Mobilizing Sustainable Bioenergy Supply Chains

Inter-Task Project Synthesis Report

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Mobilizing Sustainable Bioenergy Supply Chains

Strategic Inter-Task study, commissioned by IEA Bioenergy

Carried out with cooperation between
IEA Bioenergy Tasks 37, 38, 39, 40, 42, and 43

KEY MESSAGES

Analysis of the five globally significant supply chains conducted by IEA Bioenergy inter-Task teams – boreal and temperate forests, agricultural crop residues, biogas, lignocellulosic crops, and cultivated grasslands and pastures in Brazil – has confirmed that feedstocks produced using logistically efficient production systems can be mobilized to make significant contributions to achieving global targets for bioenergy. However, the very significant challenges identified in this report indicate that changes by all key members of society in public and private institutions and along the whole length of supply chains from feedstock production to energy product consumption are required to mobilize adequate feedstock resources to make a sustainable and significant contribution to climate change mitigation and provide the social and economic services possible. Notably, this report reveals that all globally significant bioenergy development has been underpinned by political backing, which is necessary for passing legislation in the form of mandates, renewable energy portfolios, carbon trading schemes, and the like. The mobilization potential identified in this report will depend on even greater policy support than achieved to date internationally.

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EXECUTIVE SUMMARY

1 THE CHALLENGE

Significant opportunities exist to reduce greenhouse gas emissions, increase domestic energy security, boost rural economies, and in some cases improve local environmental conditions through the deployment of sustainable bioenergy and bio-based product supply chains. There is currently a wide selection of possible feedstocks, a variety of conversion routes, and a number of different end products that can be produced at a range of scales. However, economic slowdown, low oil prices, lack of global political will, and lingering questions regarding land use change provide a challenging global context to speed the pace of investment.

There are a number of social, economic, institutional and technical barriers to market penetration of bioenergy that will need to be overcome in order to realize opportunities on a wider scale. Some of the most significant barriers include issues related to supply chain complexity and cost, including logistics and intermediate storage, competition for biomass raw materials for different end-uses, market development and penetration, confidence in feedstock inventory estimates, development status of prospective conversion technologies, and satisfying a growing number of sustainability requirements.

2 THIS REPORT & TEAMS INVOLVED

This report provides a synthesis of key messages that are derived from very extensive underpinning documents written by over 70 colleagues from around the world with many decades of experience in all aspects of sustainable bioenergy production systems. It summarizes the results of an IEA Bioenergy inter-Task project involving collaborators from Tasks 37 (Energy from Biogas), 38 (Climate Change Effects of Biomass and Bioenergy Systems), 39 (Commercialising Conventional and Advanced Liquid Biofuels from Biomass), 40 (Sustainable International Bioenergy Trade: Securing Supply and Demand), 42 (Biorefining – Sustainable Processing of Biomass into a Spectrum of Marketable Bio-based Products and Bioenergy), and 43 (Biomass Feedstocks for Energy Markets). The purpose of the collaboration has been to analyze prospects for large-scale mobilization of major bioenergy resources through five case studies that determine the factors critical to their sustainable mobilization. The following bioenergy resources have been analyzed, with special focus on selected countries and regions that cover different conditions:

- forest biomass in temperate and boreal ecosystems, including a broad range of countries and conditions;
- agricultural crop residues focusing on supply chains in Denmark, the United States of America and Canada;
- biogas production from municipal solid and liquid waste, oil palm residues, and co-digestion of agricultural crops and residues and animal wastes;
- lignocellulosic crops in agricultural landscapes, with special attention to their place in sustainable landscape management and design; and

- bioenergy involving feedstock cultivation on pastures and grasslands, with special focus on sugarcane ethanol in Brazil.

Several different novel and existing frameworks of analysis have been used in the case studies to develop an operational, business and policy-based understanding in order to explain the factors that contribute to globally significant sustainable supply chains. They include elements of techno-economic analysis, availability of feedstock, applicable conversion processes, GHG balances, land use issues, governance mechanisms, and other aspects of bioenergy production and supply. Sustainability impacts evaluated include environmental, legal, economic, and social considerations. The analytical approach used in this project has allowed the authors to integrate numerous regional and national perspectives in their work across the complex systems which aim to support transfer of knowledge to new and upcoming bioenergy technologies and feedstock mobilization in different regions of the world.

3 CURRENT STAGE OF DEVELOPMENT FOR SIGNIFICANT GLOBAL BIOENERGY SUPPLY CHAINS

Biomass supply chains and conversion technologies are in various stages of commercial readiness and exhibit different levels of complexity; therefore, the applicability and extent of the barriers listed above varies from supply chain to supply chain. Understanding the various sustainable feedstocks and conversion pathways leading to biofuels, bioenergy, and co-produced bio-based products is crucial to overcoming these barriers and developing an effective business case for emerging industries. Energy market penetration depends heavily on the existing energy profile of a country, oil prices, the rate of energy technology development (outside of bioenergy), and the existence of mandatory government targets and incentives to promote renewable energy (e.g., the EU Renewable Energy Directive of 2009).Energy market penetration depends heavily on the existing energy profile of a country, the rate of energy technology development (outside of bioenergy), and the development of government targets and incentives to promote renewable energy (e.g., the EU Renewable Energy Directive of 2009).

One of the major challenges to realizing mobilization potential is that biomass supply infrastructure has not yet been fully established in many parts of the world. Efficient and commercially viable conversion technologies are also lacking for a number of supply chains and regions; and the valuation of by-products and co-products such as CO_2, ash, lignin is often lacking. Furthermore, the willingness of stakeholders to invest in infrastructure and technology is challenged by uncertainties surrounding long-term feedstock supply of both crops and value chain residues. This variability is due to different operational, sustainability, and conversion constraints acting along specific supply chains, which must be better understood to develop a realistic resource assessment.

4 INSTITUTIONAL CHALLENGES & DRIVING FORCES

Barriers to mobilizing bioenergy supply chains are not only present in the technologies and the economics of logistical systems, but also in institutional development. Review of country experiences generally shows that almost all significant bioenergy development has political backing which is necessary for passing legislation in the form of mandates, renewable energy portfolios, carbon trading schemes, etc. Policies need to be coordinated across departments (e.g., forestry, agriculture, energy, environment, and climate change) to support and govern emerging bioenergy systems. Comprehensive and scientific guidelines, regulations and standards must ensure that increases in biomass outputs respect sustainability considerations, which also need to be better understood. One example is the increased utilization of the residues from forests and agriculture, which requires safeguards that describe the conditions under which residue can be removed to maintain nutrient balances, soil carbon content and minimize erosion. Furthermore, the increased demand for forest wood and agricultural biomass in general can be expected to stimulate measures to intensify forest and agricultural management whilst mitigating the risk of direct and indirect land use change (LUC). Increased demand for both residues and primary products will need to be managed in a responsible way, which will require the development of appropriate indicators to assess social, economic and environmental sustainability, updated recommendations and education for best management practices for forestry and agronomic production systems, and good governance systems to ensure that supply chains are sustainable.

The most prominent driving forces for modern bioenergy expansion on a global scale are political instruments, agreements, and regulations to reduce reliance on non-renewable, imported fuels and to meet GHG reduction targets. The desire for growth of the bioenergy sector and emergence of bio-refineries is also driven by a number of other factors, including rural economic development and employment, a need for product diversification in the forest and agricultural sectors, the desire to find innovative uses for residue streams and waste products, and efforts to improve the productivity of forests, fields, and degraded lands.

Generally speaking, policy drivers (mandates, renewable portfolio standards) underpinned by financial incentives aimed at renewable energy production and domestic energy security have been more critical in influencing bioenergy expansion at local to global scales than market factors, and as a result, outside of local, small-scale applications, many supply chains are not yet economically viable without external support. Government commitment and support and financial incentives therefore continue to be important for significant, large-scale mobilization of the bioenergy supply chains this project evaluated.

5 OPPORTUNITIES TO SIGNIFICANTLY TRANSFORM BIOENERGY PRODUCTION SYSTEMS

If bioenergy supply chains are to be sustainable over the long term and appeal to a wide range of stakeholders, they must be economically attractive, socially acceptable and offer social and economic benefits to communities, and maintain or improve ecosystem services. In short, they must offer solutions, not problems, for a growing world. In situations where trade-offs between different needs have to be made, stakeholders will have to evaluate and agree on which values are most important in a given context, which trade-offs are considered acceptable, and how systems can be designed to minimize negative consequences while maximizing desired benefits. Sustainability is value driven and time specific.

Critical to supporting the mobilization of sustainable bioenergy supply chains is continued research and development into supply chain optimization, particularly developing more efficient and cost-effective technologies and making use of all of the outputs of bioenergy systems (e.g. including CO_2, ash, lignin, etc.).

Significant opportunities also exist to increase supply chain efficiencies through technology transfer (from regions with well-developed supply chains to regions with minimal bioenergy deployment) and learning-through-doing. Technical learning and putting entrepreneurs to work to increase profits and reduce costs is critical to advancing the efficiency and economic competitiveness of bioenergy systems. Transferring best practices and technologies from more experienced regions while accounting for regional differences, optimizing local conditions, and making use of existing infrastructure can be effective in getting supply chains off the ground. Streamlining biomass supply chains with existing silvicultural and agricultural practices (e.g., timing of operations, use of machinery) to increase efficiencies and cost effectiveness should increase adoption, and can increase the overall productivity of existing practices. Using small-scale niche applications and model farms as a platform for scaling up may be another effective approach to testing and improving supply chain technologies, gaining experience, and increasing stakeholder and investor confidence. Improved financing opportunities for bioenergy would make entry into the market more attainable for smaller firms and enable the development of scalable enterprises such as these.

From an institutional standpoint there are a number of opportunities to not only create a more conducive environment for the mobilization of sustainable bioenergy supply chains but at the same time also improve management of other renewable resources; but leadership needs to be shown.

6 SUPPLY CHAIN SPECIFIC RECOMMENDATIONS FOR MOBILIZATION OF SUSTAINABLE BIOENERGY

6.1 Temperate and Boreal Forests

- The most important driver to increase use of forest biomass for bioenergy is policy-supported price for feedstocks and energy products such as wood pellets.
- There are significant opportunities for further mobilization through enhanced technological and institutional learning; that is, learning-by-searching; learning-by-doing; learning-by-using; learning-by-interacting; and upsizing (or downsizing) a specific technology.
- Trade offers opportunities/incentives for biomass mobilization. Trade can enable the creation or re-establishment of logistic systems that are required for a national mobilization of biomass. The current expansion of the USA wood pellet production capacity, destined for export to the EU, could provide a market and logistical "stepping-stone" to the transition of the USA feedstock supply system that is essential for the scale-up of the USA bio-refining industry.
- One social innovation for increasing supply chain mobilization is the expansion of markets throughout cooperative organization structures, such as: forest biomass supply cooperatives; forest biomass energy firms; and forest biomass trade centers. Support for cooperative organization structures (including items such as the development of professional corps, associations, and formal educational programs) can also be a way to increase the professionalism of the workforce in forest biomass supply chains, which has been identified as one important factor for increased biomass mobilization.
- Integration of energy and forest systems is essential to realize regional to global mobilization potentials. This will require careful attention to the following.
    - Management of biomass quality among stakeholders along the entire supply chain.
    - Integrated planning of bioenergy and conventional wood products sectors.
    - Conversion efficiency and cascading use whereby the forest product value chain is optimized both in added value and in GHG reduction.
    - Integrated forest land planning for energy, conventional wood products and ecosystem services to gain synergies for e.g. forest fire protection, conservation of balanced soil nutrients, biodiversity and water quality.
- Achieving many of the opportunities list above will probably require a culture change in society and certainly in the forest and energy sectors. The following will contribute.
    - Development of a shared vision, and recognition and acceptance of different views and understandings.
    - Development of common sustainability criteria from local to global scales.
    - Development of technical standards for bioenergy products to help remove trade barriers, increase market transparency and increase public acceptance.

Based on the analysis report here, mobilization of forest biomass from boreal and temperate biomes using management systems employed today might provide 5 to 7 EJ $year^{-1}$. More substantial gains in mobilization to the levels projected by the Renewable Energy Roadmap (Remap) 2030 of the International Renewable Energy Agency (IRENA) and others can only be achieved through an increase in forest management intensity resulting in a substantial increase in the utilisation of forest NPP to mobilize up to 14 to 28 EJ per year (see Table 2.5). Such an increase would require a fundamental shift in the forest and energy systems of many countries. For example, for Canada, reaching a Roundwood-to-NPP ratio of 10% would entail a tripling of the current annual allowable cut (AAC); this would require a fundamental increase in management and utilisation intensity over the current system which is based on extensive forestry, and expansion into currently unmanaged forests. Since forests are publicly owned in Canada, such change would require a public debate.

6.2 Agricultural Crop Residues

This multi-country case study assessed the potential opportunities and barriers to the mobilization of agricultural residues for bioenergy and biorefining in Denmark, the USA and Canada. Collectively, these case studies show that there is a real potential for further development of viable bioenergy and biorefining supply chains based on agricultural residues, if there is political support, best practices are followed for residue removal, and there is continued supply chain development and optimization. Large-scale crop residue removal needs to make economic sense, be environmentally sustainable and be compatible with the agricultural practices in a given area. Future mobilization and sustained establishment of agricultural residue supply chains will be possible if the overall production system satisfies the criteria of diverse clients in the following ways.

- Establish a consistent and stable policy framework that supports bioenergy and products made from renewable biomass and wastes.
- Increase awareness of key stakeholders about the availability of credible, transparent knowledge on processes, costs and sustainability aspects (e.g., for farmers, energy producers and other stakeholders along the supply chain) using a variety of social media and educational and extension programs.
- Develop long-term contracts to increase stakeholder confidence.
- Provide incentives for farmer groups, biomass aggregators and bio-processors to bear the initial investment risk (e.g., subsidies or credits for GHG offsets and energy security enhancements).
- Develop and distribute tools to underpin the confidence of processors of consistent biomass supply addressing how variability will be managed, including quality and storage issues.
- Develop Best Management Practices for a variety of soil types and operating conditions that ensure residue removal is not detrimental to soil health over the long term.
- Develop and agree widely upon credible sustainability guidelines.

IRENA estimates that 13-30 EJ $year^{-1}$ of agricultural residues must be used by 2030 to meet the Sustainable Energy for all (SE4All) target of doubling the share of renewable energy in the global energy mix before 2030 (Nakada et al. 2014). The IPCC special report on renewable energy (Chum et al. 2011) reviewed the vast body of literature on bioenergy resources and reports a technical potential of agricultural residues by 2050 of 15-70 EJ $year^{-1}$. However, agricultural crop residues are not as good a fuel as forest woody biomass for bioenergy to generate heat and power. These feedstocks are not grown in as high a density as forest biomass, meaning cost of crop residues can be high. The analysis reported here indicates that IRENA and other projections may be possible to achieve with concerted effort at societal levels. The following factors all constitute significant constraints on supply and therefore will need to be overcome or mitigated: world grain market fluctuations; biophysical limitations (e.g., extreme weather events); sustainability considerations (e.g., soil fertility and erosion control); competing uses of residues; distance to processing plants and inefficient transport restricting location of supply regions; uneven distribution of benefits along the entire supply chain from farmers to energy consumers; and lack of incentives for producers to harvest residues.

6.3 Biogas from municipal solid waste (MSW), oil palm residues and co-digestion

This case analyzed biogas production from agricultural and organic residues and considered three potentially significant regional biogas production chains — Municipal Solid Waste (MSW), oil palm residues and co-digestion. Current global MSW production, 1.3 billion tonnes per year, is expected to increase to 2.2 billion tonnes by 2025 (World Bank 2012); about 560 million tonnes is of organic origin; the biogas potential is 48 million Nm^3 or 1.0 EJ. By 2025, 6 billion tonnes of urban waste will contain 1 billion tonnes organic waste with a biogas potential of 86 million Nm^3 (equivalent to 1.8 EJ). Agricultural residues and wastes constitute feedstocks suitable for biogas production. Estimates include: all crop related waste (excl. manure and MSW) amounts to 2.2 billion (10^9 basis) wet (as received) tonnes today and 2.8 billion wet tonnes by 2020; manure amounts to 16 billion wet tonnes today and 18.8 billion wet tonnes by 2020; and straw amounts to 0.8 billion wet tonnes today and 0.9 billion wet tonnes by 2020 (E4Tech 2014). These E4Tech (2013) figures are thought to be on the high side when compared with other studies. However, not all of these residues are accessible and harvesting and logistical costs are relatively high (see also agricultural crop residue chapter), and significant amounts of potential feedstocks mentioned above may already be utilized for other purposes (e.g. energy by direct combustion, producing bio-based products, beneficially recycled on farms). A conservative estimate suggests biogas production in 2020 could generate some 5.3 EJ.

This report identified a number of recommendations essential to improve the mobilization of biogas production. Reliable, long-term financial support (e.g. feed-in tariffs) is especially essential for biogas production based on energy crops; since these crops are produced on agricultural land, production costs can be considerable.

The dependency of biogas production on a constant, reliable flow of high-quality, affordable biomass makes it vulnerable to market disruption and dependent on stable public and political support until a fully competitive business model for feedstocks and energy products emerges.

The following policy recommendations for enhancing biogas development are essential for mobilization potentials to be achieved.

- Inefficiencies, inconsistencies, and intrinsic barriers for biogas production in existing policies need to be identified and removed at local, regional, and national levels.
- Experience indicates consistent policy support is essential, including, where necessary, sufficient economic incentives for investments in AD installations or infrastructure for marketing and utilizing biogas, upgraded gas, and locally- generated electricity.

- Policies that support fossil fuels frustrate development of renewable energy alternatives, hinder new technologies from becoming competitive, and intensify the competition for scarce public funds.

- The public image of biogas production needs to be improved to remove negative perceptions of biogas production, improve supply chain development, and increase community regional support for development of feedstock, gas, and energy markets.

- The general business case for digester performance needs to be improved. Relatively low energy content per unit of feedstock, high initial investment costs, and considerable logistical complexity and cost are formidable barriers to competitive AD systems. As for the other supply chains evaluated in this project, effort must be placed on developing efficient logistical systems, investment in infrastructure, and RD&D to develop advanced hardware and management systems.

- Develop biogas supply and value chains (including access to the grid of many small biogas producers, biogas storage systems) that are integrated with existing residue management systems (e.g., collection of municipal waste, food waste) to improve the competitiveness of biogas production while also garnering public and political support.

6.4 Lignocellulosic Crops In Agricultural Landscapes

Many lignocellulosic crops (e.g. short-rotation willow (*Salix* spp.), the mallee Eucalyptus species native to Australia, switchgrass (*Panicum virgatum*), and poplars (*Populus* spp.) short rotation coppice) that are produced in agriculture-dominated landscapes can produce biomass for energy as well as provide additional ecosystem services and environmental, social, and economic benefits. Positive impacts can be optimized if such systems are carefully designed following consultation with all stakeholders along the supply chain. Their integration into landscapes can help conserve and improve soil quality and reduce eutrophication of aquatic ecosystems, improve habitat heterogeneity in agricultural landscapes, reverse negative biodiversity effects of land abandonment in marginal regions and enhance biocontrol services in agriculture landscapes thus reducing the need for pesticides.

Yet many of the lignocellulosic crop options identified as promising future biomass supply sources are either used very little today, or are used for purposes such as animal feed and pulpwood production. The values of additional ecosystem services can be large but mechanisms for crediting the producer providing them are rarely found and they are often neglected.

This report has identified many opportunities for mobilization of sustainable lignocellulosic crop systems in a range of operational environments. These include the following recommendations.

- Remove policy barriers related to bioenergy in general and lignocellulosic crops in particular that are currently of concern in specific individual countries.
- Anticipate reducing the cost of lignocellulosic bioenergy technologies as production systems mature, and costs fall as operational experience and the scale of production grows. As for forest supply chains, there are significant opportunities for further mobilization through enhanced technological and institutional learning.
- Level the playing field across all energy production systems through concerted public policy discourse.
- The public image of lignocellulosic crops for bioenergy and bio-based product production must be improved. This will require increasing stakeholder confidence and knowledge; available information must be made more widely available through a variety of media; we must broaden the public

discussion of the true costs and benefits of dedicated energy crops so that all stakeholders can be informed by information about all the benefits of the lignocellulosic crops supply chain.

- The promotion of holistic approaches is essential since a narrow focus on biomass production can reduce the value of biomass plantings with regard to the provision of other ecosystem services.

A range of different reports have indicated the potential of lignocellulosic crops as bioenergy feedstock. For example, IRENA estimates that the supply potential of energy crops that must be achieved by 2030 to double the share of renewable energy in the global energy mix is 33-39 EJ per year (Nakada et al. 2014). The IPCC special report on renewable energy (Chum et al. 2011), based on several reports in the literature, gives a much wider range of the technical potential of dedicated biomass production on agricultural land by 2050, stating that it is between 0-700 EJ per year (when also including conventional agricultural crops, with 0 (zero) being the case when no surplus agricultural land will be available due to food sector development). Despite the broad variation in these estimates, which depend on the land availability assumed or on the sustainability issues that need to be satisfied, our report shows that several lignocellulosic crop systems for biomass production for energy can contribute towards fulfilling these potentials. This is further confirmed in the analyses of feedstock cultivation on pastures and grasslands.

6.5 Cultivated Grasslands and Pastures

This case focused on the Brazilian experience, and especially producing sugarcane for ethanol on grasslands and pastureland, since it is an option that could be promoted in several other countries where sugarcane can be cultivated. The project team described sugarcane ethanol production conditions and prospects for expansion, governance, and factors affecting market demand for Brazilian ethanol, including the interaction between the sugar and ethanol markets. Lignocellulosic and other feedstocks were also briefly discussed, especially palm oil biodiesel that has received increased attention in Brazil in recent years. The influences of water resource availability and use were given special attention because of their strong influence on the prospects for bioenergy feedstock production on grasslands and pastures in Brazil and around the world.

This report has found that grasslands and pastures represent a very large resource base on a global level. In Brazil, large-scale mobilization of bioenergy supply chains in Brazil is very possible. Few techno-economic barriers exist and legal conditions for production are settled throughout the country; production systems are mature; and there is technology and capacity to rapidly increase production in response to increasing demand. Progressive infrastructure investments further strengthen capacity, notably in export routes via the Amazon River basin. Brazilian agricultural production can grow without extensive conversion of forests and other native vegetation. Large areas of extensively used pastures are suitable for cultivation of sugarcane and other bioenergy feedstocks, and land productivity improvements in meat and dairy production can accommodate a large expansion of such cultivation. More widespread use of water-efficient irrigation could boost Brazilian agriculture output significantly. The following factors must be understood clearly to enable such mobilization to occur and therefore justify taking action.

- As for other bioenergy options, mobilization can be hampered by uncertainty concerning future markets and evolving regulations. Specifically for the Brazilian sugarcane case, low margins for sugar and ethanol are magnifying the importance of surplus electricity sales to the grid but several barriers inhibit development for electricity co-generation in ethanol mills. Clear and consistent policy definitions and targets providing stable market conditions are required. Policies can either guarantee markets or increase fossil fuels prices sufficiently to make bioenergy options competitive. More favorable conditions for power generators and resource planning integrating bioelectricity with other renewable electricity resources can stimulate development.

- The governance situation in Brazil is illustrative of possible challenges for sustainable mobilization around the world: incentives and alternative regulation (e.g., licences and conditional credits) may be needed to complement governmental command and control to protect native vegetation and promote land use productivity. While consumer demand for sustainable products is increasing, sourcing can be challenging due to diverging views on sustainability aspects, the variety of issues to be considered, and the many suggested indicators for representing these issues. A polarized debate about the priorities of agriculture production versus environmental protection may in itself be a barrier against progress and sensible balancing of these objectives, since debate and conflict contributes to uncertainty about future markets, including sustainability standards and regulations imposed on producers.
- Sustainably increasing food, biomaterials, and bioenergy production on grasslands and pastures requires structural shifts and incentives rewarding higher productivity. This is especially important in cattle production where, historically, ample supply of new land in frontier regions has fostered a culture among cattle producers and associated actors where management options to increase land-use efficiency are less important.
- The analyses showed that productivity improvements in meat and dairy production could release very large grassland and pasture areas for other uses. Illustrative calculations on the global level show that several hundred EJ per year could be produced. Brazilian ethanol production could be many times larger than today. Best management practices for cultivating low productivity pastures will be important since much of the land that can become available through intensification is currently used for extensive grazing. Criteria, data and methods are needed to distinguish highly biodiverse grassland from other land and to address hydrological aspects of grassland and pasture cultivation.

7 GENERALIZED SYNTHESIS OF URGENT OPPORTUNITIES AND RECOMMENDATIONS

The list of barriers to mobilizing sustainable bioenergy supply chains may appear daunting, but fortunately there is an equally long list of corresponding opportunities. The case studies in this report have presented solutions for overcoming barriers to the mobilization of sustainable bioenergy supply chains, and also opportunities for enhancing environmental, social, and economic values through sustainable supply chain development (Figure 1).

7.1 Solutions for supporting the mobilization of sustainable bioenergy supply chains

Critical to supporting the mobilization of sustainable bioenergy supply chains is continued research and development in supply chain optimization, particularly developing cleaner, more efficient, and more cost-effective technologies. Expanded funding for research programs and demonstration plants would support necessary technological innovation and supply chain optimization.

Significant opportunities also exist to increase supply chain efficiencies through technology transfer (from regions with well-developed supply chains to regions with minimal bioenergy deployment) and learning-through-doing. Technical learning and putting entrepreneurs to work to increase profits and reduce costs is critical to advancing the efficiency and economic competitiveness of bioenergy systems. Transferring best practices and technologies from more experienced regions while accounting for regional differences, optimizing local conditions, and making use of existing infrastructure can be effective in getting supply chains off the ground.

Streamlining biomass supply chains with existing silvicultural and agricultural practices (e.g., timing of operations, use of machinery) is another opportunity to increase efficiencies and cost effectiveness, while at the same time increasing the overall productivity of existing practices.

Using small-scale, niche applications as a platform for scaling up may be another effective approach to testing and improving supply chain technologies, gaining experience and increasing stakeholder and investor confidence. **Improved financing opportunities for bioenergy** would make entry into the market more attainable for smaller firms and enable the development of scalable enterprises such as these.

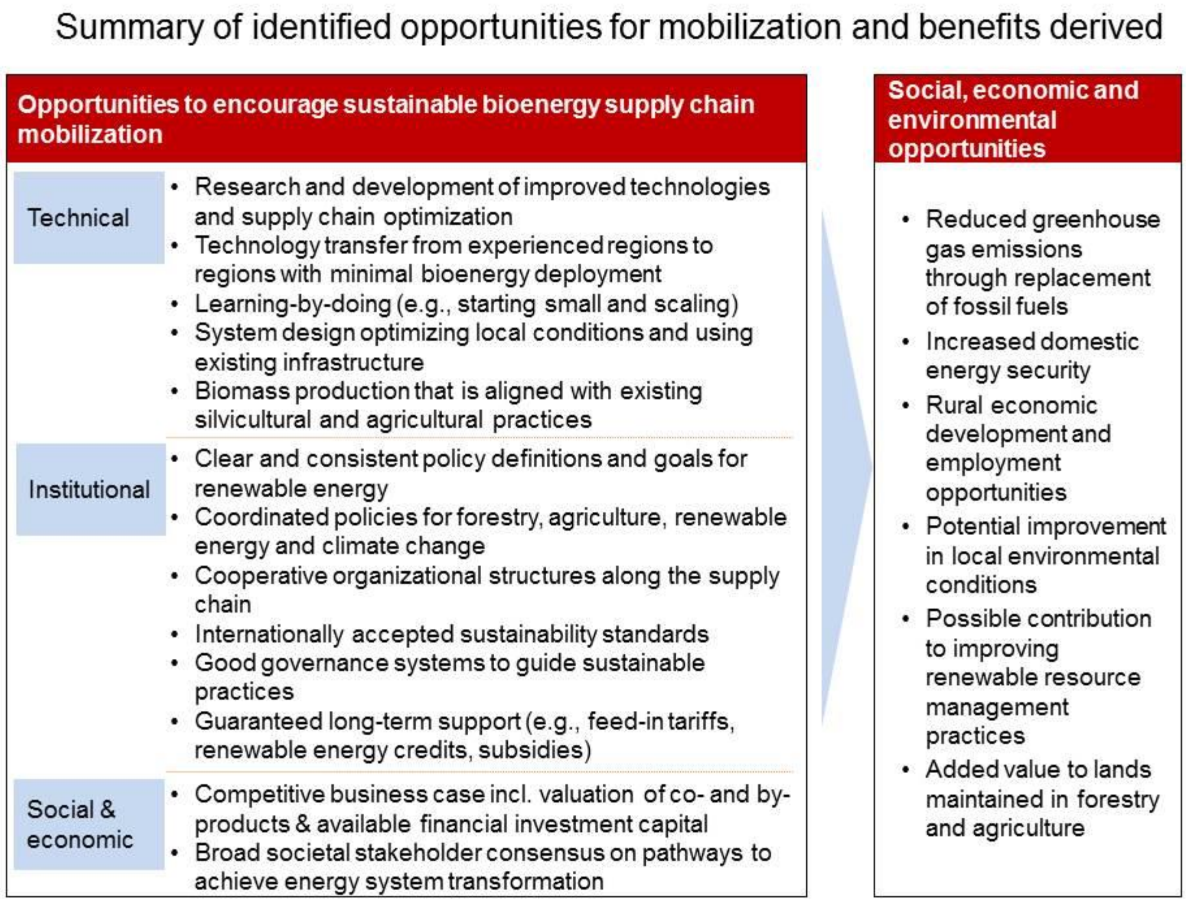

Figure 1. Summary of opportunities identified to mobilize bioenergy and realize positive benefits in all five supply chains that were evaluated.

From an institutional standpoint there are a number of opportunities to not only create a more conducive environment for the mobilization of sustainable bioenergy supply chains but at the same time also improve management for other renewable resources. These include:

- the development of **internationally accepted sustainability standards** for biomass;
- the creation **of incentives to improve the management of renewable resources in general** (e.g., biomass sustainability standards may lead to a demand for similar standards for other resources and/or may address management issues that have previously been overlooked);
- the **development of a common agenda for agriculture and forestry** that balances demands for traditional products (e.g., food, wood products, fiber), biomass and ecosystem services;
- the **creation of cooperative organizational structures along the supply chain** (biomass suppliers, energy firms and trade centers);
- increased **incentives and regulatory control encouraging better management for land productivity** (e.g., as discussed in Chapter 6, to allow for the production of multiple products without putting additional strain on ecosystem services);
- the **use of decision support systems** integrating biophysical and socio-economic data to guide the sustainable mobilization of biomass, food, and other resources;
- the **coordination of energy, forestry, agriculture and climate change policies** at national and multi-national levels;
- the **creation of common, clear and consistent definitions** related to renewable energy and climate change;
- the provision **of long-term guaranteed financial support (e.g., feed-in tariffs, subsidies, renewable energy credits, etc.)** for emerging businesses; and
- **government support for research and development programs**.

7.2 Potential environmental, social, and economic benefits of sustainable bioenergy production

With careful planning and management, sustainable bioenergy supply chains can provide a number of opportunities to improve on social, economic, and environmental values. These include:

- reducing greenhouse gas emissions through the replacement of fossil fuels;
- increasing domestic energy security;
- adding value to existing silvicultural and agricultural practices;
- boosting rural economies;
- creating job opportunities;
- improving biodiversity, soil productivity and/or hydrological conditions (e.g., where carefully designed lignocellulosic crops replace or complement annual cropping systems; better waste

management opportunities through biogas production; adding value to lands kept in forests or agriculture; etc.);

- encouraging dialogue on sustainable land use management for multiple products, including the development of sustainability criteria and indicators and efforts to assess the efficacy of governance systems for renewable resource management; and
- inspiring technological innovation in forestry, agriculture, and waste management.

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