustainable harvesting of residues; ▶ CAP, pillar 2 – Rural development: Introduce (where they are not existing) targeted national and/or regional rural development programmes focusing on shift to low-carbon economy (including on-farm renewable energy production). ▶ Specific stimulation measures can be included for establishment of non-food/industrial crops; ▶ Provide support in the form of grant or tax exemptions for improving existing wood trade centres and including other biomass forms, such as straw bales, prunings, etc.
Information & education, Policy support	▶ Capacity building to existing wood trade centres on handling agricultural residues as well; ▶ Capacity building for improved quality handling and storage of straw and other field agricultural residues (e.g. prunings, etc.); ▶ Learn from Good Practices.
Research & demonstration	▶ Introduce new varieties with higher yields and good adaptation to local ecosystems and reinforce research programmes on selection and adaptation of varieties suitable to local ecosystems.

TABLE 3 Recommended policy actions for biowastes mobilisation

Policy typology	Recommended actions
Regulatory instruments	▶ Refine terms and conditions in the EU Waste Framework Directive and respective legislation in Member States and account for all potential uses of organic wastes; ▶ Introduce regulations for recycling of waste wood by the wood industry.
Economic instruments & financial incentives	▶ Introduce feedstock premium with favourable pricing in the waste streams. Set up waste treatment systems as alternative for landfill; ▶ Set up separate collection systems of waste streams to increase the availability of organic waste fractions;
Information & education, Policy support	▶ Capacity building and guidelines on best practices for waste treatment; ▶ Measures to promote re-use and stimulate industrial symbiosis; ▶ Provide clear definitions of 'end-of-waste' criteria (i.e. when certain waste ceases to be waste and obtains a status of a product or a secondary raw material).

TABLE 4 Recommended policy actions for logistics

Policy typology	Recommended actions
Regulatory instruments	▶ Refine terms and conditions in the EU Waste Framework Directive and respective legislation in Member States to set up collection systems of waste streams; ▶ Obligations for local authorities to manage and collect roadside cuttings; ▶ Quality assurance and quality control of marketable commodities.
Economic instruments & financial incentives	▶ Building roads, tracks and other infrastructure to improve access to forests; ▶ Support for regional hubs & biomass trade and logistic centres; ▶ Support demonstration of pre-treatment technologies to commoditise low-quality material; ▶ Support and organise decentral pre-treatment to open markets.
Information & education, Policy support	▶ Bring stakeholders together to stimulate industrial symbiosis (connect local supply and demand); ▶ Facilitate setting up quality standards for pre-treated biomass, preferably at EU or international (ISO) level.

TABLE 5 Recommended policy actions for biobased products

Policy typology	Recommended actions
Regulatory instruments	▶ Development of product norms; ▶ Certification / labelling of value chain impacts (e.g. carbon footprint)
Economic instruments & financial incentives	▶ Project support for demonstrators: ▸ Project financing ▸ Financing support: providing guarantees, soft loans with low interest rates
Information & education, Policy support	▶ Fostering knowledge exchange through interdisciplinary and multi-sector cooperation; ▶ Specific sector targets for the biobased economy.
Research & Demonstration	▶ R&D support towards scaling up new biobased products and production processes.

TABLE 6 Challenges and opportunities for the development of bioeconomy policies. (ADAPTED FROM PANOUTSOU ET AL., 2016)

Policy typology	Challenges	Opportunities
Regulatory instruments	Planning: There is a variety of regulations and funding mechanisms- but it is fragmented and difficult to access and understand both at market sectors and regional governance level.	Develop regional roadmaps with realistic short, medium and long-term objectives – including quantified targets – for increased use of lignocellulosic biomass.
	Cross border collaboration	Evaluate synergies and create joint partnerships.
Economic instruments & financial incentives	Improve regional attractiveness for investments	Work with regional authorities to improve the investing environment in terms of simplified procedures, outreach to industry, etc. More cooperation between regions and the industrial sectors but also among industries themselves (fear of competitors)
	Mobilise capital and infrastructures	Support regions with low development to initiate their bioeconomy with pilot and demonstration facilities. Regions with higher development can benefit from improved support mechanisms targeting innovation for existing value chains.
	Limited financial support for new production facilities	Increase awareness about grants and funding opportunities. Facilitate integration of public grants across regional and national administration levels. Consider the establishment of Bioeconomy Strategic Investment Funds.
Information & education, Policy support	Networking different sectors to form regional bioeconomy societies with producing different biobased products and bioenergy for local use.	By forming bioeconomy societies resource-efficiency is taken better into account, also energy by RES will increase and waste is reused or recycled better.
	Lack of skilled workforce	Leverage education value from innovation projects
	Improve clarity: Messages for bio-based economy should be clear and simple, yet factual and scientifically solid.	Ensure that producers can make informed decisions on the use of their residues/wastes. Enhance also education to serve bioeconomy sector.
	Mobilise domestic feedstock supply	Promote information for the availability of feedstock.
	Limited financial support for new production facilities	Increase awareness about grants and funding opportunities.
Research & Demonstration	Lack of long term research programmes for bioeconomy	Bigger R&D&D projects to be established.
	Mobilise domestic feedstock supply	R&D for logistical routes for that facilitate multi-feedstock processing capability.

TABLE 7 **R&D priorities for policy formation and updates at European, national, regional and local level.** (ADAPTED FROM PANOUTSOU ET AL., 2016)

Policy analysis		
Medium	Optimise supply system tools taking into account various land use, resource efficiency, displacement effects, market interdependencies, etc.	R&D
Medium **Low**	Supply and demand analysis and impacts for policy and financing mechanisms (local, regional level).	R&D Coordination Action
High **Medium**	Best practices, mobilisation, benchmarking	Coordination Action
High	Analysis and estimation of direct and indirect impacts over employment and economy at regional and national scale from specific value chains and the use/promotion of biofuels	Coordination Action

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MISTRA
The Swedish Foundation for
Strategic Environmental Research

Gamla Brogatan 36-38
SE-111 20 Stockholm, Sweden
phone: +46 8 791 10 20, fax: +46 8 791 10 29
mail@mistra.org www.mistra.org