For Official Use **DSTI/STP/BNCT(2016)7/FINAL**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **03-Oct-2017**

English - Or. English

DIRECTORATE FOR SCIENCE, TECHNOLOGY AND INNOVATION
COMMITTEE FOR SCIENTIFIC AND TECHNOLOGICAL POLICY

Working Party on Biotechnology, Nanotechnology and Converging Technologies

BIOMASS FOR A SUSTAINABLE BIOECONOMY: TECHNOLOGY AND GOVERNANCE

This report partially fulfils the requirements of Module 3.1 Bio-production, Theme 3.1.1 Biomass Sustainability, of the Programme of Work and Budget (PWB) of the BNCT for Biennium 2015-2016 , see Figure 1 of [DSTI/STP(2014)39].
It incorporates changes requested subsequent to the Fourth Session of BNCT in December 2016 and the Fifth Session in May 2017.
This Policy Paper was produced by the OECD Working Party on Biotechnology, Nanotechnology, and Converging Technologies. In accordance with OECD procedure, the final version of this paper was declassified by the Committee for Scientific and Technological Policy.

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JT03419936

Complete document available on OLIS in its original format

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NOTE BY THE SECRETARIAT

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EXECUTIVE SUMMARY

Bioeconomy and sustainability

More than 40 countries have proposed boosting their biotechnology-based sectors in their economic and innovation strategies. Some seven countries and the EU have comprehensive, dedicated "bioeconomy" strategies. Economic growth is the key goal, but with growth grounded in the three pillars of environmental, economic and social sustainability. Biodiversity and biomass powerhouses, such as Brazil, South Africa and Malaysia, invest in the bioeconomy to increase the local value added from their vast biological resources. The EU, Japan and the US see the bioeconomy as a means to re-industrialise across many sectors on the basis of their leadership in the biosciences. Innovation-focused countries like South Korea, China and India identify the biotechnology-based industry as a nascent field where they will quickly compete with the most advanced nations (El-Chichakli et al., 2016).

There are many competing definitions of bioeconomy and it is not the aim of this report to produce a definitive definition. Nevertheless, it is important to clarify how this report uses the term. Consistent with the 2009 OECD publication, *The bioeconomy to 2030: Designing a policy agenda*, bioeconomy is defined here as the set of economic activities in which biotechnology contributes centrally to primary production and industry, especially where the advanced life sciences are applied to the conversion of biomass into materials, chemicals, and fuels.

The key question of this report is whether and how the growth of the bioeconomy can advance larger sustainability goals. The bioeconomy has a strong potential to serve sustainability, as it leads more naturally to recycling (circular economy), it includes green chemistry, and it favours substitution from oil and other fossil fuels which are a major source of carbon emissions. However, the use of biomass for bio-based production in ambitious bioeconomy plans is fraught with the risk of unsustainable, over-exploitation of natural resources. A possibility is to develop only modest bioeconomy strategies, but this may not achieve the longer term goals of highly ambitious greenhouse gas (GHG) emissions reductions. Another option is to create ambitious bioeconomy plans that look to make biomass production and utilisation more efficient. However, studies point to the need to also use more land for biomass production. Above all, the report aims to guide countries toward more sustainable outcomes as they design and implement their bioeconomy policies and strategies.

The 2015 United Nations Climate Change Conference, COP 21, negotiated the Paris Agreement in Paris, a global agreement on the mitigation of climate change, representing a consensus of the 196 parties in attendance. It will be legally enforced if 55 of the parties sign up to it between 22 April 2016 and 21 April 2017. The agreement calls for zero net (anthropogenic) GHG emissions to be reached during the second half of the 21st century. This reflects OECD views, and the OECD was one of the first international bodies to call for zero net emissions in the second half of this century (OECD Policy Brief, 2015). The parties will also pursue efforts to limit the temperature increase of global warming to 1.5°C, as a result of widespread scepticism about the safety of a 2°C limit.

In the time since COP21 in Paris and the Global Bioeconomy Summit, interesting developments have occurred. For example, the Rockefeller Family Fund stated in April 2016 that there is "…*no sane rationale for companies to continue to explore for new sources of hydrocarbons*" while the global community works to eliminate the use of fossil fuels. Officials of the royal family of Saudi Arabia have pledged to end the country's reliance on oil in a mere four years. The United Kingdom, for example, will enshrine a long-term goal of reducing its carbon emissions to zero in law as called for in the historic Paris climate deal.

Just previous to COP 21, the UN Sustainable Development Goals (SDGs) were adopted by the United Nations[1]. There are seventeen of these, and they can be seen as laying down foundational goals towards achieving the aspirations of the original *Brundtland Report* on sustainability. They have a central theme of reduction of inequality (Hicks et al., 2016). They are all big, bold statements, many of which will be impossible without action on climate change. Big, bold policy statements, however, need to be enabled.

This is the critical moment for sustainable development. And as so many countries are now developing bioeconomy policies, it is an opportune time to ask where and how, exactly, the bioeconomy fits into the sustainability agenda? This paper focuses specifically on sustainability of biomass for use in bio-production processes. It is organised into sections dealing with the following:

1. The convergence of global trends and challenges that point to the necessity and advisability of increasing bioproduction relative to production based on fossil fuels.

2. The particular challenge of reconciling food and industrial use of biomass.

3. The measurement of biomass sustainability.

4. The potential of biotechnology to improve the food production system.

The report advances four core arguments and suggests several areas for policy attention. The core arguments are: (1) Sustainability will require better measures and standards for biomass; (2) Bio-based chemicals and materials receive too little attention in bioeconomy policy; (3) Policy consistency will be critical to promote investment; and (4) Biotechnology policies can accelerate productivity and efficiency. This introduction will summarise these themes as well as their policy implications, and provide a roadmap for the report.

Sustainability will require better measures and standards for biomass

Biomass is a key ingredient in the bioeconomy value chain. It is also the most sensitive and critical issue of all for a bioeconomy. Most bio-processes have yet to achieve mass production scale. Partly this is because biology is not designed for mass industrial production and bio-processes are currently highly inefficient compared to petrochemistry. This is being addressed through a convergence of industrial biotechnology with green chemistry. The much larger and uncertain issue is biomass sustainability. The defiantly intractable conundrum is the dual use of biomass for food and industrial use. In other words, sustainability and zero emissions imply renewable sources of carbon, and easily the most abundant source is biomass. However, food security has to come first.

This effectively creates a competition for land between food and industrial use of biomass unless other non-food sources of biomass are utilised in large volumes. This also calls for greater efficiencies in land use and more sustainable agricultural practices. It is a massive task to create a bioeconomy in the post-fossil era. It is quite a different proposition to create a sustainable bioeconomy. The over-exploitation of biomass has severe consequences that could even result in worsening climate change – deforestation, soil damage and destruction, imperilled water security.

1 https://sustainabledevelopment.un.org/sdgs

A central issue for the future of the bioeconomy is how this potential collision with food security is managed. Governments must make 'food first' the top priority whilst looking at creating solutions in land use, agricultural, aquaculture, capture fisheries, waste collection, recycling and reuse, but also technological solutions to maximise the efficiency of bio-production. As the population of the planet increases, the needs for more food are relatively quantifiable – by 2050 there will be a need for 50-70% more food than in 2009 (UN FAO, 2009). That food will need to be produced in the face of stresses on land and water supply. Modelling has forecast potentially catastrophic droughts in the future. This makes large-scale expansion of industrial use of biomass improbable without government intervention.

Biomass sustainability is not guaranteed so long as the tools to measure it are not internationally accepted, as countries implementing the standards on their soil might at the same time be importing biomass from countries which do not. The amount of biomass that can be grown and harvested sustainably, the biomass potential, is not known. The tools to measure biomass potential are incomplete as the criteria and indicators to construct the measurement tools are not accepted and harmonised. The environmental indicators are the most easily measured, although ease of measurement is relative. A goal of measuring biomass sustainability is to include triple bottom line indicators – economic, social and environmental. Social indicators are the most difficult to measure and there is a tendency to assign them the lowest value.

Biomass trade is already conducted internationally, with most of the biomass going to OECD countries, at this stage principally for burning wood pellets in power stations. Biomass disputes have already occurred internationally, and these can be expected to increase in number in the absence of biomass sustainability assessment and certification that is agreed by importing and exporting nations.

Bioeconomy policy should focus more attention on chemicals, material products and green chemistry

The world is already on a trajectory for a massive transformation of the energy regime, as exemplified by the *Energiewende* in Germany, where a switch to renewable energy and to increased energy conservation is being enacted now. Bioenergy is part of the equation for renewable energy alongside solar, wind and other renewable energy technologies. Zero net emissions cannot be met by using fossil sources for materials. The only source of renewable carbon present in vast quantities is biomass.

The aforementioned OECD publication *The Bioeconomy to 2030: Designing a policy agenda* foresaw three critical elements in a bioeconomy: advanced knowledge of genes and complex cell processes; renewable biomass; and the integration of biotechnology applications across sectors. Biotechnology processes have traditionally been seen as more environmentally benign than chemical processes. This is not necessarily so, and has to be proven case-by-case. However, it is now becoming clear that the third element can be a reality: bio-based products are now seen in markets including fine and commodity chemicals, medicine and healthcare, automotive, consumer goods, food and nutrition, construction, and, most critically, energy. It is also becoming clear that many bio-based products are indeed more environmentally benign than their petrochemical and fossil equivalents. To achieve zero net emissions will not only need huge changes in the energy regime. The same will apply across industry, and this is often either not realised or is forgotten – the chemicals sector accounts for about 10% of total global energy use and is the third highest industrial source of emissions after steel and cement making. Moreover both steel and cement making rely on chemicals.

The replacement of fossil-based by bio-based materials has started, but is still in its infancy. Political progress has not met technical progress as renewable energy and fuels have taken centre-stage in the sustainability agenda. The chemicals industry has long been a cornerstone of several OECD country economies, and is increasingly so in some of the BRICS countries. At one and the same time, the chemicals industry has been an engine of innovation, but also a major source of emissions and a large consumer of energy. The French government, for example, has orchestrated policy towards green chemistry for over a decade to enable that a substantial proportion of the feedstock for the chemicals industry is plant-derived. Industrial biotechnology is another technology focussed on creating renewable chemistry.

However, in policy support, bio-based materials have been relatively ignored beyond R&D subsidies. This is understandable as the top priority goals and big prizes in energy security and climate action are dominated by electricity and liquid fuels. Governments should also bear in mind however, that bioenergy and biofuels are likely to be transient. Electric light vehicles are making steady technological and market progress, and the first diesel-electric hybrid trucks are available. The internal combustion engine is ultimately replaceable, at least in light transport, albeit currently requiring huge government intervention. Chemicals and materials, in contrast, are here to stay and will become even more important in the future as new manufacturing demands new materials. It is time for governments to realise this and see beyond the top priority goals of energy and fuels. Bio-based chemicals and materials can also create many jobs.

Policy consistency will be critical to promote investment

Most of the investments for this vision of the future must, of course, come from the private sector. Investors are understandably cautious when many events reiterate the need for society to change but concrete political action is lacking. Policy support for bio-production is not simple, however. With bioenergy and biofuels the most important policies deployed across many countries are feed-in tariffs and mandated production, respectively. The application of these policies to tens, then hundreds of chemicals is not intuitive. Consultation with various industry actors suggest that subsidies are not wanted as they are rarely stable over long periods of time. In addition to subsidies, the policy toolbox includes tax breaks, loan guarantees and various types of Public/Private Partnerships (PPPs).

The overarching message from the private sector is that, whatever these policies are, they should be long-term and consistent to allow the investments to be made with the confidence that u-turns will not be made and leave investments stranded. A suggestion has been made of a 15-25 year competitive advantage for bio production over fossil-based production. As much as this seems disproportionate, it should not be forgotten that fossil fuel subsidies for consumption and production are still deployed on a very large scale, easily the largest subsidy system in the world, and have been deployed for decades.

Biotechnology policy should be part of bioeconomy strategies

The further development of biotechnology will be important in achieving sustainable growth and achieving the Sustainable Development Goals. Technology policy should be an important policy intervention on sustainability right next to economic instruments like tax credits.

Whether through the genomic sciences or genetic modification (GM) technologies, the life sciences are making large contributions to food security. Applying genomic data to animal and plant breeding is seen as a way of speeding up traditional breeding and removing the trial and error inherent in breeding to make it more accurate (as implied by the term ‘precision crops’). Genomics-enhanced breeding has been applied to most row crops and to farm animals, milk production, and important aquaculture species. It even has applications in wild fisheries. As such it is making important contributions to food security, and therefore to a sustainable bioeconomy.

More controversial are genetic modification and now gene editing technologies. Resistance to GM crops remains in some regions, notably in Europe. Nevertheless, five main crops are at 90% GM adoption or more in the US, and the largest uptake of GM crop technologies has been by resource-poor farmers in developing countries. Recently the very first GM animal (salmon) and the first gene-edited foodstuff (a mushroom) have been approved in the US as safe for human consumption.

The application of biotechnologies in bio-based production is less controversial as this is normally about production strains of safe microorganisms in contained conditions of a bioreactor. In terms of economic impact, however, these applications are of much lower value to date than applications in food. This is an industry in its formative days, however, and many applications will follow. A goal of consolidated bioprocessing (CBP) is that modifications can be made to biocatalysts that negate the need for more expensive (and technically more difficult) bioprocess changes. Thus it can be foreseen that metabolic and genetic engineering in bio-production will have far-reaching consequences for the operation of full-scale biorefinery facilities. More controversial will be the genetic engineering and gene editing of non-food crops for bio-production.

Several OECD governments are making large-scale investments in synthetic biology, some with a view to future bio-production. An overall goal of synthetic biology is to bring engineering methods to biology, e.g. standardisation of parts and systems, the separation of design from manufacture. The economic impacts of synthetic biology are only just starting, but progress is accelerating. However, this is happening in a limited number of OECD nations. For the others, the danger is of having to invest at a future date to catch up rather than to lead.

Policy implications

The policy regime for realising a sustainable bioeconomy will require a complex, interwoven network of technology-push and market-pull measures that requires a new approach to governance. Policies will span the spectrum from relatively trivial R&D subsidies to the public-private financing of huge production infrastructure such as integrated biorefineries and their supply chains. This report cannot aim to provide a full account of possible measures. Rather, the policy implications of the above themes are highlighted, which could provide critical pieces of that puzzle. These policy implications carry across several key sectors – agriculture, energy, environment, chemicals and materials, even human health – at multiple scales.

On the international scale, for instance, governance policies will be required to uphold sustainability goals without presenting undue trade barriers. For example, the prevention of deforestation has the likelihood to become more important as the bioeconomy grows, and policies such as those deployed by Norway to prevent deforestation in Liberia are likely to become linked to carbon pricing and trading. The markets for bio-based chemicals are immature, and public procurement can help drive market uptake. Lessons learned from bio-ethanol will need to be applied to systems innovation throughout bio-production. The issues of land use change are intricate and of an international nature, and await techniques of measurement to allow policy to be designed properly.

At the local end of the scale, policies governing the practice of on-the-ground management and certification of biomass production will be critical.

What follows cannot be comprehensive in terms of policy implications. Rather, it is a snapshot in time at the very early stage of the sustainable bioeconomy. Some of the policy implications will disappear with time, others will endure. More will follow. This calls for long-term policy development that is co-ordinated to prevent lock-ins and expensive replications. As with all international trade policy, dialogue is paramount to prevent barriers developing accidentally.

Policy alignment: taking a planned adaptive risk regulation approach

Clearly for the increased deployment of a bioeconomy in any country there is a need to align broader policy agendas: agriculture, industry, trade, biodiversity and environmental. This is difficult in any country, but the challenges are amplified in attempts to harmonise across borders. When commitments have been made to international treaties and policies, domestic policy cannot be easily changed. But this is precisely what will be required to prevent trade barriers, which can even now occur over seemingly trivial matters (Bosch et al., 2015). Therefore the goal of policy alignment needs to be seen with a long-term view, and needs to be sufficiently flexible to take account of future changes. The approach suggested is similar to that of planned adaptive risk regulation. In this approach to risk, the stages of the process can be:

- Prepare: Fund research to inform on benefits and risks;

- Discriminate: Foster initial applications with most favourable priors;

- Observe: Harvest and process information from initial experience;

- Adapt: Learn from experience and update/correct practices.

Develop reliable measures of sustainable biomass potential to support bioeconomy policies at the national and international level

- A highly ambitious estimate of available biomass increases the risk of a non-sustainable supply and over-exploitation of natural resources. Furthermore, in light of growing trade in biomass, the numbers need to be continuously re-assessed.

- Harmonised and transparent methodology for estimating sustainable biomass potential is important for both domestic estimates and for international trade.

- For these purposes, environmental, economic, and social aspects should be included with attention to both positive and negative impacts. Assessment should include water impacts and landscape effects such as habitat and diversity and quantify the impacts as well as land-use change.

Improve indicators for environmental assessment

- The development of robust and agreed indicators for doing sustainability analysis and standard-setting is critically important for realising sustainable bioeconomy, and although there has been a proliferation of standard-setting activities, the landscape is disorganised and not harmonised. Addressing this lack of harmonisation is important.

- There should be a fundamental review of the utility of life-cycle assessment (LCA) in biomass sustainability assessment. LCA is a crucial environmental tool, but one which does not address economic and social impacts at all. Social impacts e.g. child labour, workers' rights, are especially difficult to quantify and are therefore easily side-lined. This is an area for careful consideration to identify the most robust indicators. Qualitative indicators (e.g. compliance with organic farming standards) merit inclusion in environmental assessment.

- An adequate forum involving a broad range of stakeholders for the critical review of LCA methodology and possible alternative approaches for the assessment of product could be identified.

- The acceptance of a market-based measurement tool such Total Factor Productivity (TFP) could be a good approach, but would require consulting with all stakeholders (policy makers, business stakeholders, NGOs) on: (1) The selection of sustainability issues (i.e. the inputs and outputs); and (2) The method for aggregating multiple input and output variables in the TFP index.

- Biomass must meet established international sustainability standards covering GHG savings, sustainable land use and environmental protection. These criteria could be integrated into supply chain certification schemes.

- Public financial incentives should only be based on higher resource and land use efficiencies, sustainability and GHG savings and the lowest possible level of competition with food.

Importance of materials and chemicals

- Careful evaluation of the impact on added value, employment and innovation should be conducted in order to strike the right balance between public support to industrial use of biomass for materials and chemicals on the one hand, and to fuels and energy applications on the other hand.

On the ground management for biomass production

- Best practices for the management for biofuel feedstock production need to be developed. Maximum environmental benefits are achieved by combining the right crop with the right location and the right cultivation practices. Guidelines for sustainable feedstock production need to be developed and will require monitoring tools for assessment.

- Using these best management practices, select suitable marginal lands and implement the growth of cellulosic feedstocks (such as agricultural residues and wood) on them. Although they are potentially less productive than high-input/high-yield crops, such feedstocks can provide more environmental benefits, which would need to be monitored.

- Give high priority to the implementation of low-input cropping systems, such as grasses.

- Establish land-use guidelines. A spatial inventory of lands in areas suitable for biofuel production is needed to inform the development of such guidelines. These should include land connectivity and assessments of potential yields. This must identify the existing land-use patterns at a small spatial scale, to be relevant for the growth of feedstocks, as an alternative land use (i.e. sub-kilometre). These should also include consideration of the fact that impacts of agricultural intensification are experienced domestically (i.e. direct land-use change) and globally (i.e. indirect land-use change).

Value added and sustainable feedstock, food or non-food: which agricultural feedstocks are best for industrial uses?

- All kinds of biomass might be accepted as feedstock for the bioeconomy. A comprehensive concept is required for feedstock allocation for food, feed, industrial material use and bioenergy.

- Potential political and financial measures should only be based on higher resource and land efficiency, sustainability, and a lower environmental footprint of the biomass, and the lowest possible level of competition with food.

- Using food crops should not be exempted from political thinking before the above are assessed - excluding them from industrial use could end up leading to a misallocation of agriculture resources.

- Research should identify the most resource- and land-efficient crops and production pathways for specific regional conditions and applications.

- Reducing food losses would also decrease pressure on arable land. Roughly one-third of food produced for human consumption is lost or wasted globally, amounting to about 1.3 billion tonnes per year.

Biotechnology policy

- Governments should more deeply invest in the use of genomics in agriculture: genomics can be a means of speeding up breeding and making it more efficient, with or without genetic modification.

- Government support for the development of breeding and selection programmes for new feedstock crops might focus on sponsoring programmes that train farmers in genomics. Bringing genomics testing to the farms will increase the range of applications as these are clearer to farmers than to researchers.

- There is a pressing need for regulatory clarity on whether the products of techniques such as CRISPR/Cas9 are to be treated differently in regulation than classical GM crops and animals. A major rise in the gene editing of crops and animals is starting. The USDA has stated that a gene-edited mushroom requires no further oversight for cultivation or sale in the US. There is a serious danger that the science runs ahead of policy and the latter blocks beneficial applications of value in food security.

DRIVERS FOR A SUSTAINABLE BIOECONOMY AND THE CONVERGENCE OF KEY GRAND CHALLENGES

> "*Grand Challenges priority should be to address global inequalities; secondly how to rapidly decarbonise the global economy. The world needs to save the biosphere as well as the banks!*"

Anthony Costello, Professor of International Child Health and Director of the UCL Institute for Global Health. https://www.ucl.ac.uk/intercultural-interaction/For_2website_Grand_Challenge_review_event_report.pdf

Introduction

1. This chapter examines the major global trends and other drivers that are pushing countries to engage bioeconomy strategies. There is need for basic changes in modes of production, principally as a result of over-dependence on fossil resources on a planet with a human population still rising. The bioeconomy offers potential advantages in this regard, but policies must help ensure that the pitfalls of food/fuel and food/products tradeoffs are avoided.

2. Many documents have discussed sustainable development in terms of the 'triple bottom line' of economic, social and environmental sustainability since the term was coined in 1994 (*The Economist*, 2009). Drivers indicate that a shift towards a *sustainable bioeconomy* is not only necessary, but increasingly urgent. Some of the drivers are well-known and are described widely as the 'grand challenges', of principal interest here being climate change, energy security, food security and resource depletion. At their roots is population growth.

3. For OECD countries there are other issues at stake. The chemicals sector, a cornerstone of some large OECD economies. As examples, the chemicals industry is responsible for 5% of South Africa's GDP, and around 3% for the Netherlands. However, the sector has seen increasing competition from Asia and the Middle East, at a time when several Asian economies are growing and diversifying their own bioeconomies. A major driver for developing industrial biotechnology capacity has been to keep chemicals competitive in several of these key OECD economies. Due to widespread increases in agricultural efficiency, many rural jobs have been lost in OECD countries over the last few decades. Another driver for a sustainable bioeconomy is rural regeneration, which is also consistent with a need for re-industrialisation.

4. Due to the international nature of a future bioeconomy and the rise of developing countries, this chapter also looks beyond the OECD area. As the economic centre of gravity has been shifting towards Asia, and much of future population growth, especially of the middle classes, is happening in Asia, it is pertinent to look in particular at Asian developments as countries in this region will not only be key bioeconomy trading partners, but will also be competing in the same area. Food security is dealt with in greater detail in a separate chapter due to its importance in a bioeconomy. A global mantra of 'food first' is developing, referring to a need to reconcile food and industrial use of biomass, perhaps the central issue for biomass sustainability.

Global trends and their sustainability challenges

5. At this point in time, several societal grand challenges are interacting with each other to create one of the most difficult periods in human history. Because these grand challenges are truly international, one of the main problems has been achieving consensus of action across countries with different starting points and levels of economic development.

6. The key to the enormity of the challenge is in the word 'interacting'. Food and water security obviously interact with each other, and measures to improve the security of one may negatively affect the security of the other. Therefore the challenges are of a planet-wide nature that interacts very much like a global ecosystem (see Box 1).

Box 1. The grand challenges ecosystem

"In an era of increasingly pervasive human influence on physical and biological components of the Earth system, what are the most effective strategies for maintaining the integrity of natural systems and the services they provide?"

National Academy of Sciences (2010).

Whenever humans intervene in a system, from the level of genetics to whole community, all the way to globally, there are interactions with other components of the system, and new consequences. The 'behaviour' of these grand challenges is assuming characteristics of an ecosystem: an intervention in one location results in changes there but also elsewhere. Single human interventions are unlikely to work. There are some such interactions that are quite clear. There will be many more that are subtle and unforeseen.

Growing more crops on more land, or increasing the productivity of crops on the existing land addresses food security, but maybe only temporarily. This strategy is likely to negatively affect soil health, and will require more water, which is already stressed in many locations. It may decrease biodiversity. And people still want wild places to visit (e.g. national parks). Higher yields will require more artificial fertilizers, which mean more emissions and agriculture becoming even more dependent on the fossil industry. More agro-chemicals can lead to further pollution while production increase reaches a maximum that cannot be further increased. Bioenergy, biofuels and bio-based materials produced from biomass instead of fossil resources addresses GHG emissions reductions, central to the mitigation of climate change. But this requires more biomass, which can impinge on food security, and can interfere in many of the ways highlighted above. The interferences can partly be ameliorated by, say, using algae as a source of biomass, or using waste industrial gases as the feedstock for fermentations. Deliberately increasing the production of algae, or removing existing stocks unsustainably, inevitably affects other parts of the marine ecosystem, and may interfere with local, traditional industries and practices. It could be that the best locations for growing, harvesting and processing algae are not served by infrastructure, such as road and rail transport. The costs of developing marine biotechnology to an extent that will significantly address global challenges are very high, so a lot of attention has to be paid to consequences.

For policy makers, these are either dream or nightmare scenarios. Faced with constrained finances, the policy challenges are long-term and there are no quick fixes. Ultimately the goal is interacting solutions to interacting grand challenges. This calls for multi-disciplinary research and systems innovation. There is no simplistic technological fix, and genomics is merely one part of the jigsaw. But it is a very important part because genomics can offer interactions. Many of the on-going R&D activities in crop science make some of these interactions foreseeable. For example, the combination of drought/heat tolerant traits with the ability of a plant to make its own fertilizers addresses several grand challenges: water security, food security, resource depletion, climate change. Unfortunately, creating such a crop is a gargantuan task. Therefore, although genetic modification and gene editing offers the possibilities to address many of the ambitions ahead, negative interactions have to also be considered, not least of them the possible public reaction to such a strategy.

Human population dynamics: asymmetry and uncertainty

7. Ultimately, there is huge uncertainty about what the eventual population equilibrium will be, and when it will be reached. It is expected that there will be over 9 billion people living on the planet by 2050. For many OECD countries the ratio of working people-to-elderly is changing quickly (Carone and Costello, 2006): in Denmark, for example, the ratio will change from currently 4:1 to 2:1 by 2050 with serious economic consequences (IMF, 2008).

8. Meanwhile, 95% of the burden of population growth will be in developing countries (UN Department of Economic and Social Affairs, 2011). Across Asia population growth is also asymmetric. By 2021, the population of India is likely to surpass that of China and the two will account then for about 36% of the world population. However, China and India have experienced a rapid fall in the average number of

children per woman. These Asian giants are also ageing, and as life standards improve, this phenomenon is expected to become even stronger.

9. In East Asia several countries, like in Europe now have very low levels of fertility, well below their 'replacement rate', meaning that their populations are ageing. Projections by the Japanese government indicate that if the current trend continues, the population of Japan will decline from about 127 million in 2014 to about 97 million in 2050 (National Institute of Population and Social Security Research, 2012).

10. Of particular relevance to this chapter is the predicted growth of the Asian middle class. As of 2010, Asia accounted for less than one-quarter of today's middle class[2]. By 2020, that share could double due to a large mass of Asian households having incomes that currently position them just below the global middle class threshold. More than half the world's middle class could be in Asia and Asian consumers could account for over 40% of global middle class consumption (OECD, 2010). Globally, the middle class could increase to 4.9 billion by 2030, with 85% of the growth coming from Asia.

Shift in the global economic centre of gravity to Asia

11. The economic centre of gravity (the average location of economic activity across geographies on Earth) is moving towards Asia (Figure 1). By 2010 Asia accounted for 34% of global activity, but by 2034 it could account for 57% of global output (OECD, 2010). Not only China, India, Korea and Japan will lead this shift, but other large countries like Indonesia, Thailand, Malaysia and Vietnam will have significant economic mass. With a growing middle class and wealth comes growth and consumption, and with growth comes several environmental costs e.g. increased greenhouse gas (GHG) emissions.

Figure 1. The global centre of economic gravity has shifted east over the past 30 years (black dots), and could well shift even farther east over the next 30 years (grey dots).

Source: Redrawn from CNN (2011). http://globalpublicsquare.blogs.cnn.com/2011/04/07/worlds-center-of-economic-gravity-shifts-east/

Food and water security *versus* land limitations

12. With so many more people alive by 2050, food and water security are also increasingly important. With 9.1-9.6 billion people alive by 2050 as estimated in the medium variant option, food

2 Defined as all those living in households with daily per capita incomes of between USD10 and USD100 in PPP terms (OECD, 2010).

production will need to rise by 50-70%, dependent on the source (UN FAO, 2009).[34] More arable land, or more efficient use of existing arable land, will be needed to meet the food demands, while less may be available because of changing climate conditions. Using more land for production also impacts biodiversity. With much of the growth in population and economic output in Asia, these challenges are all the more acute. Moreover, developing countries have changed dietary patterns. In about the last 30 years meat consumption in developing countries has doubled, and egg consumption has quadrupled. The demand for more meat has significant environmental implications. Beef production is notoriously costly in resources such as water and land, and is also responsible for high GHG emissions compared to some other forms of animal protein. For every kilogram of beef produced, 4-5 kilograms of high energy feed are required, and well over 10 000 litres of water is consumed.

13. As much as 40% of the food in the world is produced by irrigated agriculture that relies largely on groundwater. Globally, 70% of all freshwater use is for agriculture (Sophocleous, 2004). But groundwater depletion is accelerating worldwide. Some of the highest rates of depletion are in some of the world's major agricultural centres, including northwest India, northeast China, and northeast Pakistan (Wada et al., 2010). Also climate change is projected to decrease freshwater availability in central, south, east and south-east Asia, particularly in large river basins.

14. Whilst bio-based production has great potential for GHG emissions savings, the production of extra non-food biomass requires a great deal of water, thus potentially putting it in competition with other vital water uses. For example, one study (Gerbens-Leenes et al., 2009) found that, for biodiesel production, soybean and rapeseed (crops mainly grown for food) had the best water footprint. Jatropha, often cited as a great future hope for biofuels production, had the least favourable.

15. The impact of bio-based production on food supply is very much a live debate. The international food prices increases that were experienced in 2008 ignited controversy over biofuels production, the so-called food versus fuel debate (e.g. IFPRI, 2010; Mueller et al., 2011). Evidence links first-generation biofuels to the price spike, but the actual extent of the linkage will probably never be known (Abbott et al., 2008; de Gorter et al., 2013). Next-generation lignocellulosic ethanol production has, as a primary policy goal, the breakage of this link between land requirements for food and fuel.

16. The impacts of GHG emissions from land use changes (see Annex 2) are considered to be critical factors in the sustainability of bio-based production. Many Members of the European Parliament (MEPs) have long been calling for ILUC to be factored into measuring the value of biofuels. However, ILUC measurement is extremely challenging. Searchinger et al. (2008) highlighted that land-use change contributions towards agricultural GHG emissions involve a high level of uncertainty, but DLUC and ILUC should not be ignored.

17. Due to the much smaller production volumes (and in some cases higher land area efficiency) compared to fuels, bio-based materials production has fewer demands on land use, and therefore the potential impacts on food supply are concomitantly lower (see, for example, Endres and Siebert-Raths, 2011). If compared on a hectare basis and without residue utilisation, most bio-based polymers score better in terms of energy savings and GHG emission reduction than bioenergy production from energy crops (Dornburg et al., 2004). An analysis by Higson (2012) (Figure 2) predicts much lower land requirements for bioplastics than bioenergy and biofuels, both at 2030 and 2050. In quantitative terms, however, much work remains to be done. Nevertheless, it seems evident that the industrial material use of biomass makes fewer demands on resources and reduces pressure on land and biomass compared to energy and fuel uses (Carus and Dammer, 2013).

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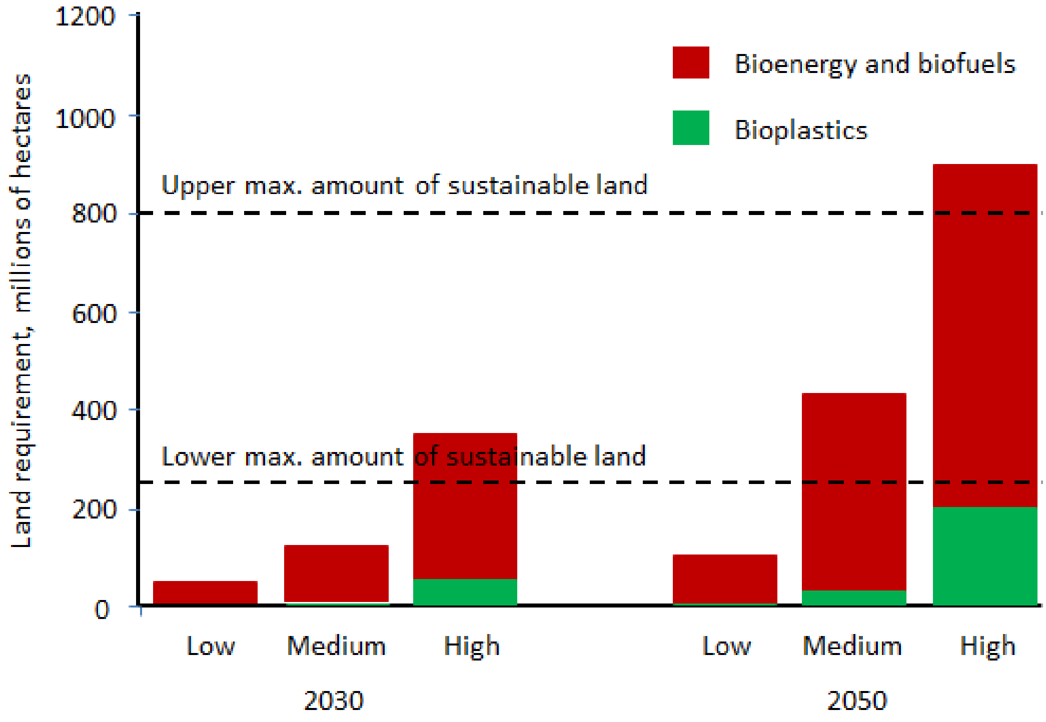
3 http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

4 http://esa.un.org/wpp/Documentation/pdf/WPP2012_Volume-II-Demographic-Profiles.pdf

Figure 2. Predicted biomass demand scenarios versus land availability in 2030 and 2050.



Source: Higson (2012).

Energy security and the shift away from fossil fuels

> "*While the global community works to eliminate the use of fossil fuels, it makes little sense - financially or ethically - to continue holding investments in these companies,…There is no sane rationale for companies to continue to explore for new sources of hydrocarbons*."

Rockefeller Family Fund trustees, April 2016 (*Financial Times*, 2016a)

18. Bioenergy and biofuels have been supported strongly in public policy in response to emissions reductions and also to address energy security. The two grand challenges are in fact linked in this fashion. At least to the medium term, bioenergy and biofuels could be major contributors to emissions reductions, although this depends on the efficiencies of converting feedstocks and other factors. There are pros and cons to this approach, but it is one that has been set in motion for more than a decade. This part of the chapter looks at the other reasons for deploying biotechnology to energy challenges –that of energy security.

19. Most countries are plagued by energy insecurity as a result of the geography and geopolitics of fossil fuel production. Many of the OECD countries are net importers of crude oil and natural gas, especially in the European Union, where there are only a few oil producers and exporters. Hungary, for example, imports 80% of its domestic crude oil requirements, and this percentage may increase (National Renewable Energy Action Plan 2010-2020, 2010). Oil production in the United Kingdom and Norway has been falling steadily in recent years following peak production in 1999 and 2001 respectively. The United Kingdom has recently become a net oil importer (OilPrice.com, 2010). The dramatic fall in the price of oil since 2014 has seen many oil towns across the world in decline with many jobs lost as the oil industry goes through another of its cycles of price volatility.

20. A greater proportion of crude oil in future will be from unconventional sources such as tar sands and the deep subsea. These sources are much more expensive and dangerous to exploit. The current price fluctuations do not change the fundamentals and higher prices are most likely to return in the future. Low prices inhibit investment in alternative energies, but also in conventional exploration. There is also a looming danger that prices rebound way beyond what is desired after a slump, causing large detrimental effects on the global economy.

21. The International Monetary Fund (IMF) has calculated that a 10% rise in oil prices removes 0.2-0.3% from global GDP growth in the first year, but the impact on a big oil consumer, such as the United States, is twice as large (*The Economist*, 2011). High prices and oil shocks have contributed significantly to historical recessions (Jones et al., 2004): Hamilton (2011) stated that 10 of the 11 post-war US recessions have been preceded by a sharp increase in the price of crude oil. Based on evidence from some European countries, Cuñado & Pérez de Gracia (2003) suggested that oil prices have permanent effects on inflation.

22. Some Asian countries typify the energy security dilemma. Thailand is highly dependent on crude oil imports, accounting for more than 10% of GDP (Siriwardhana et al., 2009). Energy security and rural and economic development led to Malaysian R&D on biodiesel derived from palm oil as early as 1982. Korea has similar needs, as the country imports 97% of its energy, which still comes from fossil fuel reserves. Korea aims to replace 30% of fossil fuel with biofuel to become more energy independent. To achieve this Korea has an important programme to develop biofuel production from algae. Likewise, China also has a huge demand for crude oil that cannot be met through domestic production, but faces limitations in sacrificing food security for energy. Recently, India has turned to bio-based energy to reduce dependence on imported oils. India has to import approaching 80% of its crude oil requirements (Ministry of Petroleum and Natural Gas, Government of India, 2009). India leads the way in planting and cultivating the non-food Jatropha plant on an industrial scale for biodiesel production (Wonglimpiyarat, 2010).

23. No country illustrates the situation better than Japan. It is the world's third largest economy, but is the weakest in energy self-sufficiency of the G8. Japan is the world's largest importer of liquefied natural gas (LNG), second largest importer of coal and the third largest net importer of oil. Japan relied on oil imports to meet about 42% of its energy needs in 2010 and to feed its vast oil refining capacity, and relies on LNG imports for virtually all of its natural gas demand. In short, Japan's dependency on fossil energy from abroad is over 90%. Without action on fossil fuel imports, Japan faces: further dependency on the Middle East; a rise in electricity prices, a rapid increase in GHG emissions and an outflow of national wealth.

There is plenty of crude oil but little spare capacity

24. Currently there is very little spare capacity in crude oil production, and the capacity that exists resides in the Middle East, not in OECD countries. New oil discoveries globally have not kept up with annual production since at least 1980. Owen et al. (2010) supported the contention held by many independent institutions that conventional oil production may soon go into decline and it is likely that the "*era of plentiful, low cost petroleum is coming to an end*."

25. The deep oceans will provide further significant crude oil discoveries, but these discoveries come with various price tags – the actual cost of extracting oil from deep-water locations, and environmental and increasing safety concerns and costs (e.g. Noble et al., 2013; Rochette, 2012). Offshore oil exploitation is moving into increasingly deep waters (over 2 kilometres today, compared to around 10 metres in the 1940s), and several recent high-profile accidents have raised public awareness of the problems.

26. Discoveries of new oil reserves have dropped to their lowest level for more than 60 years, pointing to potential supply shortages in the next decade (*Financial Times*, 2016c). Unconventional oil sources have problems, including price, environmental sensitivity and technical production problems.

Competition for crude oil from and chemicals and plastics

27. Plastics production is the largest sub-sector of the petrochemicals industry, and such is the success of plastics as materials that their market position is going to increase at a significant pace. Plastics have shown an almost exponential growth during the past decades and currently over 200 million tonnes per annum are produced world-wide. One source has predicted that overall demand for plastics could increase four- to five-fold by the end of this century (Lemstra, 2012). Similarly, the USDA (2008) has predicted that overall chemicals production could almost double by 2025 (compared to 2005).

28. Before the recent economic recession, more than 70 million motor vehicles were sold every year round the world – bringing the total number on the road to over 800 million recently. By 2030, this figure could reach 1.3 billion vehicles and by 2050, the total may be more than doubled again to three billion vehicles – mainly due to growth from emerging markets such as Brazil, Russia, India and China.[5]

29. There will probably be at least a doubling of the plastics used in automotive production by 2030, and quadrupling the quantity by 2050, and probably more as new plastics applications are researched in order to reduce the weight of vehicles. The question is open about how much more efficiency can be wrought from the ICE by 2050.

30. Growing demand for plastics and chemicals creates an obvious dilemma for the petrochemicals industry. The feedstock for producing synthetic plastics is almost exclusively crude oil and currently around 5% of oil production is used for making plastics, with another 3 or 4% required for the energy to make plastics. For plastics production alone, by the end of this century 20-25% of current crude oil production would be required for plastics production. To this has to be added the increasing demand for chemicals production, meaning that the demand for crude oil from chemicals and plastics alone in relation to total production may become unsustainable. Demand for plastics in Asia is still growing, and several Asian governments see a bioplastics industry as a priority for the future. Thailand is a good example (Box 2).

5 www.sciencescotland.org/feature.php?id=70

Box 2. Bioplastics and Asia

Thailand has more than 4 000 companies in the petro-plastics industry, and is also very rich in biomass. Since 2006, the Thai Government has declared the bioplastics industry to be one of the strategic industries that the government is promoting in its drive towards sustainable growth and development. This resulted in 2008 in a National Roadmap for the Development of Bioplastics Industry, developed by the National Innovation Agency (Ministry of Science and Technology of Thailand, 2008). This action plan for 2008-2012 was focused on four main strategic areas:

- Sufficient supply of biomass feedstock;
- Accelerating technology development and technology co-operation;
- Building industry and innovative businesses;
- The establishment of supportive infrastructure.

Several Asian countries (e.g. Malaysia, Japan, Korea, Singapore and China), offer attractive tax reductions to companies that want to research and invest in the bioplastics sector (OECD, 2013). Both Japan and Korea have well-developed policy frameworks for the development of bioplastics industries.

31. In 2012 the Korean government announced a *Strategy for Promotion of Industrial Biotechnology*, with the goal of establishing a mid- to long-term strategy to develop related technology and devise detailed measures for implementation, contributing to lowering the existing dependence of the economy on crude oil. By 2020, this effort is expected to result in replacing 4.8% of crude oil imports with biochemical product manufacturing, reducing CO_2 emissions by approximately 10.8%, and generating at least 43 000 new jobs.

32. Following the ratification by the Japanese Government of the Kyoto Protocol in June 2002, the Government announced (December 2002) two measures: the *Biotechnology Strategic Scheme* and the *Biomass Nippon Strategy*. The main objective of the two measures was to promote the utilisation of biomass and to reduce the consumption of fossil resources and to mitigate global warming through the use of biotechnology. The policy objective stated in the *Biotechnology Strategic Scheme* is to replace approximately 20% (2.5 to 3 million tons per year) of conventional plastics with plastics from renewable resources by 2020. This stimulated some major Japanese corporations into sourcing bioplastics for their products e.g. Toyota.

Climate change and global warming

33. UNEP (2010) calculated that a doubling of wealth leads to an 80% increase in emissions. An objective of building a bioeconomy is to break this vicious cycle so that economic growth can be achieved without increasing the threats of climate change.

34. Among papers expressing a position on anthropogenic global warming (AGW), an overwhelming percentage endorses the scientific consensus on AGW, with a very small number rejecting it (Cook et al., 2013). To date 167 countries have signed up to the Copenhagen Accord,[6] in trying to limit the temperature rise, compared to pre-industrial levels, to 2ºC. And yet, taking into account the impact of measures already announced by governments to improve energy efficiency, support renewables, reduce fossil fuel subsidies and, in some cases, to put a price on carbon, the world seems on a trajectory consistent with a long-term average temperature increase of 3.6°C (IEA, 2013).

6 http://unfccc.int/meetings/copenhagen_dec_2009/items/5262.php

Most remaining hydrocarbon reserves cannot be burned

35. The world is not on track to meet the 2°C target. Despite positive developments in some countries, global energy-related CO_2 emissions increased by 1.4% to reach 31.6 Gt in 2012, a historic high (Green and Stern, 2015). The need for new forms of renewable energy and sustainable manufacturing has never been more urgent.

36. The implication is that most of the known and projected fossil fuel reserves may be unburnable (Meinschausen et al., 2009; Carbon Tracker, 2013). This has recently been quantified: a third of oil reserves, half of gas reserves and over 80% of current coal reserves should remain unused from 2010 to 2050 in order to meet the target of 2°C (McGlade and Ekins, 2015). What is worse, achieving a 2°C scenario means only a small amount of fossil fuels can be burned unabated after 2050. In the view of Friedlingstein et al. (2014), two thirds of the CO_2 emission quota consistent with a 2°C temperature limit has already been used, and the total quota will likely be exhausted in a further 30 years at the 2014 emissions rates. By century end, the IPCC (2014)[7] has warned that GHG emissions need to be close to zero to achieve the 2°C obligation.

Drought, temperature and crop yields

37. One important impact of climate change concerns agriculture. Agricultural productivity is ultimately defined by crop yield. Elevated temperatures have long been known to affect plant growth. Schlenker and Roberts (2009) demonstrated for three major US crops that an increase in temperature above the optimum for each resulted in a very rapid decline in yield. Their modelling suggested that average yields could be predicted to decrease by 30–46% before the end of the century under the slowest warming scenario and decrease by 63–82% under the most rapid warming scenario. The US Environmental Protection Agency (EPA) has predicted that by mid-21st century, crop yields could increase up to 20% in east and south-east Asia. In the same period, yields could decrease up to 30% in central and south Asia[8].

38. The US has just experienced its most widespread drought in more than half a century (Reardon and Hodson, 2013), and the drought in 2014 in California was perhaps the worst ever recorded (*National Post*, 2014). In 2015, for the first time in decades, officials in California forced thousands of farmers to reduce water use[9]. A NASA sponsored project[10] concluded that if greenhouse gas (GHG) emissions continue to increase along current trajectories throughout this century, there is an 80% likelihood of a decades-long mega-drought in the Southwest and Central Plains of the US in the second half of this century. This drought risk is unprecedented in human history (Cook et al., 2015). In Brazil, the three most populous states have recently experienced their worst droughts since 1930[11]. As agriculture accounts for around 70% of all freshwater use, measures that conserve water are of the utmost social and economic importance.

39. High temperatures in many cases can be expected to be accompanied by drought conditions. Evidence suggests that heat and drought stress can cause disproportionate damage to important crops

7 IPCC (Intergovernmental Panel on Climate Change) (2014), "IPCC: GHG emissions accelerate despite reduction efforts", Press Release, 14 April, 2014. http://www.ipcc.ch/pdf/ar5/pr_wg3/20140413_pr_pc_wg3_en.pdf

8 http://www.epa.gov/climatechange/impacts-adaptation/international.html

9 http://www.bbc.com/news/business-33119960

10 http://www.nasa.gov/press/2015/february/nasa-study-finds-carbon-emissions-could-dramatically-increase-risk-of-us

11 http://www.bbc.com/news/world-latin-america-30962813. January 24, 2015

compared with either stress individually (Atkinson and Urwin, 2012). Therefore, improvement of dual stress tolerance to heat and drought in crop plants has become a top priority for the development of agricultural biotechnology for both food and bioenergy markets. In addition, the number of crop varieties may be expanded to varieties that are better adapted, and to include orphan crops. Another consideration is that increasing temperatures may also be beneficial for areas that are now too cold.

Bio-based production and GHG emissions

40. Weiss et al. (2012) compared cradle-to-grave GHG emissions associated with conventional and bio-based chemicals, based on a total of 44 LCA studies covering approximately 60 individual bio-based materials and 350 different life cycle scenarios. They found that the bio-based materials save, on average, 55 +/- 34 MJ non-renewable energy and 3 +/- 1 kg CO_2 per kg material compared to their fossil-based counterparts.

41. However, LCA studies on bio-based product GHG savings abound. An observation from the Weiss paper is large variability in the calculations, which results from differences in background assumptions, system boundaries, and methodologies in the LCA calculations. All can differ in different studies, and the results are not easy to compare. Also most such studies deal with ethanol, polylactic acid (PLA) or polyhydroxyalkanoates (PHA). Another limitation is that bioprocess data are often limited.

42. Hermann et al. (2007) attempted to standardise cradle-to-grave methodology to compare the environmental impacts of various bio-based chemicals with their fossil-based equivalents (Table 1).

Table 1. Potential worldwide annual production and best case GHG savings of nine bio-based chemicals, with corn starch feedstock and using cradle-to-grave analysis.

	Annual GHG savings (kt CO_2/year)	
Product	**Today**	**Future**
Acetic acid	N/A	9570
Acrylic acid		4380
Adipic acid	N/A	7880
Butanol	3040	9610
Caprolactam		20 100
Ethyl lactate	1580	2220
Ethylene	191 050	245 710
Lysine	1370	2280
Succinic acid	6070	6780

Note: The analysis did not account for future chemical industry changes.
Source: Hermann et al. (2007).

43. They showed that the potential GHG savings for current technology and corn starch as feedstock was already 45% compared to the fossil equivalents. The future saving potential is even higher if lignocellulosics or sugar cane are used as feedstocks.

44. Substantial further savings are possible in the future through improved fermentation and downstream processing, and improvements due to consolidated bioprocessing and synthetic biology are entirely in the future. They concluded that worldwide CO_2 savings in the range of 500-1 000 million tons per year are possible using future technology.

45. Sophisticated predictive modelling to 2030 in the Netherlands (Hoefnagels et al., 2013) indicates that the production of only three bio-based chemicals (ethylene, caprolactam and hydrogen) and second-generation biofuels can result in large reductions in CO_2 emissions (over 27% compared to 2006 values).

46. If such predictions become reality, then bio-based chemicals production offers excellent opportunities for mitigating GHG emissions and decreasing dependence on fossil energy sources. However, the variability in calculations is a serious impediment to bio-based production, and international standardisation is required for the credibility of the industry. Serious misgivings concerning the use of LCA as the sole tool in environment impact assessment have been raised (ANEC, 2012). The authors claim that in some cases European policy was based on flawed LCA results (e.g. biofuels). The subject merits further attention by policy makers.

Soil destruction

47. Often overlooked in policy making, soil is the ultimate genetic resource; soils are the critical life-support surface on which all terrestrial biodiversity depends. More than 99.7% of all food is derived from cropland (Gore, 2013). But soil is being destroyed at unprecedented rates due to soil erosion (e.g. through deforestation), pollution and salination. About 2.5% of arable land in China is too contaminated for agricultural use (Chen and Ye, 2014).

48. It takes around 500 years to form 25 mm of soil under agricultural conditions, and about 1 000 years to form the same amount in forest habitats.[12] Therefore soil should be treated as a non-renewable resource. In the bioeconomy and sustainability context, soil accounts for some 20% of the capture of human CO_2 emissions (European Commission, 2007).

49. In the EU, the annual cost of soil degradation alone is estimated at some EUR 38 billion (European Environment Agency, 2007). The overall message is clear – our society is utterly dependent on maintaining the global stock of healthy soil. Any plans for a future bioeconomy dare not ignore this. An increasing rate of soil degradation must be reversed. In the face of soil destruction, more crops will have to be grown more efficiently, while methods should also be explored to halt or limit soil destruction.

Job loss in rural areas

50. The issues around bioeconomy and rural regeneration are summarised here. A separate chapter deals with jobs and turnover in greater detail for a bioeconomy (the first systematic approach of its kind).

51. Modern agriculture is a highly efficient enterprise in many OECD countries, with strong productivity growth being recorded in developed countries, especially from the 1960s through the 1990s (OECD, 2011), but these efficiencies have led to job losses in the sector. For the United States, a major driving force for industrial biotechnology is the regeneration of the rural environment, where a huge number of agricultural jobs have been lost due to increased efficiency (USDA, 2010). Over the last 60 years, the percentage of the US population directly involved in production agriculture has gone from 15% to less than 2%, but the average farmer produces food for 155 people today, as compared to his counterpart 60 years ago, who produced food for only 25 people. Agricultural job loss is a major and continuing trend linked to global economic developments which is observable in all technologically advanced countries.[13]

52. The development of biorefineries has recently also become a topic on the agenda of the European Union, with a focus on the use of agricultural and forestry materials as the feedstock for bio-based

[12] Food and Agriculture Organisation (FAO), www.fao.org/sd/epdirect/epre0045.htm

[13] http://ec.europa.eu/agriculture/envir/report/en/emplo_en/report_en.htm

production. The main limitation in the use of raw materials from agriculture is related to their typical low economic value and energy density. Long distance transportation is a limiting factor in economic terms (Mayfield et al., 2007). Therefore there are valid reasons for considering the rural environment as the location for biorefineries (or at least the first production lines involving agricultural residues), to be as close as possible to the main agricultural or forestry areas.

53. However, the promotion of a new industry in rural areas is typically hindered by the scarcity of human capital, lack of information, infrastructures, and there are sometimes competing interests (Lopolito et al., 2011). The various public policy options have strengths and drawbacks, posing the problem of finding the best compromise for public decision makers.

54. The greatest potential for rural development will be through second generation cellulosic biorefining, in which materials such as agricultural residues and wood are used as feedstocks for biorefineries. A recent study (Bailey et al., 2011) has shown a high potential for economic development and job growth through lignocellulosic biorefining, especially in the logging sector and in rural regions of Alabama, which is a state that combines both abundant timber resources and persistent rural poverty.

55. Whilst environmental aspirations for the bio-based industries are important, the job creation possibilities are likely to be at least as important a priority for policy makers (Peters et al., 2011). Both chemicals and plastics industry jobs in the United States went into steep decline from the 1980s, as oil rich countries began to aggressively invest in their own petrochemical industries (Biotechnology Industry Organization, 2010), and thus the jobs moved nearer to the feedstock. For every job created in the business of chemistry in the United States, 7.6 related jobs are created in other sectors[14] and on average they are highly paid compared to other manufacturing jobs. The employment opportunities also seem excellent compared to fossil industry employment. Compared to fossil fuels in Europe, biofuels create 50-100 times the number of jobs; electricity from biomass creates 10-20 times the number of jobs; and heat from biomass creates double the number of jobs (European Commission, 2005).

56. The Blue Green Alliance estimated that shifting 20% of current plastics production into bioplastics would create a net 104 000 jobs in the United States economy (Heintz and Pollin, 2011). Federal policy in the US supporting biofuels had resulted in an additional 240 000 jobs and contributed USD 65 billion to GDP in 2008 (Carr et al., 2010). If current growth in bio-based chemicals can be maintained in the United States, it would create or save tens of thousands of additional jobs, even in the near-term (*Industrial Biotechnology*, 2011, Industry Report).

57. Meanwhile, modelling in Europe indicates that bio-based chemicals and plastics production can support more jobs per tonne of biomass than biofuels and bioenergy applications. Carus et al. (2011) have estimated that materials use can directly support 5–10 times more employment and 4–9 times the value-added compared with energy uses, principally due to longer, more complex supply chains for material use.

58. The government of Flanders recently published a bioeconomy report (summary in English edited by Van Melkebeke, 2013) that confirmed that, in Flanders, bio-based products (such as paper, wood-fibre boards, bioplastics and biochemicals) have created five times more added value (based on gross margin calculations) and ten times more employment than bioenergy (i.e. bio-based electricity or heat, and biofuels). A publication of the BRIDGE 2020 PPP (public-private partnership), under development in Europe[15], shows similar job numbers in Europe for biofuels and bio-based chemicals and plastics, of the order of 150 000 in each sub-sector, whereas bio-based chemicals and plastics generated a turnover of EUR 50 billion compared to EUR 6 billion for biofuels (BRIDGE 2020, 2012).

[14] www.americanchemistry.com/Jobs

[15] Now referred to as the Bio-based Industries Consortium, http://biconsortium.eu/

59. Modelling to 2030 by Hoefnagels et al. (2013), using a variety of scenarios, indicates that 3-5% of agricultural employment will be related to the production of biomass for bioenergy or bio-based chemicals. In all scenarios, the added value is predicted to increase in all sub-sectors of bio-based production, i.e. electricity, transport fuels and chemicals. However, the share of income in these sub-sectors is predicted to be greatest due to the quantities of bio-based chemicals production, this modelling being done for only three bio-based chemicals. In their economic analysis, this bio-based substitution requires hardly any subsidy if competing with high fuel prices.

RECONCILING FOOD AND INDUSTRIAL NEEDS FOR BIOMASS

Introduction

60. Key objectives for a bioeconomy are now embedded in the strategic activities of more than 40 countries (Bioökonomierat, 2015), with an increasing number developing a national bioeconomy strategy. In the post-fossil world, major sources of carbon are still required, however. The internal combustion engine is ultimately replaceable, but society will forever need chemicals to maintain the current lifestyle of developed countries, and to bring this more comfortable lifestyle to other countries. The foreseeable sources of carbon are renewable biomass carbon and waste industrial gases. As the latter is the target of climate change mitigation and waste reduction policies, it also will dwindle with time. Therefore, renewable biomass carbon is envisaged to become the source of carbon for chemicals, plastics, textiles and aviation fuels of the future.

61. This immediately creates a dilemma as the food and industrial uses of biomass clearly come into competition. It is true that there are fewer people hungry now than ever before, but food security is still elusive in many countries[16]. Moreover, this conflicting use of biomass has geographical and geopolitical implications. Many of the OECD countries can be expected to be importers of biomass (some already are) due to a shortage of land and high population densities. Many non-OECD, developing economies, on the other hand, are rich in biomass e.g. Brazil, China, India, Indonesia Malaysia, Russia. It may be tempting for the latter to become merely exporters of natural resources, as has sometimes been the case in past.

62. Two problems with this latter strategy for developing nations would be:

- Simply exporting natural resources may inhibit technological development in those countries. There is far greater value-added for a nation to develop the technologies of a bioeconomy e.g. industrial biotechnology, green chemistry and modern agricultural practices;

- In the absence of strong governance, it is possible for biomass to be over-exploited as a resource, resulting in market and societal failures such as deforestation and soil destruction. Many potential social risks can be imagined e.g. warlordism, displacement of landowners, threats to traditional lifestyles and job losses and job gains within the same society (Obidzinski et al., 2012).

63. This chapter draws on material from a joint workshop of the OECD and the German Bioeconomy Council (Bioökonomierat) at the Global Bioeconomy Summit in Berlin, November 2015. The central argument is that bioeconomy policies must balance food and industrial needs of biomass as a feedstock of the future, and that food must take priority. Given the global market and political economy of biomass, the chapter necessarily takes a view beyond the OECD countries. There is a particular focus on ASEAN, African and Brazilian interests and policies, and this is set into the context of the OECD countries.

Biomass flows

64. Current global biomass flows point to a trade issue for OECD economies. Many OECD countries are advanced economies that lack access to large amounts of biomass within their boundaries. Therefore bioeconomies in these nations currently rely on biomass imports. This may encourage exporting countries to grow and harvest biomass unsustainably. If this involved food crops destined for industrial use, then there is a potential threat to food security. There is a massive quandary at the beating heart of the

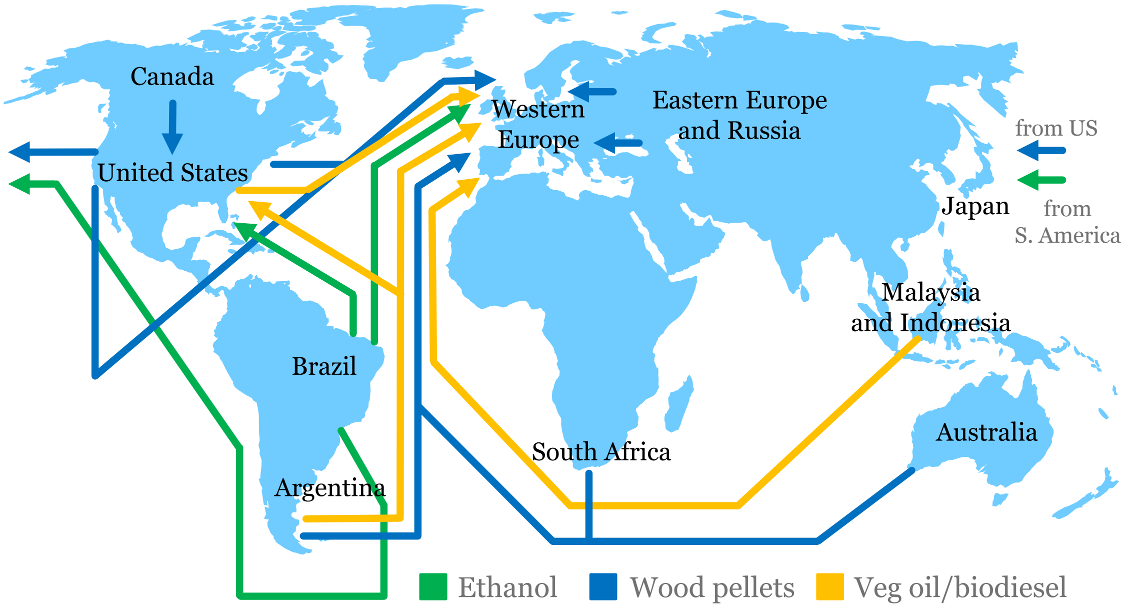
16 http://www.fao.org/economic/ess/ess-fs/en/

bioproduction concept – how to reconcile the food and feed use of biomass with the needs of industrial production.

65. Figure 3 shows world biomass shipping routes for 2011. It quite clearly shows how biomass flows should concern the OECD: every single arrow-head points to an OECD nation or region.

Figure 3. World biomass shipping routes in 2011.

Not only do all the arrow-heads point to OECD nations, but there is a significant convergence on Western Europe.



Source: Redrawn from BP-EBI (2014). Biomass in the energy industry. An introduction. Pub. BP plc, London, UK

66. For OECD nations which lack biomass resources, there is the danger that a bioproduction fails to achieve policy goals like energy security as the dependence is simply switched from oil exporters to biomass exporters. For biomass exporting countries, relying simply on exporting raw materials would miss the opportunity to create the greater value-added bio-production industries, and could lead to unsustainable practices, particularly over-exploitation.

67. The bioeconomy can deliver great benefits for society as a whole. Energy resources would be more distributed rather than concentrated in small, politically unstable regions of the world. Certainly, agricultural productivity (the value-added per agricultural worker) of many Asian countries is much lower than in developed countries[17]. Farming is characterised by small farms, subsistence farming and high levels of poverty. There are great gains to be made in food supply through both changing agricultural practices and the application of modern biotechnology.

68. A large reliance on forestry for industrial biomass could also lead to environmental degradation as a result of the direct consequences of deforestation. Logging in past has led to negative societal outcomes, including violent conflict. Illegal logging is already costing nations tens of billions of dollars each year, and tropical deforestation contributes 12% of total anthropogenic carbon dioxide emissions globally (Lynch et al., 2013). Therefore illegal logging works against two founding policy goals of a

17 http://wdi.worldbank.org/table/3.3

bioeconomy – economic growth and climate change mitigation. Paying to prevent deforestation is likely to be contentious, but contributions from OECD countries may be less expensive than allowing it continue unabated (Box 3).

Box 3. Controlling deforestation in Liberia

Forest covers more than 40% of Liberia and the country is considered one of west Africa's most important carbon sinks and biodiversity hotspots. The UN estimates that 30 000 hectares of primary Liberian forest is cleared each year. The country's administration, backed by more than USD 150 million of international aid, is driving policy aimed at enabling the country and communities to make money from reduced carbon emissions. First, carbon levels are measured in a forest. Then, if the land is not cleared, the carbon that is retained in the forest — or not emitted through clearing — can be sold as offsets.

Norway is providing USD 70 million to help Liberia develop the policy framework and create capacity to implement the changes. It is providing a further USD 80 million to pay for the first carbon offsets. Other governments and private investors are welcome to buy the offsets. It will take time to see whether such a system could succeed, but this could be test-bed for deforestation prevention. A bioeconomy is likely to stimulate markets for wood further, and this policy is consistent with one of the major policy goals of a bioeconomy, that is, emissions reductions.

Source : *Financial Times*, 2016b

69. One of the answers is to use waste materials (so-called 'bio-wastes') as feedstocks for bio-based manufacturing. These include agricultural and forestry residues, municipal solid waste and waste industrial gases. But this also poses large technical questions, and the answers are as yet far from clear. How much biomass can be generated this way sustainably? How do we measure the sustainability of bio-wastes?

The twin dilemmas of food and energy security are intimately linked

70. The snapshot of issues described shows how easily it will be for the bioeconomy to develop unevenly. The case of India is illustrative. Like the majority of countries, India imports crude oil at great expense. During the last decade, India's import of crude oil more than doubled to 140 million tons from 57.8 million tons at the end of fiscal 2000. During the next 25 years, demand for electricity in India is expected to increase five-fold. The biotechnology sector is seen as an important potential contributor to solving India's growing energy problem and its need for energy security. India faces the ultimate dilemma of the bioeconomy – can it produce sufficient biomass to contribute to energy security and economic growth through bio-based production whilst still feeding the nation? Many nations with bioeconomy aspirations face the same dilemma.

71. Korea imports 97% of its energy, which still comes from fossil fuel reserves. Many African countries are in the same position, if not worse, as their economies are developing more slowly than some of those of South East Asia. Projections by the Japanese government indicate that if the current trend continues, a serious population decline by 2050 will have occurred. Moreover, Japan has a dwindling number of farmers and they are ageing and farming very small plots. This poses problems for agricultural vitality (Karan, 2005). The average age of its farmers was 65.9 years in 2011. In 2012, the agriculture industry employed 2.51 million people, less than 20% of its peak of 14.54 million in 1960 (*The Japan Times*, 2013), and farmers' children do not want to stay in farming. This is by no means unique to Japan – for example, the rural population of China is also declining, the average age of farmers is rising, and fewer young people are choosing farming as a vocation (Yang, 2013).

How much biomass is available: the biomass potential

72. The recurring theme is "uncertainty". When the issue of sustainability is applied to biomass, there are no internationally accepted metrics or tools (Bosch et al., 2015). In such a situation, it is no surprise that biomass potential estimates are extremely variable. There have been many such, but the situation was very well illustrated by Saygin et al. (2014). From 17 separate studies they identified a discrepancy in estimates of biomass potential of 20 fold from highest to lowest (75 to as high as 1500 EJ/yr in 2050).

73. Table 2 contains data which highlight the above issues very well. It demonstrates that, if OECD countries are to be seen to be active in world food security, very soon there will be no farmland available for industrial use.

Table 2. Land potentials (farmland) for non-food use, scenario - business as usual (BAU). (Adapted from Deutsches Biomasse Forschungs Zentrum, 2011). Figures are x 1 000 hectares

	2010	2015	2020	2050	2010	2015	2020	2050
Europe	102 717	115 134	127 096	171 446	44 531	20 315	0	0
N America	65 621	59 090	53 709	33 144	27 759	10 135	0	0
C America	-3, 545	-11 765	18 639	-42 219	1 171	446	0	0
S America	35 786	29 132	24 170	18 066	21 182	9 364	0	0
America	97 865	76 458	59 240	9 992	50 113	19 945	0	0
Oceania	33 157	28 185	23 362	-6 416	14 026	4 834	0	0
Asia	-62 219	-113 430	-153 786	-292 920	18 540	6 734	0	0
Africa	-56 818	-91 310	-121 677	-322 022	6 385	3 717	0	0

Note: Adapted from Deutsches Biomasse Forschungs Zentrum, 2011.
Figures are x 1 000 hectares.

74. This table shows the farmland potentials (i.e. farmland for non-food use) in the "business as usual" (BAU) scenario developed by the authors of the report. On the left part of the table is the farmland potential if the countries in these continents (134 countries in total) do not take part in food security for nations in food deficit. On the right side of the table is the remaining non-food land potential when the group of countries participate on a *pro-rata* basis in exports to cover the deficit food supply of the import countries. The following is a quotation from the report from which the Table is derived (bold text is this author's emphasis).

"The data for the "BAU" scenario indicates that ***no more farmland potentials for non-food use will be globally available from the year 2020****. However, there is still grassland for non-food use. Since no more farmland is available for non-food purposes, the big surplus states for agricultural primary products, such as Europe, North America and South America would have to export as of 2020 all agricultural primary products, which are no longer needed for their own food supply, into countries in deficit (mainly Asia and Africa)".*

75. If this is so, and is accepted worldwide, then using waste sources for biorefining is not a luxury, but an absolute necessity. What is more, this is a near-term situation. However, the figures may vary according to the assumptions and this table relates to one resource (farmland). The overall discussion is broader and considers more resources, e.g. forests, residual biomass, the marine environment, waste gases, etc. It is this variability in assumptions that leads to such great variety in studies.

What can biotechnology offer?

76. Biotechnology may hold some of the answers, both in food and industrial production. This in itself may create an unbalanced bioeconomy if the countries with greatest strength in biotechnology are

also developed countries, mostly OECD countries. What is emerging, however, is that developing economies are also rapidly building capacity in biotechnology.

77. The ambitious bioeconomy strategy of Malaysia, for example, envisages a bio-production industry in the country and Malaysia has had early successes in attracting foreign investment. Malaysia is committing large resources to a bioeconomy with a focus on value-added (OECD, 2015), not simply as a biomass provider. China is quite clearly gearing up for a future bioeconomy with biotechnology as a major technology platform (Sun and Li, 2015).

78. In 2012, the Association of Biotechnology Led Enterprises (ABLE) unveiled plans to grow India's bioeconomy to more than USD 100 billion by 2025, a level that would place it on par with India's information technology industry today (Burrill Media, 2014). However, there is apparently a perception in India, of policymakers and the Indian people, that biotechnology is a cause of social injustice and inequality. And yet the aims of a bioeconomy are quite the opposite.

79. The potential of biotechnology is beyond detailed description in this chapter. Rather, some areas of biotechnology directly relevant to a bioeconomy and the food/industry use of biomass are referenced.

Cellulosic biorefining and ethanol

80. The primary goal of cellulosic biorefining is to specifically avoid the use of food crops in biorefining. Cellulosic or ligno-cellulosic biomass can be grouped into four main categories:

1. Agricultural residues (e.g. corn stover, wheat straw, rice hulls, sugarcane bagasse);

2. Dedicated energy crops (e.g. switchgrass, *Miscanthus*);

3. Wood residues (including sawmill and paper mill discards), and;

4. Municipal solid waste (MSW) and paper waste.

81. After some delay, the first cellulosic biorefineries are open for the production of second generation ethanol. These are considered by many to be the main model for the future of the biorefining industry. These initial plants are critically important for the industry as cellulosic biorefining has to be seen to be a success, and these are the test-bed facilities. Upon their success hinges the future of biorefining for fuels (Peplow, 2014), and to some extent for materials.

Metabolic engineering for bio-based manufacturing of chemicals and materials

82. The production of useful chemicals from microorganisms is centuries old. However, metabolic engineering in microorganisms is now being used to make entirely unnatural petrochemical equivalents e.g. Yim et al. (2011). Several countries have been investing heavily in bio-manufacturing using metabolic engineering as a platform technology, now allied to software and synthetic biology. For example, the US Defense Advanced Research Projects Agency (DARPA) has a Living Foundries programme. The programme involves many companies, national laboratories, and universities working to develop new tools to enable rapid engineering of biology (National Academy of Sciences, 2015). It is tackling "impossible today" industrial projects that could become "possible" if genetic designs and operating systems never before accessible for industrial production are enabled. And its most recent large-scale initiative, the 1 000 Molecules Project, seeks a fundamental disruption of traditional chemicals and materials industries and processes by developing 1 000 new chemical building blocks for entirely new materials in the next 3-5 years.

Genomics and food production

83. Many food sources are now under scrutiny using genomics to create crops and livestock with improved performance e.g. higher yields, increased resistance to disease. Such foods include beef, pork, lamb, and many major crops such as wheat and rice. There are other applications to food production less obvious than these e.g. DNA barcoding of wild fish stocks for improved identification and for fraud prevention. It is important to point out that these efforts need not involve genetic modification, but can be used in conjunction with traditional and modern breeding techniques to enhance the efficiency of breeding programmes.

84. For example, the Aviagen[18] genomics project is concerned with identifying naturally occurring markers within the genome of elite chickens and using those markers to help breed stronger and more productive birds through the current selective breeding programme, a completely natural process. Aviagen became the first company to include genomic information as a critical additional source of information in a R&D breeding programme.

Crops that make their own fertilizer

85. Some leading biotechnologists have opined that within the next decade that there will be engineered crop plants that partially fix their own nitrogen (Keasling, 2015), although full nitrogen fixation will take longer. Synthetic fertilizers make a direct linkage between agriculture and the fossil industry. When the price of Brent crude oil rose from around USD 50 per barrel to about USD 110 by January 2013, the prices for ammonia in Western Europe and the Mid-Western corn belt in the US roughly tripled over the same period.[19] Therefore here is an opportunity in the longer term to significantly decouple agriculture from the fossil industry.

Policy perspectives from non-OECD countries

86. An OECD workshop (OECD, 2016) at the Global Bioeconomy Summit (November 2015) brought together speakers from Africa, ASEAN (Association of Southeast Asian Nations), Brazil and Europe. All have different perspectives on the future of the bioeconomy. From Africa the presentation gave the evidence of a will to embrace bio-production, while being mindful of a large number of other policy issues that have to be balanced with using biomass for industrial uses. The presentation from the ASEAN countries concentrated on food security. Reconciling food and industrial uses is important in the region as four of the countries of ASEAN (if Papua New Guinea is included as a candidate/observer nation) are megadiverse.[20] Brazil is another megadiverse country but is also a world leader in bio-production through decades of experience with ethanol as a renewable fuel. The European perspective came from the Netherlands, a key biomass country in Europe as Rotterdam receives much of the biomass imported to Europe, primarily for electricity generation (bioenergy).

Enabling food security in the Southeast Asia: ASEAN food security initiatives

87. Several of the key ASEAN countries have some features in common that make them particularly amenable to dual biomass use: they import large amounts of fossil fuels; they have large populations, so food security is definitely high on the agenda; their bioeconomy plans include bio-based production of fuels and/or chemicals, and; several of these countries are on the list of megadiverse countries. For these

18 http://en.aviagen.com/research-development/

19 http://marketrealist.com/2013/02/brent-oil-moves-nitrogenous-fertilizer-prices/

20 http://www.biodiversitya-z.org/content/megadiverse-countries

countries aligning climate, industry, food and agriculture and biodiversity policies is a priority. Each of these policies puts claims on biomass, and for sustainability to be guaranteed, a national and international balancing act is needed to prevent over-exploitation.

88. The UN FAO definition of food security[21] is:

> "*Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*".

89. The body that oversees the overall ASEAN cooperation in food and agriculture is the Special Officials Meeting of the ASEAN Ministerial Meeting on Agriculture and Forestry (SOM-AMAF[22]). In order to respond to trade globalisation, ASEAN cooperation in food, agriculture and forestry is now more focused on the enhancement of food, agricultural and forestry products competitiveness in international markets, while sustaining agricultural production. Harmonisation of quality and standards, assurance of food safety, and standardisation of trade certification are amongst the priorities being addressed, building upon the experience of some Member States and existing international standards.

90. The 37th Meeting of AMAF (37th AMAF) on 10 September 2015 in Makati City, the Philippines adopted the Vision and Strategic Plan for ASEAN Cooperation in Food, Agriculture and Forestry, 2016-2025. This new Strategic Plan (SP) for the FAF sector 2016-2025 is an implementation of the post 2015 vision. The SP has been designed to guide ASEAN towards the completion of the Millennium Development Goals (MDGs) and the post-2015 Sustainable Development Goals (SDGs), and to achieve the related goals of the UN Zero Hunger Initiative.

91. This vision is:

> "*A competitive, inclusive, resilient and sustainable Food, Agriculture, and Forestry (FAF) sector integrated with the global economy, based on a single market and production base contributing to food and nutrition security and prosperity in the ASEAN Community*".

92. To achieve the vision and goals for the FAF sector, ASEAN member states will jointly act to benefit from the opportunities and confront the major challenges in the priority areas of cooperation supported by seven identified strategic thrusts and 57 action programmes. The seven priority areas for cooperation are:

1. Enhance quantity and quality of production with sustainable, 'green' technologies, resource management systems, and minimise pre- and post-harvest losses and waste;

2. Enhance trade facilitation, economic integration and market access;

3. Ensure food security, food safety, better nutrition and equitable distribution;

4. Increase resilience to climate change, natural disasters and other shocks;

5. Assist resource constrained small producers and SMEs to improve productivity, technology and product quality, to meet global market standards and increase competitiveness;

21 http://www.fao.org/docrep/013/al936e/al936e00.pdf

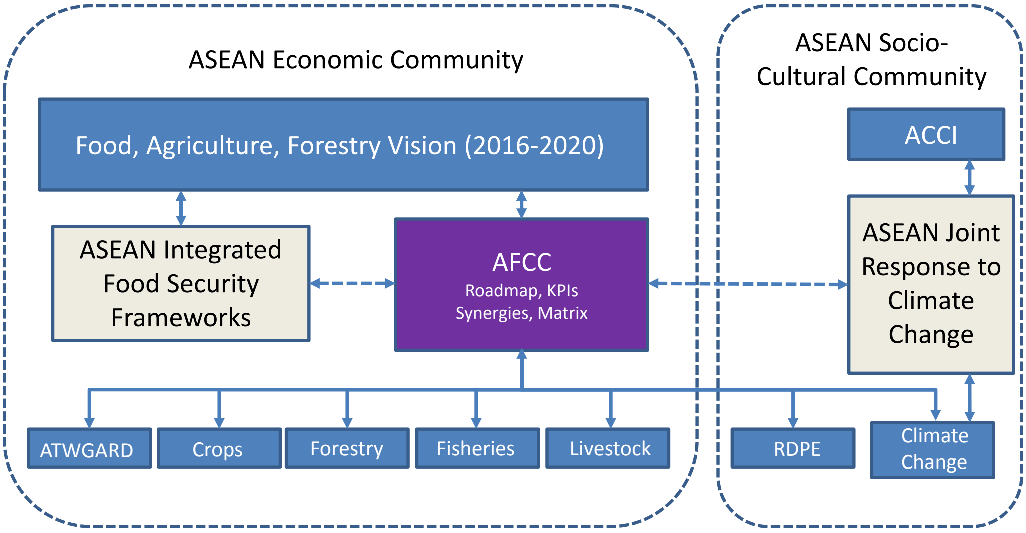
22 http://www.asean.org/asean-economic-community/asean-ministerial-meeting-on-agriculture-and-forestry-amaf/

6. Strengthen ASEAN joint approaches on international and regional issues affecting the FAF sector;

7. Promote sustainable forest management.

93. The ASEAN network of interacting committees also interacts with climate policy in the region (Figure 4).

Figure 4. ASEAN cooperation in food, agriculture and forestry and its relation to climate policy



Source: Redrawn from Yoovatana (2015)

Note: ATWGARD = ASEAN Technical Working Group in Agriculture and Research Development; AFCC = ASEAN Multi-Sectoral Framework on Climate Change: Agriculture, Fisheries and Forestry towards Food Security; ACCI = ASEAN Climate Change Initiative; RDPE = Rural Development and Poverty Eradication.

94. For the individual countries of the ASEAN, alignment of industrial needs for biomass with food security policies will be required as several of these countries have ambitions in bio-based production (Box 4).

Box 4. Bio-based production in ASEAN countries

Malaysia

Announced by the Prime Minister in 2012, Malaysia launched its Biotechnology Transformation Programme (BTP) as part of the nation's economic transformation strategies. To do so, Malaysia is providing an incentivised platform for the bio-based industries to contribute to the nation's sustainable development agenda, to improve industry competitiveness, to encourage public-private partnerships and bring socio-economic benefits (see Bioeconomy Malaysia, 2014);

Indonesia

Indonesia and Malaysia are world leaders in palm oil production. There is strong government support for bioenergy projects in Indonesia. The utilisation of bioenergy is being continuously implemented and improved in order to strengthen national energy security and to reduce emissions. Like many countries in Asia, Indonesia imports large amounts of fossil fuels. Government bioenergy policy support has a further policy goal of reducing the use and importation of fossil fuels.

Thailand

The National Biotechnology Policy Framework (2012-2021) of Thailand (Ministry of Science and Technology, Thailand) describes four strategic sectors for further development in the country. The first is food and agriculture, the third is bioenergy and the fourth is bio-based industry.

In 2021 Thailand intends to meet 25% of its energy needs through renewable sources. This calls for securing additional and alternative raw materials. In so doing, the government has realised that particular attention must be paid to avoiding conflicts with food production as most bioenergy is presently generated from food crops such as sugarcane, cassava and palm oil. In Thailand, food industry demand and limited cultivatable lands virtually assure that palm oil biodiesel production has reached its ceiling. Taking such constraints into account, the government has emphasised research and development for future biodiesel production.

By 2021, the government aims to realise a three-fold increase in biogas supply above current production. Such growth is possible due to readily available raw materials such as waste generated by livestock farming, agriculture and food processing and domestic waste. There is also a drive to establish a strong base for ethanol production from agricultural waste cellulose, and thence advancement to third generation bioenergy from algae feedstocks.

The Thai government wants to improve its bio-production market position by applying multiple technologies including genomics, genetic engineering, fermentation technology and manufacturing technologies. It has initiated a 15-year plan that entails tariff reductions, development of the local bioplastics industry, and the creation of a competitive global market for Thai bioplastics.

Republic of the Philippines

In the Philippines, The Biofuels Act or Republic Act (RA) 9367 (Republic of the Philippines, 2006) was signed in January 2007 making the Philippines the first country in Southeast Asia to have biofuels legislation in place. RA 9367 mandated that by February 2009, the annual total volume of petrol sold and distributed by oil companies in the country should contain at least 5% ethanol, increasing to a 10% blend by February 2011. RA 9367 also mandated a minimum 1% biodiesel blend in all diesel fuels by February 2007, to increase to a 2% blend after 2 years. Sugarcane and molasses are used in Philippine ethanol production, and coconut methyl ester (CME) is the preferred biodiesel feedstock. The Biofuels Act gives priority to local ethanol over imports, and disallows biodiesel importation.

Source : Various

95. In all the examples in Box 4, the primary feedstocks for bio-based production are food crops, but there is a realisation that alternative feedstocks have to be found and developed.

Biotecnologia Industrial: The most promising vector for Brazil's reindustrialisation

96. Brazil has long been at the forefront of bio-based production, and demand for first and second generation ethanol means that the country will have to rapidly increase capacity. That has raised concerns about effects on food supply, farming practices and the potential for deforestation. The response is to increase productivity of sugarcane through technology advances (e.g. planting energy cane) and by planned land extensification. The major policy action to maintain sustainability and prevent negative environmental outcomes is land planning, the so-called agro-ecological zoning, to ban expansion of new ethanol production facilities in sensitive ecosystems.

97. In 1975 Brazil launched the National Alcohol Program (*Pró-Álcool*) in response to the oil shocks to capitalise on its expertise and market position with sugarcane. Sugarcane is regarded as one of the most sustainable, if not the most sustainable, and efficient forms of biomass for bio-based production. Now there are over 450 ethanol mills country-wide. To date, the country has successfully transitioned from importing almost 80% of its total oil consumption some 40 years ago to becoming virtually energy independent and a world leader in renewable energy. Today, the success of the original *Pró-Álcool* programme is reflected in the importance that sugar and ethanol production play in the Brazilian economy. The two industries account for 3.6 million jobs and 3.5% of GDP, while ethanol production alone consumes 50% of the total sugar cane supply (Sorda et al., 2010).

98. Sugarcane production needs to expand to accommodate the booming demand for sugarcane-derived products, and especially for renewable first- and second-generation ethanol. Higher volumes of cane can be obtained in the future thanks to productivity gains, but additional land dedicated to sugarcane will also be required. Proper land use planning is essential to manage this growth while simultaneously preserving and protecting natural resources, and that is a key policy theme for Brazil.

99. Brazil has also taken a lead in bio-based chemicals production as sugar cane ethanol can also serve as a substitute for oil to produce bio-based plastics, notably using bio-based ethylene as a monomer. Bio-based chemicals production in Brazil is increasingly under consideration by government and policy agencies.

100. However, Brazil is also a megadiverse country, and there have been repeated fears over biodiversity loss, especially through deforestation in Amazonia, that will have to be addressed in future plans for the expansion of bio-production in Brazil. Moreover, the three most populous states in Brazil have just experienced their worst droughts since 1930[23]. So the large increases in demand for Brazilian ethanol (and other bio-based products such as ethylene) have to be managed in the face of increased water insecurity.

101. Some technological responses in Brazil are:

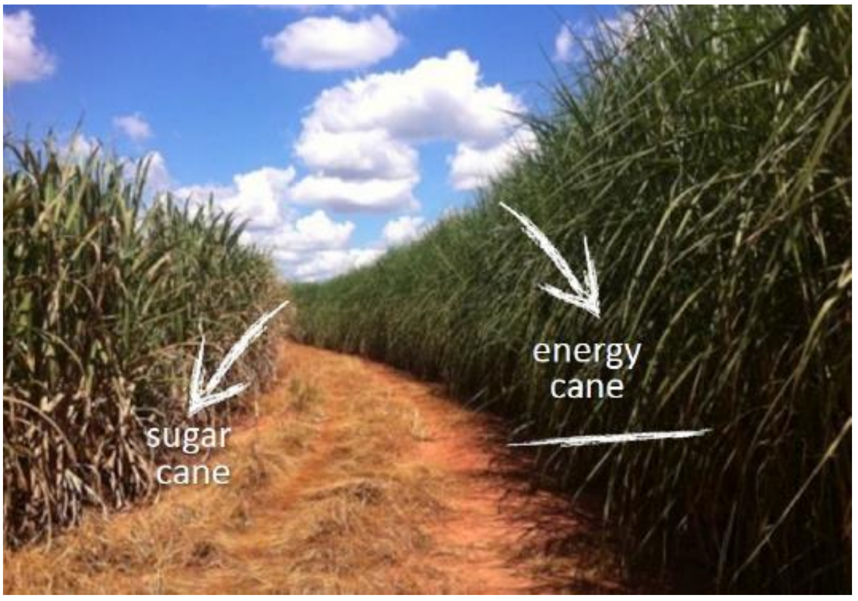
- It is believed that the use of energy cane (as opposed to food use sugarcane) (Figure 5) as a feedstock can more than triple the productivity of ethanol production;

- Bioenergy is another innovative area for sugarcane, where leftover sugarcane biomass (bagasse) is burned and converted into clean electricity. Today the installed capacity is 4 160 average MW, but the potential is much higher (more than 15 200 average MW by 2020, almost 9% of Brazil's electricity matrix). Although petroleum and derivatives account for the largest source of energy in the country, the renewable energy sources of sugarcane products and hydroelectricity come second and third, respectively (EPE 2010);

[23] http://www.bbc.com/news/world-latin-america-30962813. January 24, 2015

- The economics of sugarcane residues – bagasse and straw *versus* purpose-grown crops – for cellulosic ethanol production are significantly better than they are were previously. In the near future, the tops and the leaves of the cane will also be utilised. These are increasingly available thanks to the mechanisation of the harvest, but are today left in the fields (in the worst case they are burned, increasing the GHG emissions burden). This new source of biomass encompasses one third of the sugarcane energy and would contribute to producing more energy with less resources.

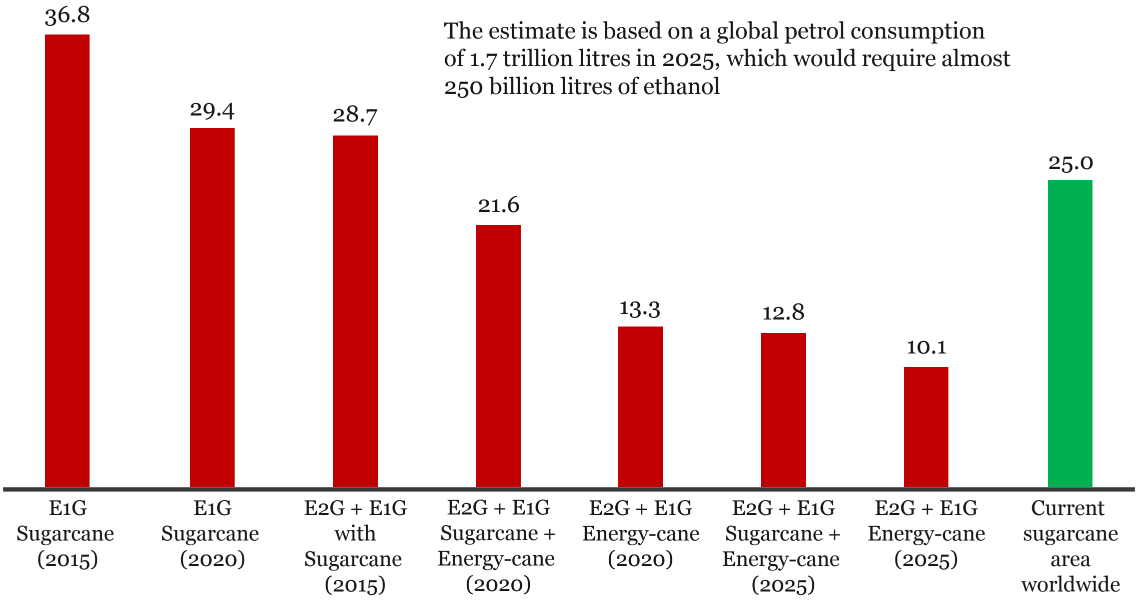
Figure 5. Increased biomass density of energy cane



Source: Silva (2015).

102. As a result, productivity is forecast to increase from 7 100 litres/ha to 21 500 litres/ha in 2025 due to processes optimisation, and technology availability to produce cellulosic ethanol and advanced bio-hydrocarbons. Productivity gains are forecast to make large savings in land requirements (Figure 6).

Figure 6. Land area required to replace 10% of world petrol consumption with ethanol (to 2025)



Source: Redrawn from Silva (2015) – original from work by BNDES, CTBE, CGEE, US NEI and FAO.

Note: Figures are in million hectares

The situation regarding deforestation is contested

103. Almost 90% of Brazilian sugarcane production takes place in South-Central Brazil, with the remainder grown in North-Eastern Brazil. Both producing regions are located some 2 000 to 2 500 km away from the Amazon. The Amazon region simply does not offer appropriate growing conditions for sugarcane, where it rains almost every day, and cannot be a target for expanded production, regardless of government regulation.

104. The largest reservoir of arable land available in Brazil is pastures, mostly degraded, that currently cover 198 million hectares. With the progressive intensification of cattle ranching activities, substantial areas of pastures are released every year for the expansion of crop production such as sugarcane, but also grains and oilseeds. Between 2002 and 2006, 5.4 million hectares of pasture land were made available for other uses, while the cattle herd increased by 18 383 heads. According to the Brazilian National Institute for Space Research (INPE), more than 65% of new sugarcane production took place on pastures while the remaining 35% expanded on cropland, and this trend is forecast to continue.

105. However, an argument that surfaces from time-to-time is whether the displacement of food production in other parts of the country relocates cattle ranching to Amazonia, where forest is then cleared. Growth in the production of ethanol that requires increased amounts of land for sugarcane may displace food crops (raising the price of food), and may force more farmers to move into the Centre-West Cerrado by increasing the price of land in coastal regions, exacerbating deforestation on the Amazon frontier. Expanding land area in the Southeast and Northeast of Brazil under sugarcane cultivation, meanwhile, could worsen deforestation in the Atlantic Forest. This has raised the argument that the expansion of sugarcane cultivation indirectly causes deforestation, a contention that is disputed and remains to be settled.

Combining future growth with land planning

106. In 2009, the Brazilian government launched the Agro-ecological Zoning for Sugarcane initiative (*Zoneamento Agroecológico da Cana-de Açúcar*[24]) to promote the expansion of sugarcane production in areas that are agronomically, climatically and environmentally suitable. This initiative is considered essential to guarantee the sustainable growth of sugarcane production.

107. The underpinning rules established by Agro-ecological Zoning include:

- No sugarcane expansion or new ethanol production facilities in sensitive ecosystems like the Amazon, the Pantanal wetlands and Upper Paraguay river basin. (However, as noted, Amazon is not a suitable location for sugarcane anyway);

- No clearance of native plants to expand sugarcane cultivation anywhere in the country, including the native Cerrado;

- Identification of suitable areas where sugarcane should be prioritised. These areas include land with proper conditions for the use of mechanical harvesting, cattle breeding areas that are underused or degraded (more than 34 million hectares), and also regions with lower need for water usage in production.

108. In 2007 the state of São Paulo and the president of that state’s sugarcane producers’ union signed an Agro-environmental Protocol, which sets deadlines to phase out and eventually eliminate sugarcane harvest burning – a major source of agricultural GHG emissions in the state – and commits sugarcane farmers to reforesting 400 000 hectares of degraded lands (Lucon and Goldemberg, 2010).

The new Biodiversity Law in Brazil

109. Brazil’s new Biodiversity Law No. 13, 123/15 was signed into law in 2015[25]. Generally, this new law outlines access to the components of Brazilian genetic heritage, protection and access to associated traditional knowledge and the sharing of benefits for preserving and sustaining Brazilian biodiversity. The main purpose of the new law is to facilitate scientific research and the economic exploitation of biological samples of Brazilian genetic heritage. The expectation is that national and international companies, such as those in the agricultural and food, cosmetic and pharmaceutical sectors, will isolate active ingredients from Brazilian genetic heritage materials to develop new products.

An inclusive bioeconomy: potential benefits for Africa

110. The bioeconomy concept is relatively new to Africa, but it is spreading. Many African nations are energy-poor, and spend significantly to import fossil fuels. Bioenergy use is at a high level already in some African nations, and there are the beginnings of mandates for bioethanol and biodiesel. A concern for Africa is to have a bioeconomy that is inclusive so that nobody is left behind, with no exclusion for gender and youth. Climate resilience is also a growing policy goal. There is a willingness to engage in bio-production, which should be mindful of food security, and there is a perspective that bioeconomy and bio-production can be linked to revitalisation of existing industries.

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24 https://www.embrapa.br/en/busca-de-produtos-processos-e-servicos/-/produto-servico/1249/zoneamento-agroecologico-da-cana-de-acucar

25 https://bricwallblog.wordpress.com/2015/06/06/brazils-new-biodiversity-law/

111. To date, only South Africa has a dedicated bioeconomy strategy of the African nations, but several others have bioeconomy strategies under development. However, in most of Africa, bioeconomy is not a well-developed concept to date. Bioeconomy so far has been linked to debates on genetic modification (GM), and the continent has mixed opinions on the benefits of GM technology.

112. However, Africa today is a continent of economic extremes. Some economies are developing extremely rapidly. Nigeria now appears to be the largest African economy[26], although it lags behind South Africa in terms of *per capita* GDP. In fact, it is sub-Saharan Africa where greatest growth is, but also where there are persistent challenges. Nigeria, South Africa, Angola, Ethiopia and Ghana accounted for 41% of the region's population and 71% of its GDP in 2013[27]. Four of the five, with the exception of South Africa, are forecast to experience strong economic growth in the coming years.

113. Sub-Saharan Africa is the epicentre of the global challenge to overcome energy poverty. Since 2000, sub-Saharan Africa rapid economic growth has been accompanied by a 45% rise in energy use (IEA, 2014). Sub-Saharan Africa produced 5.7 million barrels of oil per day in 2013, primarily in Nigeria and Angola. And yet, while 5.2 million barrels per day of crude oil were exported, around 1.0 million barrels per day of oil products were imported. While a large proportion of the population is employed in farming, agriculture remains largely unmodernised, with huge scope for productivity gains.

114. Bioenergy accounts for about 60–80% of energy consumption in some African countries. People burn wood or manure in open fireplaces, which not only leads to serious health problems and many premature deaths but also contributes to deforestation. Decentralised, modern solutions combining bioenergy with other renewables are of utmost importance for improving livelihoods of these communities. And this does not have to focus on modern biotechnology. Many of the solutions are amenable to local innovation e.g. a combination of dairy and biogas production, local mini-grids electrified by biogas from waste or bio-briquettes produced from wastewater.

115. Nevertheless, the potentially disruptive power of biotechnology can be turned to Africa's economic advantage via: promoting the integration of biotechnology research across commercial applications; and facilitating dialogue and public education among governments, industry, civil society and national populations.

Engaging the bioeconomy in Africa

116. The African Union Science, Technology and Innovation Strategy for Africa 2024 (STISA-2024)[28] places science, technology and innovation at the epicentre of Africa's socio-economic development and growth. Its mission is to accelerate Africa's transition to an innovation led, knowledge based economy. A vision of the African Centre for Technology Studies (ACTS[29]) strategic plan (ACTS, 2014) is to catch-up with most advancing countries through a bioeconomy for Africa.

117. The New Strategic Plan seeks to unlock Africa's potential for inclusive growth by catalysing investments, policy, institutional and organisational incentives in knowledge based and green economies through five programme areas.

26 http://www.bbc.com/news/business-26913497

27 http://blog.euromonitor.com/2014/09/special-report-sub-saharan-africas-top-5-economies.html

28 http://hrst.au.int/en/sites/default/files/STISA-Published%20Book.pdf

29 http://www.acts-net.org/

1. *Inclusive Bioeconomy*: aiming at an African economy where bioresources, biosciences, and biotechnologies contribute a significant share of economic output particularly from agriculture, food, water, and renewable energy sectors.

2. *Information Economy*: aiming at an African economy in which knowledge is the primary raw material and source of value drawn from the application of Information and Communication Technologies (ICTs), development of ICT infrastructures including Open and Big Data (i.e. the Data Revolution).

3. *Climate Resilient Economies*: aiming at an African economy that has transitioned from a state of vulnerability to a state of resilience to the impacts of climate change through: climate change adaptation and mitigation; disaster risk preparedness; climate resilient infrastructure; and low carbon development.

4. *Responsible Natural Resource Economies in Africa*: characterised by responsible extractive industries; the triple bottom line (people, planet and profits); sustainable use and conservation of biodiversity resources; natural capital accounting and ecosystem valuation.

5. *Gender, Youth and Inclusive Development*: aiming at an African economy that recognises the role of women, youth and other marginalised or vulnerable groups in harnessing science, technology and innovation for economic development and sustainability in Africa.

118. The mission of the Inclusive Bioeconomy programme of ACTS is to provide policy choices that support the generation, uptake and harnessing of biosciences, bio-based resources, and biotechnologies for sustainable and diversified livelihoods, socio-economic development, and biodiversity conservation in Africa. Its view is that biotechnology offers technological solutions to many of the economic, social, and environmental sustainability challenges facing Africa and much of the world. Applications of such can increase the supply and environmental sustainability of food; improve water quality; provide renewable energy; improve the health of humans and livestock; enhance manufacturing, and conserve the environment and biodiversity.

119. There are several critical elements of the Inclusive Bioeconomy programme.

- *Research*: Critical appraisal of the bioeconomy policy landscape in Africa and review of the legislative and policy frameworks for biosciences, biotechnologies, biosafety, and bioeconomy overall, to assess the need for African bioeconomy policies and strategies.

- *Strengthening legislative and policy frameworks*: for the production, commercialisation and uptake of bio-based innovation products and services.

- *Technology brokerage*: Support for local production, commercialisation and uptake of bio-based innovation products for food, feed, energy and other purposes,

- *Revitalisation of mature industries*: through bio-based innovation products and processes.

- *Policy engagement*: convening high level regional policy roundtables on bioeconomy policy strategies.

- *Capacity building*: training on the global bioeconomy policy strategies, opportunities and challenges for Africa.

Anecdotes of an emergent African bio-economy

120. An example was used that points to the central (potential) conflict between food and industrial use, and the need for their reconciliation. The speaker referred to an example where a human-wildlife conflict was resolved by planting *Aloe vera* instead of corn. When small farmers plant corn, it attracts elephants as they eat corn, and this can overnight devastate a small farmer's food crop. If the farmer switches to planting *Aloe vera*, elephants will not eat it and will not destroy the crop. Therefore the farmer now has a high-value crop that is in demand by industry. In Western economies *Aloe vera* extracts are prized in several life-style and skin care products, and therefore has a relatively high value. So the small African farmer wins.

121. However, if this was adopted across much of African corn cultivation, the corn production should be replaced elsewhere if a food security incident is to be avoided. The small farmer may be blind to this possibility as he is profiting from the bioeconomy trade, and the Western partners in the trade may be equally detached from a food security issue. What looks like a classic developed-developing country bioeconomy trade could have negative repercussions in food security. It may be necessary for government policy to be created to prevent food insecurity while also promoting bioeconomy trade.

122. Other examples of benefits to Africa of an inclusive bioeconomy were new uses for old crops and revitalisation of mature industries, both of which are perfectly legitimate policy goals for a bioeconomy. The use of old crops requires the skills and knowledge of local farmers as well as bringing new knowledge and markets to make new income streams for the farmers. Again, mature industries have well-developed skills and their revitalisation means an easier shift to new economic conditions, as opposed to trying to generate new industries from scratch. The latter may be easier in a developed economy where there would be greater potential for public policy support and subsidy and where educational and industrial infrastructure is easier to build. Revitalisation of mature industries could also be the springboard for launching new industries. This would appear to be a less expensive, more efficient way for a government to introduce some of the changes and capacity building inherent in a sustainable bioeconomy – supporting local populations to do what they do better and learn from this stock of traditional knowledge for new market opportunities.

123. Box 5 gives some examples of bioeconomy initiatives in some African countries.

Box 5. Some bioeconomy initiatives in African countries

Ghana Bioenergy Strategy

The goal of the strategy is to develop and promote the sustainable supply and utilisation of bioenergy to ensure energy security for Ghana whilst maintaining adequate food security. To achieve this, the strategy envisages:

- Reserving a specified proportion of land earmarked for biofuel feedstock cultivation for food production;
- Improving and sustaining local enterprises in the production and supply of biofuel feedstock;
- Increasing biofuel supply in the national petroleum product mix to 10% by 2020;
- Banning the importation of biofuel to encourage local production, banning the export of biofuel feedstocks, and imposing levies and taxes on biofuel exports;
- Establishing fiscal incentives for the promotion of biofuel production, supply and marketing;
- Enforcing standards to ensure quality of the products;
- Establishing adequate storage and distribution facilities throughout the country.

Kenya

Biomass provides 69% of Kenya’s energy requirements while petroleum accounts for about 22% and electricity 9%. Renewable energy sources already contribute to 74.5% of electricity production with fossil fuels filling the rest (25.5%). The renewable energy sector is very active and the government has proposed clear strategies for the future (Grantham Institute, 2015).

Kenya does not have locally produced fossil fuels and spends a significant proportion of its GDP on imports. Kenya took the view that it needed to cut its GHG emissions before it was required to. But efforts to implement the necessary activities to do so were constrained by the absence of a national strategy. This precipitated a strategy for the development of a sustainable biofuels programme.

Kenya National Climate Change Action Plan (2013 -2017)

Both bioethanol and biodiesel are written into the National Climate Change Action Plan (Government of Kenya, 2013) as means towards emissions mitigation.

Kenya biodiesel strategy

The major objectives of developing this strategy (Ministry of Energy Kenya, 2008) are to:

- Fast track the development of the biodiesel energy resource in Kenya;
- Increase security of energy supply by reducing vulnerability resulting from dependence on imported fossil fuels;
- Diversify rural energy sources by promoting substitution of kerosene with biodiesel and the use of decentralised energy systems;
- Contribute to poverty alleviation through diversification of income sources;
- Contribute to efforts to address global warming through substitution of petroleum fuels.

Bioethanol Strategy (2009-2012)

Kenya has a pilot programme for a 10% ethanol-gasoline (E-10 Mandate) blend in government and public transport vehicles.

Mali Biofuel

The government of Mali adopted its national strategy for the development of biofuel which is based on the energy policy and the renewable energy strategy[30]. The objective of the national biofuel strategy is to replace 20% of diesel oil consumption with biofuel by 2022. Jatropha oil and ethanol have been identified as the most promising sources for biofuel production in Mali.

Mauritius Ocean Economy (2013)

The government of Mauritius aims to make the Ocean Economy one of the most important future contributors of GDP for the country. Mauritius launched its first oceans economy roadmap in 2013 (Mauritius Prime Minister's Office, 2013; UNCTAD, 2014). The roadmap placed emphasis on the need to make use of the untapped value locked up in the exclusive economic zone (EEZ) by ensuring sustainable and coordinated utilisation of living and non-living resources.

Mozambique National Biofuel Policy and Strategy

In 2009 the government of Mozambique established a regulatory framework for production of biofuels by the public and private sectors, based on principles of transparency, social and environmental protection. The instrument centred on promotion of ethanol and biodiesel produced from agricultural raw materials appropriate for the country's agricultural and climate conditions. The document set out the guidelines of the country's biofuel policy, namely its compatibility with food production, as well as a map of land that is appropriate for use to grow the chosen crops (jatropha, sugar cane, sorghum and sunflowers).

Source : Various and the German Bioeconomy Council

Policy instruments for sustainability in bioeconomy value chains

124. This European perspective is about how sustainability can be measured to make sure a sustainable bioeconomy is created. The criteria for measuring sustainability for biomass are still not agreed internationally, and therefore the tools for measuring sustainability are at best incomplete. The tasks along the way might be: integrating value chains and homogenising sustainability criteria; introducing cascading criteria, and; coupling and improving social and food competition criteria. Then there is the issue of governance, whether self-regulation, state regulation or a hybrid is the best model.

125. This presentation gave a European perspective on sustainable bioeconomy policy specifically about guaranteeing the sustainability of value chains. The arguments come back to the criteria that should be used to measure sustainability, and the tools that are used for the measurement, topics that were covered in depth previously (OECD, 2014b). Table 3 shows some perspectives by the speaker. These criteria are not internationally agreed. For example, international stakeholders (non-governmental organisations, policymakers, research and development, bioenergy producers, end-users and traders) from 25 European and 9 non-European countries surveyed in 2011 agreed unanimously on only one criterion - minimisation of GHG emissions (van Dam and Junginger, 2011). However, that does not take into account the three pillars of a sustainable bioeconomy, it only satisfies one environmental criterion. To take account of all three pillars, social as well as economic factors also have to be included (Bosch et al., 2015).

30 http://www.globalbiopact.eu/case-studies/mali.html

Table 3. What could be the criteria for deciding sustainability?

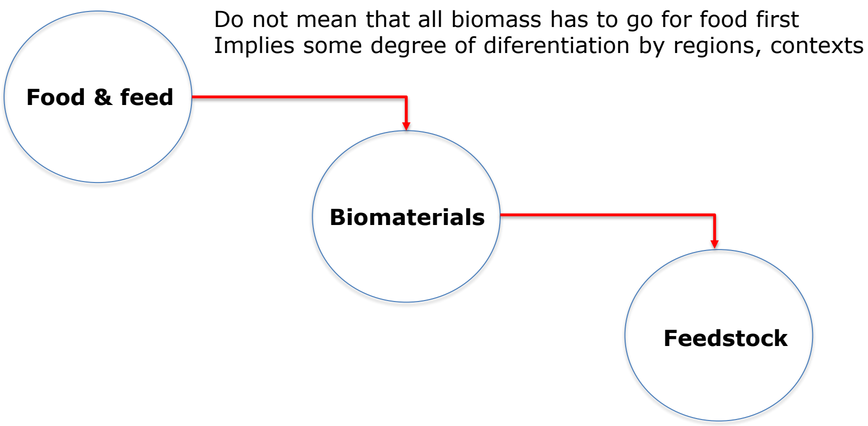
	Feedstock	Biomaterials	Food and feed
Decarbonisation	√√√ (Mandatory)	√√ (Voluntary)	X (Voluntary)
Biodiversity	√√ (Mandatory)	√√ (Voluntary)	√√√ (Voluntary)
Other environmental	√ (Voluntary)	√ (Voluntary)	√ (Voluntary)
Social issues	√ (Voluntary)	√ (Voluntary)	√ (Voluntary)
Competition with food	X (Voluntary)	X (Voluntary)	

Source: Ugarte (2015).

126. The speaker suggested how to make sustainability assessment for policy makers in three different tasks:

- Task 1: Integrate value chains and homogenise sustainability criteria;
- Task 2: Introduce cascading criteria (Figure 7);
- Task 3: Couple and improve social and food competition criteria.

Figure 7. Cascading criteria analysis



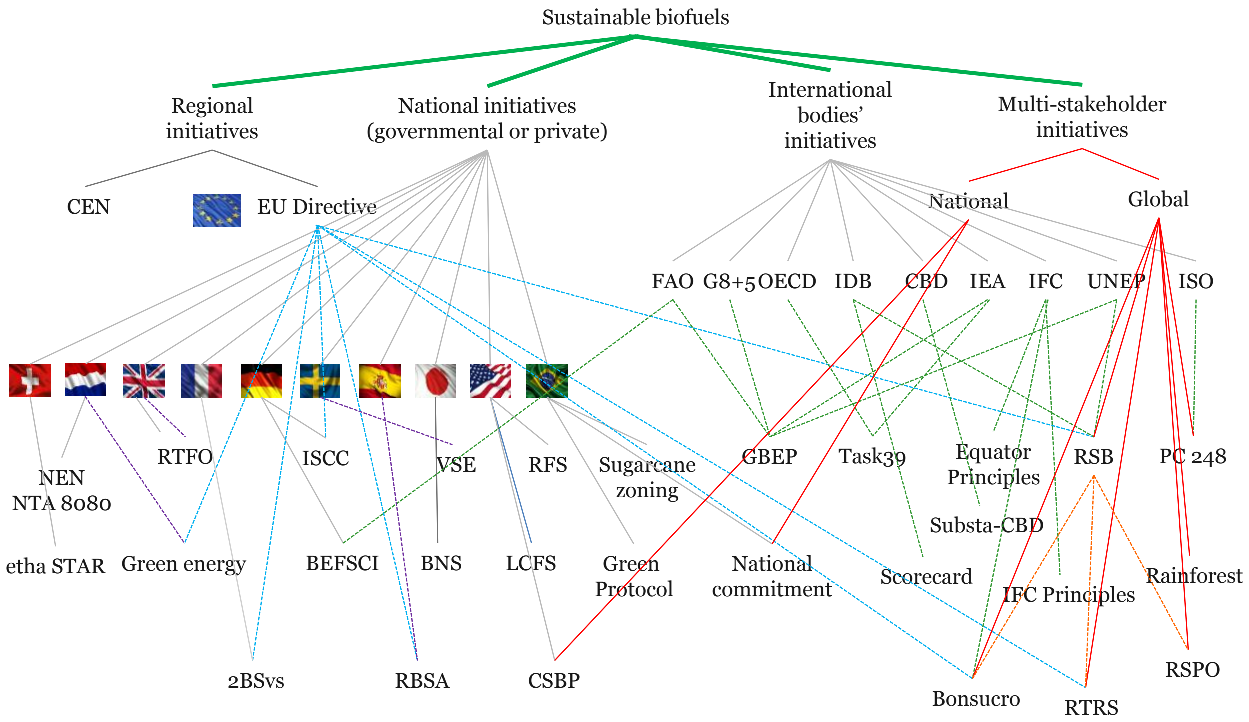
Source: Ugarte (2015).

127. There is a choice between self-regulation and imposed regulation at government level. In voluntary implementation, the regulation is entirely up to market players. This would assume self-verification or third party certification. Third party certification would reduce the possibilities for greenwashing, which private sector players should actually welcome. However, another option may be optimal, that of co-regulation, in which public regulation and private initiatives (certification) are dovetailed and harmonised.

128. One of the problems at the certification and accreditation level is that, certainly for biofuels, there is a large number of voluntary schemes already in existence (Figure 8). This leads to confusion for the consumer and frustration for the producers.

129. The road to biomass sustainability is, of course, more complicated than laid out here. Suggesting criteria and tools is one thing. International consensus is quite another, and achieving agreement is a long-term process. That is why it has been suggested that the OECD is the near-optimum forum for achieving this.

Figure 8. Biofuels sustainability certification



Source: Redrawn from http://sugarcane.org/sustainability/folder.2012-01-18.0277222169

Policy implications

Policy alignment: taking a planned adaptive risk regulation approach

130. Clearly for the increased deployment of a bioeconomy in any country there is a need to align large policy and important policy regimes: agriculture, industry, trade, biodiversity and environmental. This is immensely difficult in any country, but the challenges are amplified in attempts to harmonise across borders. When commitments have been made to international treaties and policies (e.g. the Cartagena Protocol),[31] domestic policy cannot be easily changed. But this is precisely what will be required to prevent trade barriers, which can even now occur over seemingly trivial matters (Bosch et al., 2015). Therefore the goal of policy alignment needs to be seen with a long-term view.

131. The approach suggested is similar to that of planned adaptive risk regulation. In this approach to risk, the stages of the process can be:

- Prepare: Fund research to inform on benefits and risks;
- Discriminate: Foster initial applications with most favourable priors;
- Observe: Harvest and process information from initial experience;
- Adapt: Learn from experience and update/correct practices.

[31] https://www.cbd.int/doc/legal/cartagena-protocol-en.pdf

132. A key element of this approach is the ‘learning by doing’ i.e. being able to learn from experience and correct practice along the way. It is argued that a similar approach to policy alignment could be applied as clearly innovation is also needed in policy. The ‘learning by doing’ approach is more likely to result in policy innovation and progress than a precautionary approach, where innovation can be stymied unless environment, health and security are clearly protected, even when risks are not easily identified (OECD, 2016a).

Agro-ecological zoning, land extensification and deforestation

133. Deforestation is a valid threat from bioeconomy activity. First of all, land extensification can directly or indirectly lead to deforestation. But there will also be an increased demand for wood in a bioeconomy. Even if countries put in place policies to ensure sustainable forestry, there is a further problem of illegal logging, which already costs governments tens of billions of dollars every year.

134. Agro-ecological zoning, as exemplified in Brazil, is a strong policy to limit deforestation. However, it is required that it be monitored and enforced. Lynch et al. (2013) argued that the only effective surveillance option will be with satellite technology, but who should pay for this – biomass exporters or importers, or both? OECD nations importing biomass from developing nations could quite clearly get caught in debates over the blame for deforestation. Therefore a policy option might be the creation of an international biomass dispute settlement facility (The Hague Institute for Global Justice, 2012).

Utilising biodiversity for sustainable development

135. Researchers from Germany and Indonesia are building an Indonesian biodiversity discovery and information system (INDOBIOSYS)[32] that aims to provide a foundation for knowledge-based biomedical discovery in Indonesia. This is a strategy for a fast assembly of a biodiversity discovery pipeline combined with an information management system. The results will be made available to the wider public. It is believed that the combination of “*primary biodiversity data and relevant metadata supporting an innovative approach towards the discovery of active compounds will create a novel platform for the targeted, efficient, and sustainable exploitation of biological resources in Indonesia*”.

136. Such an approach in megadiverse emerging economies can be more widely applied to bioeconomy projects such as bio-based production. In this strategy there are several elements at the heart of the sustainable bioeconomy concept:

- International collaboration between developed and developing economies;
- Benefits sharing;
- The building of a knowledge-based economy in developing nations rather than simply being providers of raw materials from the wealth of their biodiversity;
- Acceleration of discovery through knowledge-based data and innovation.

137. Approaches such as this could break down trade barriers and build trust between trade partners with the overall goal of a sustainable future as a primary goal, not an after-thought. Support from governments through public research subsidy would give the added confidence that it is not simply a private sector endeavour with goals limited to profit, thus building trust between nations.

[32] http://www.indobiosys.org/

Concluding remarks

138. Far greater attention has to be paid to the food-industrial use of biomass conundrum that is currently. A future event could be hosted in the OECD but should include more stakeholders, such as the UN Food and Agriculture Organisation (FAO), the European Commission, the German Bioeconomy Council, some of the key sustainability certification organisations e.g. ISCC, GBEP, government ministries with direct interest e.g. the USDA and Department of Energy.

139. In the fossil era the world is divided geopolitically between the producers (of fossil fuels) and the consumers, especially in the cases of oil and gas. The consequences are clear to see – almost permanent price volatility, swings between economic growth and decline, including contributions to major global recessions (Hamilton, 2011), a constant search for new reserves that is going into more expensive, ecologically sensitive and dangerous places, and even armed conflict. The distributed nature of biomass could help to prevent such situations in the future.

140. Nevertheless, there are also those countries that are biomass-poor and those that are biomass-rich. In a sustainable bioeconomy, the balance of power among nations would be more even, but this requires very serious consideration of another critical balance – between food and industrial use of biomass. An international trade of biomass in which industry security is achieved in consumer nations (many OECD nations) and food insecurity is a result in exporting nations would defeat the purpose in some ways. Whilst the needs of climate change mitigation may be achieved, food security and energy security may be threatened.

141. The policy regime governing this transition is enormously complex. What is quite clear is that international policy will be just as essential as domestic policy. There is much to be gained in a bioeconomy, but ultimately if it does not achieve sustainability, then a great opportunity for inclusive economic growth will have been missed.

MEASURING BIOMASS SUSTAINABILITY

Introduction

142. Given what has been said about the drivers for the development of a global bioeconomy, and the policy events of 2015 related to sustainable development and climate change, the need for new forms of renewable energy and sustainable manufacturing are increasingly important. Achieving the huge reductions in GHG emissions that are currently envisioned (e.g. IPCC, 2014) requires either the replacement of carbon in society or finding a source of carbon that is renewable: practically, a dual strategy is emerging. Two thirds of the CO_2 emission quota consistent with a 2°C temperature limit has already been used, and the total quota will likely be exhausted in a further 30 years at the 2014 emissions rates (Friedlingstein et al., 2014).

143. Emphasis on policies that increase energy efficiency may accomplish comparatively impressive emissions reductions in the time frame up to 2020. However, they are trade-offs and will not help in the long run (Frame et al., 2014). It is the imperative of reducing emissions that needs to be addressed. As of COP21 in December 2015, the political will to reduce (anthropogenic) emissions to zero sometime this century has increased considerably[33]. The OECD has joined the call for zero emissions during the second half of this century (OECD Policy Brief, 2015).

144. Much of the world is embarking on the long, expensive process of making the new energy order, in which renewable forms of energy can substitute some of the carbon requirement for electricity generation. It is foreseeable how the internal combustion engine (ICE) can be replaced eventually for light transport. However, replacing the huge number of organic chemicals in use by something other than carbon is hard to imagine. Equally, it is hard to imagine society finding life acceptable without these chemicals. Therefore a strategy that looks to preserve crude oil for as long as possible whilst transitioning to another form of carbon is the strategy that makes most sense.

145. The question then is about what is the form of carbon that does least environmental damage. The answer has to be renewable carbon, and the only form available in large amounts is biomass. Biomass is the fourth largest energy source after coal, oil and natural gas. Bioenergy is the most important renewable energy option, at present and in the medium-term (Ladanai and Vinterbäck, 2009), but biomass is also required for bio-based liquid and gaseous fuels and to make materials such as chemicals and textiles.

146. The use of biomass for bio-based production in ambitious bioeconomy plans is fraught with the risk of unsustainable, over-exploitation of natural resources. A possibility is to develop only modest bioeconomy strategies, but this may not achieve the longer term goals of highly ambitious GHG emissions reductions. Another option is to create ambitious bioeconomy plans that look to make biomass production and utilisation more efficient. However, studies point to the need to also use more land for biomass production. So a dual strategy can be envisioned – land intensification and land extensification. Each brings its own problems; the most frequently discussed being those that relate to sustainability, and the inevitable competition for land between food and industrial use.

147. This chapter examines the issues around setting biomass sustainability as an essential element to a future bioeconomy. There is as yet no international agreement on how to measure biomass sustainability

33 The UK, for example, will enshrine in law a long-term goal of reducing its carbon emissions to zero, Parliament was told on Monday March 14, 2016 - as called for in the historic Paris climate deal. The UK's remaining coal-fired power stations will be shut by 2025 with their use restricted by 2023.

and the estimates of biomass potential (how much can be grown sustainably) show large levels of variability by consequence. New institutions may be necessary to harmonise sustainability assessments.

Land intensification and extensification

148. Using land more efficiently and intensely is already subject to a variety of strategies e.g. using food and non-food (energy) crops with higher yields, applying breeding and selection technologies to create new crops with higher yields and improved disease resistance, improved farming and harvesting techniques. This is generally referred to as sustainable intensification (Schiefer et al., 2015). The one that has received most attention is cellulosic biomass as it avoids conflict with food and feed. This improves land use efficiency by using waste materials from existing crops e.g. tops and tails of sugar cane as well as selecting crops for this very purpose. For bio-based production, the need still exists to perfect, at industrial scale, the technologies for conversion of this biomass to fermentable substrates.

149. Land extensification (introducing production into land areas that were previously unused or used for less intensive purposes) bears these technical challenges (Canadell and Schulze, 2014), but also greater sustainability and political ones. In particular, there is the concern that opening up previously unused land could have the exact opposite outcome from what is wanted, an increase in GHG emissions, and a decrease in biodiversity through deforestation and perhaps soil destruction. There are also social risks such as those relating to landowners' rights, workers' rights, displacement of populations. Together, there is clearly potential for biomass sustainability disputes, and as trade in biomass intensifies, these disputes could become international.

Important challenge: quantifying how much biomass can be grown sustainably with imperfect methods to measure sustainability

Sustainability measurement tools and indexing

150. Quantitative and semi-quantitative measurement tools such as life cycle analysis (LCA) and Environmental Performance Index (EPI) have been used in the past to evaluate the environmental benefits of bioenergy potential. Compared to other environmental tools, LCA is widely recognised for its comprehensive life cycle approach (Georgakellos, 2002). However, LCA outcomes are complex and difficult to interpret due to methodological assumptions, conversion routes and combinations of feedstock involved. Its complexities and uncertainties highly impact the end results of GHG balance assessments. Approaches such as standardised GHG accounting are desired but the lack of standard methodologies to assess the GHG savings from indirect land use change is still being researched (Cherubini and Strømman, 2011).

151. Alternative solutions, such as deriving a market-based single sustainability index, similar to the manner in which Total Factor Productivity (TFP) is used in assessing agricultural economic productivity, is also being considered. Although providing a single metric to measure sustainability (see Butchart et al., 2010) is not new, approaches have failed to incorporate all dimensions (social, economic and environmental) of sustainability. The TFP approach for measuring sustainability involves a multi-criteria analysis of ranking the most important indicators according to a weighting and integrates all the dimensions of sustainability (Box 6). It may be possible, by incorporating environmental (Glendining, 2009) and social criteria to make a single index of sustainability of commodities based on price-related productivity measures (Pavanan et al., 2013).

Box 6. What is Total Factor Productivity in this context?

This is an index approach for sustainable benchmarking of biomass production chains based on the concept of TFP which has been routinely used in agriculture (Lynam and Herdt, 1989; Ehui and Spencer, 1992; Chung et al., 1997; Glendining et al., 2009; Gaitán-Cremaschi et al., 2015). The general idea of TFP is that it reflects the rate of transformation of inputs (capital, labour, materials, energy and services) into outputs (biomass stock), where negative social and ecological externalities associated to different sustainability issues are included in terms of “bad” outputs.

For example, the outputs of a soy production system may include soy oil and soy meal and the inputs of the same soy system may consist of land, seed, labour, pesticides and fossil fuel. The use of fossil fuel emits greenhouse gases to the atmosphere contributing to climate change (this last output is a “bad” output of soy production). The quantification of outputs and inputs needed for the index may partly be obtained from an LCA analysis. The TFP index takes the analysis one step further in that it incorporates the several sustainability issues into *a **single measure of sustainability***. Hence, the index facilitates the integration and comparison of sustainability issues affecting human well-being at different temporal and spatial scales. Thus, a biomass chain with the best sustainability performance, i.e. the highest TFP score, is the one that produces the highest ratio of output to input where the “bads” are output penalties that lower the sustainability performance. Multiple chains with different sets of outputs and inputs can be compared using the TFP index.

In order to use the TFP index, the multiple input-output variables must be expressed using a common denominator. One solution is to use prices that reflect the relative importance of input and output variables towards sustainability. In this solution, observed prices can be used for the marketable inputs and outputs and shadow prices need to be estimated for externalities that are non-tradable in conventional markets, and therefore, related price information does not exist. TFP indexes using (shadow) prices reveal the relative performance of a biomass production chain reflected in the form of price signals. A second solution for aggregating multiple inputs and outputs into a single index is the use of distance functions. This solution is based on input and output quantity information (including “bads”) as the way to identify a sustainable frontier of the production possibilities set (see Annex 1).

152. Generating a quantitative (numerical) or semi-quantitative scale of sustainability is attractive, as it implies uniform comparability that would lend itself to certification and international harmonisation. Certification is the process whereby an independent third party assesses the quality of data in relation to a set of predetermined standards. These are mostly formulated as criteria that have to be fulfilled for the certification of a product or process.

153. Critical to generating the criteria are the quality and quantity of indicators that are used in their derivation. The Global Reporting Initiative[34] (GRI) cites 36 indicators that seem to be related to sustainability. For efforts in international harmonisation, however, a small number of critical indicators is necessary, or the task becomes unwieldy.

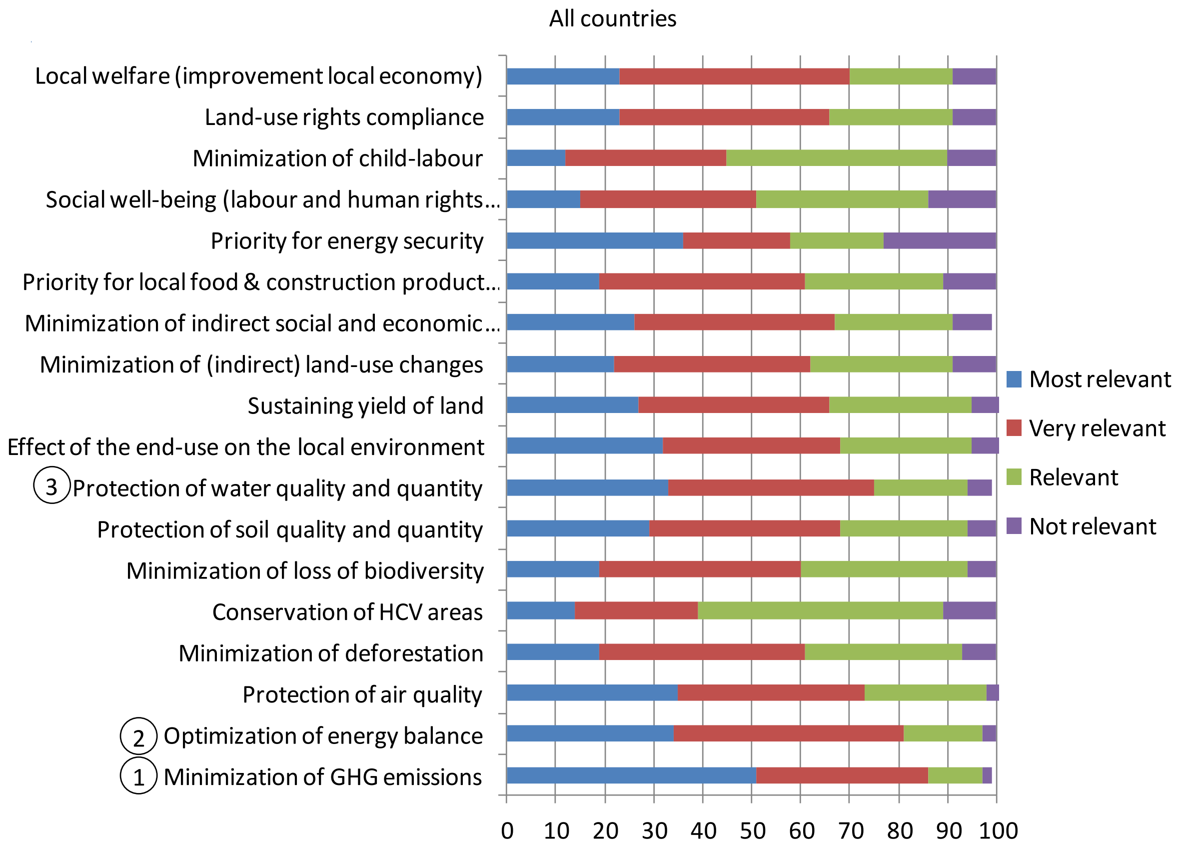
154. International harmonisation requires not only robust analysis, but consensus, and the latter is often more difficult to achieve. The experience of van Dam and Junginger (2011) is illustrative (Figure 9). Based on responses to a questionnaire sent to international stakeholders from 25 European and 9 non-European countries, the respondents rated the following three sustainability criteria with the highest scores in terms of relevance to include in a biomass and bioenergy certification system:

1. Minimisation of GHG emissions (87% of respondents);
2. Optimisation of energy balance (81%);
3. Protection of water quality and quantity (76%).

155. However, there was much disagreement. For example, optimisation of energy balance was not a high priority in some European and non-European countries. Instead, minimisation of deforestation was given very high priority in these countries. There was only agreement amongst the respondents that a criterion on the minimisation of GHG emissions should be included, and that the other two above were considered “highly relevant”. Moreover, social criteria are sometimes regarded as low in reliability and practicability, and tend therefore to be assigned a low ranking.

34 www.globalreporting.org/

Figure 9. Total response in all countries surveyed to indicate the importance of sustainability criteria to include in a biomass and bioenergy certification system



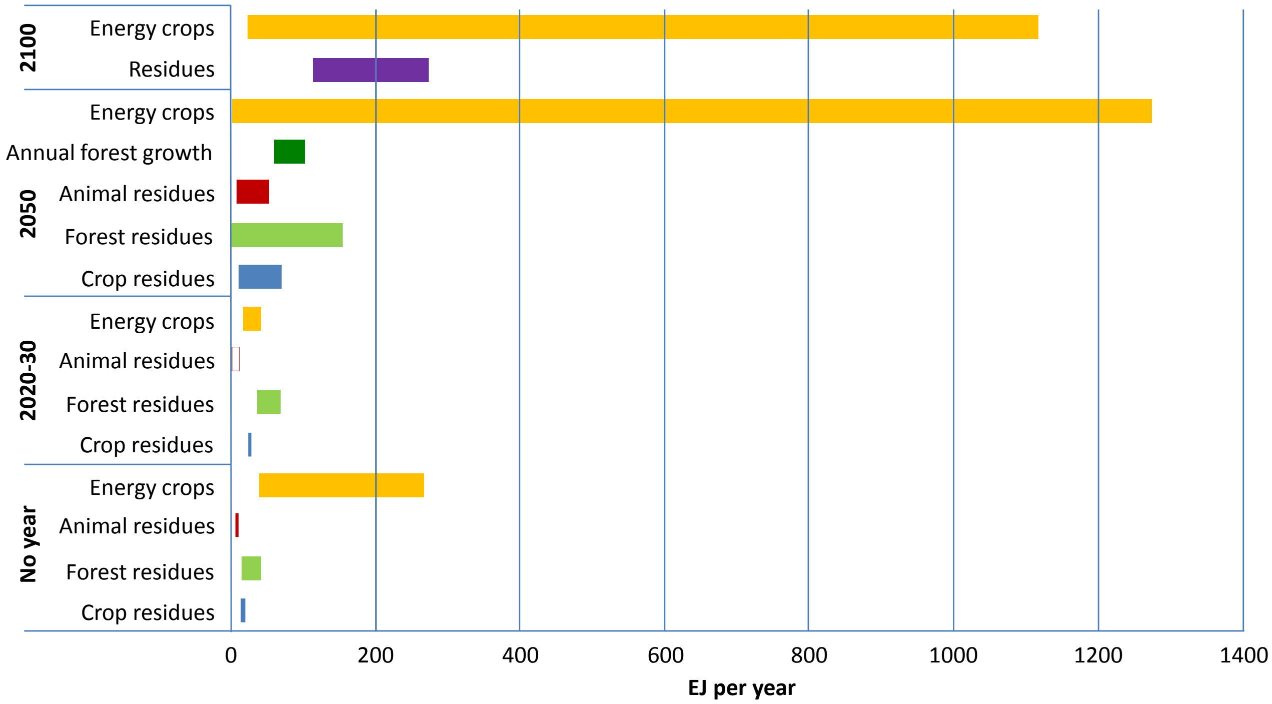
Source : van Dam and Junginger (2011). In total 473 responses were collected from 25 EU member countries and 9 non-European countries, ranging across NGOs, the policy sector, the R&D sector, bioenergy producers (industry), end-users (small-scale and industry) and traders (respondents involved in the trade and distribution of biomass).

Types of biomass potential assessment

156. Several studies over the past years have used a range of techniques, from simple data assumptions to robust high resolution land mapping techniques to estimate the available land for bioenergy production. Hence, large differences in estimates exist. Most of these studies provide detailed insights into the future biomass potential but fail to include all critical factors involved in the assessment. An ‘ideal’ study to evaluate biomass potential should take into account the global and regional trends and specific local conditions such as soil types, water availability, possibility of irrigation and land use planning, taking biodiversity and soil quality into account (Dornburg et al., 2008). However, the possibility has to be considered that this ideal cannot be attained or is only possible at a restricted regional level.

157. *Sustainable biomass potential* can be defined as the fraction of the technical biomass potential which can be developed in a way which does not oppose the general principles of sustainable development, i.e. the fraction that can be exploited in an economically viable manner without causing social or ecological damage (Biomass Energy Europe, 2008). These crucial factors can hugely alter the range of sustainable biomass potential. Seidenberger et al. (2008) have attempted to compile global biomass potential ranges from 18 different studies (see Figure 10).

Figure 10. A collection of global biomass potentials



Source : Adapted from Seidenberger et al. (2008). EJ = Exajoules

158. This shows the minimum and maximum potentials estimated by different studies. Figure 15 graphically illustrates the wide discrepancies in the range of estimates.

Discrepancies in biomass potential estimates

159. Studies that have attempted to estimate the availability of biomass have considered both optimistic and pessimistic approaches. The variations in range can be attributed to the following reasons:

- Different objectives over different time frames. Most biomass potential studies have future estimates until 2050 but less information is available on the short term i.e. 2020 or 2030;
- Variety of methodologies and approaches;
- The lack of a commonly agreed definition on the types of biomass (forest residues, harvest and process residues);
- Different data sets and scenario assumptions;
- Studies lacking transparency and omission of key factors;
- Geographical scope.

Land use changes and GHG emissions

160. The impacts of GHG emissions from land use changes (direct, DLUC, and indirect, ILUC) (see Annex 2) are considered to be critical. However, their measurement, especially of ILUC, is extremely

challenging. The analysis by Searchinger et al. (2008) highlighted the significance of land use change contributions towards agricultural emissions of GHG. Although the approach involved a high level of uncertainty, the consequences of GHG emissions from direct and indirect land use changes should not be ignored. Key data and modelling challenges, such as calculating the impact of land conversion on carbon stocks, data set variations on land use characteristics and complex interaction of socio-economic forces, all guarantee large uncertainty in results (USDOE, 2011a). To assess accurate levels of emissions from these sources, it is important to develop strategies that provide improved and deeper understanding of the interaction between land use changes and GHG emissions.

161. A few possibilities listed below could minimise the impact of land use change (direct and indirect) associated with large scale production of bio-based products from biomass. These alternate feedstock options considered eliminate the competition of land used for food crops, maintaining increased carbon gains while addressing pressing sustainability and food security challenges.

- Perennial crops grown on degraded lands[35] can minimise the impacts of direct and indirect land use. Additional carbon gains can be achieved if the land selected for cultivation provides high yield and has not stored large amounts of carbon initially (Tilman et al., 2009).

- Bioenergy from forest and crop residues, such as rice, wheat, corn stover and branches, can contribute towards the sustainable supply as these sources are rich in soil nutrients, preserving soil quality and preventing soil erosion. However, complete stripping of forest residues can have the opposite effect.

- Augmenting the efficiency of bioenergy by use of municipal and industrial wastes. Suitable biomass conversion techniques need to be developed to convert organic matter into valuable products.

162. The feedstock alternatives mentioned above rely on technology push. This includes efficient agro-technological conversion processes, high resolution satellite imaging for measuring land use changes, and impacts from carbon and nitrogen cycles. Multi-disciplinary and integrated research efforts are needed to achieve sustainability targets for a bio-based economy (van Dam et al., 2005).

How much biomass can be grown and how much is needed?

Calculating biomass potential and estimating the size of a potential bioeconomy in Europe

163. In a system of bioproduction, the sources of carbon that can displace fossil carbon are limited, and if the carbon is to be renewable, there is effectively only one option – biomass-based carbon. While the options for replacing liquid fossil fuels in the long-term are numerous, for material uses – plastics, chemicals, textiles, as examples – once the options are examined, quantitatively the only serious option is biomass. Bioenergy is the most important renewable energy option, at present and in the medium-term (Ladanai and Vinterbäck, 2009). However, bioenergy also offers the greatest potential for unsustainable, over-use of biomass due to the volumes required.

164. Dual use of biomass effectively a competition for land. Food use always has to come first. The availability of sustainable biomass as a future substitute for fossil resources is dependent on:

- The available land for biomass cultivation; and

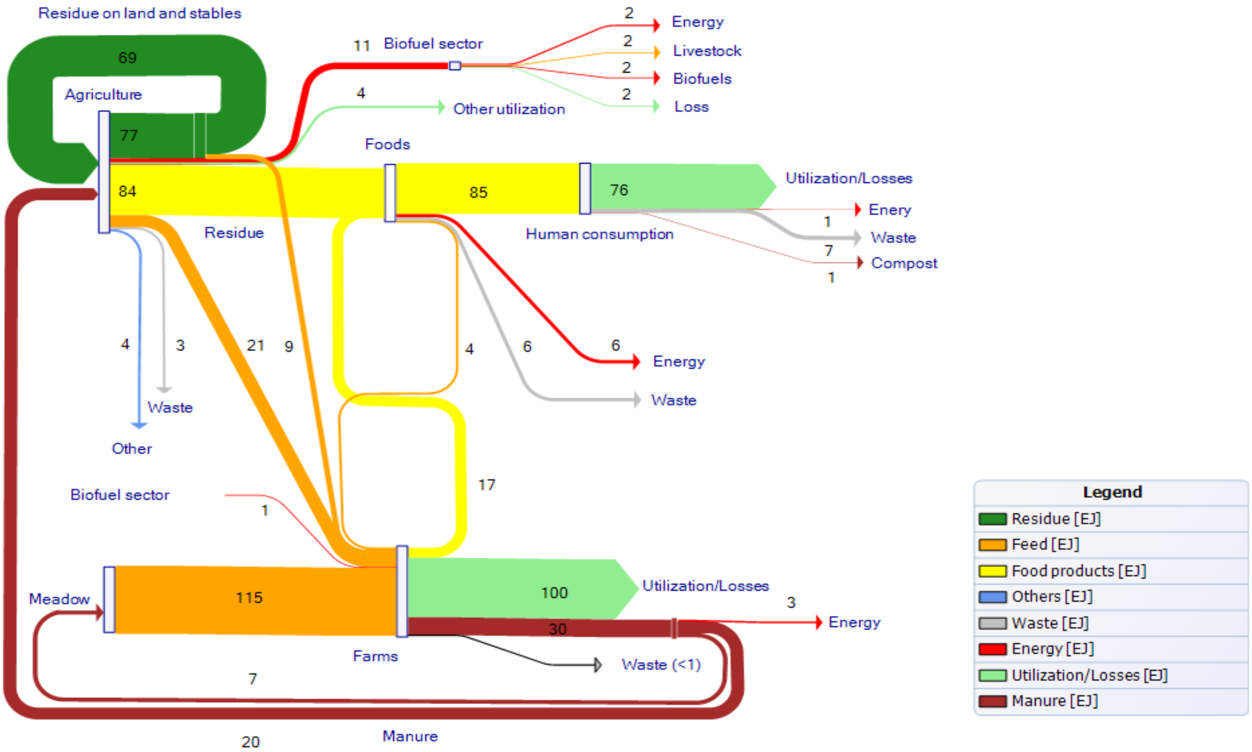
35 Degraded lands: Unfertile lands that cannot be used for agricultural activities without production costs exceeding profits.

- Options to use the biomass produced in agriculture and forestry more efficiently.

165. To start to understand these two factors, it is necessary to know how biomass currently flows in agriculture and forestry. If these flows of biomass over the world can be quantified, the potential to use more biomass for new applications without disturbing current applications can be assessed. An analysis of recent biomass flows (2010) and scenario studies including sustainability criteria provide more insight in the possibilities to support a larger bio-based economy in 2050. Unsurprisingly there have been many estimates of biomass flows, all with high levels of uncertainty. Figures 11 and 12 show estimates of agricultural biomass flow (in exajoules, EJ, 10^{18} J) and wood biomass flow (in megatonnes, Mt), respectively.

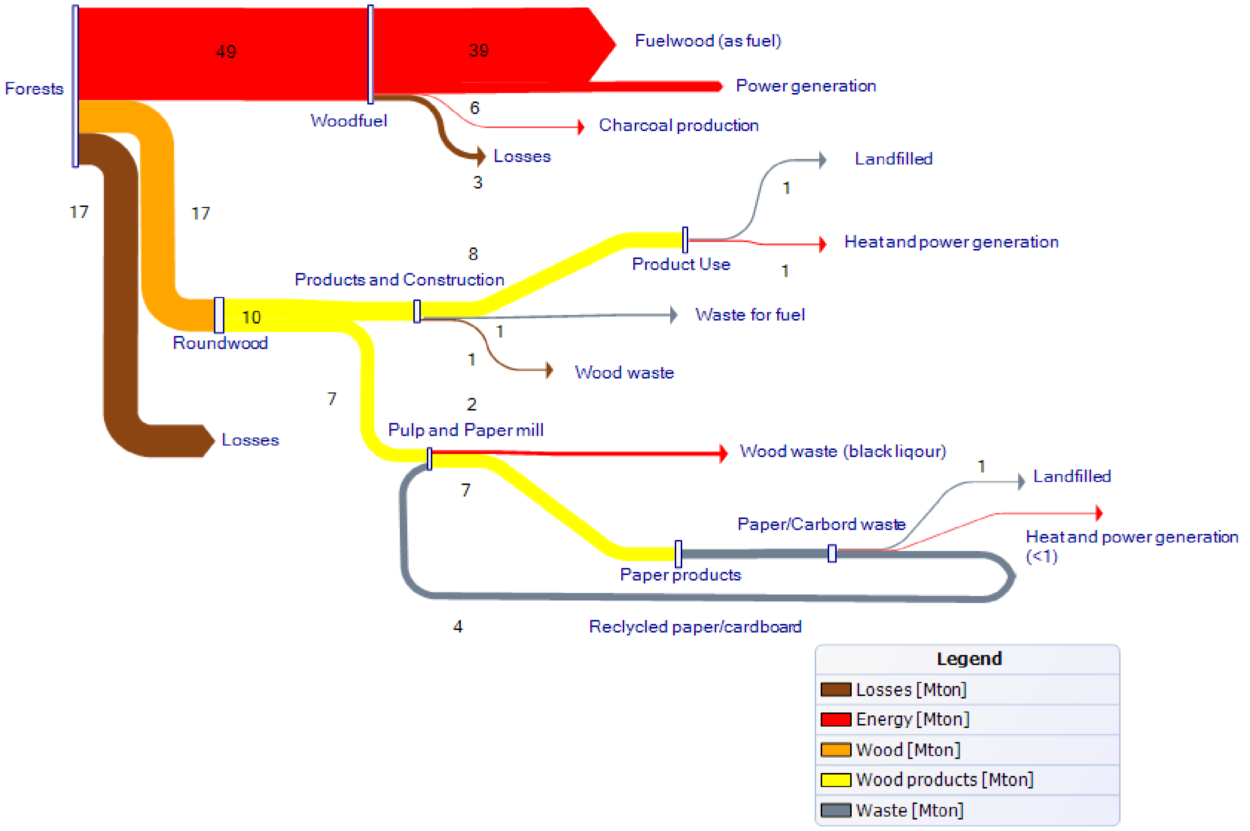
166. One main source of uncertainty is the underlying assumption regarding the amount of unused agricultural land available for the cultivation of bioenergy crops, and to what extent natural grasslands contribute to this potential. In particular, assumptions regarding future agricultural productivity and future consumption of animal products have a great impact on the results. Furthermore, the uncertainty in the amounts of available waste and residue resources strongly depends on the still uncertain future demand for other applications such as animal feed and soil quality improvers. Moreover, current estimates are necessarily indicative, because future trade is uncertain.

Figure 11. Global agricultural biomass flows



Source : Ros (2014). Methods and approaches to estimate global biomass potentials. Presentation at the OECD workshop “Sustainable Biomass Drives the Next Bioeconomy: a New Industrial Revolution?”, June 10-11, 2014, Paris.

Figure 12. Global wood biomass flows



Source : Ros (2014). Methods and approaches to estimate global biomass potentials. Presentation at the OECD workshop “Sustainable Biomass Drives the Next Bioeconomy: a New Industrial Revolution?”, June 10-11, 2014, Paris.

167. The energy content of agricultural crops including their residues produced across the world is estimated at 200 EJ, grass- and rangelands produce about 115 EJ. Both mainly deliver the inputs to the human food system. Most of the energy is not available for the energy system, because it is vital in the livestock system and also for people. If the unused and sometimes burned crop residues would be used for energy, the extraction could increase by about 24 EJ. In this assumption sustainable soil carbon management is considered (roughly half of the above-ground carbon should remain in the soil). Other potential energy sources are better use of waste flows from industrial processing and consumption. This could produce an additional 21 EJ.

168. Another feature of estimating biomass potential is uncertainty in the future extent of the bioeconomy, which is decided politically as well as scientifically. Therefore estimates often rely on scenario development. The work described by Ros defined three different scenarios for biomass potential to 2050:

- High:
  - Very productive agriculture, leaving land for energy crops;
  - Almost all of the sustainably available residues and waste is used;
  - New developments are quite successful.

- Mid:
  - Agriculture will be more productive, but land for energy is quite limited;
  - About half of the sustainably available residues and waste is used;
  - Only a few new developments for niche markets.
- Low:
  - Land use for the energy crops is not considered sustainable;
  - Only a small part of residues and wastes is used;
  - No new developments.

169. In these scenarios, Ros assessed the global biomass potential for energy use in 2050. The PBL (The Netherlands Environmental Assessment Agency) and ECN (Energy Research Centre of the Netherlands) conclude that most studies support an economically feasible estimated range of potentially available sustainable biomass in the world by 2050 of 150 to 400 EJ. For 2030 PBL consider 100 EJ as a realistic estimate and 200 EJ as a quite optimistic estimate of available sustainable biomass on the world market.

170. To bring this potential into the perspective of Europe: if an equal distribution per capita in 2050 is assumed, the potential for Europe (including trade) would be about 10 EJ based on 'mid' expectations. In case of a distribution based on income, it might be twice that potential. The EU will therefore probably depend on the world market to supply the biomass for its bioeconomy in the future.

Policy implications

- The total supply of sustainable biomass in 2030 may be enough to fulfil the demand in a 10% bio-based economy (PBL, 2012).
- A highly ambitious bioeconomy increases the risk of a non-sustainable supply and over-exploitation of natural resources.
- In light of growing trade, the numbers need to be continuously re-assessed.
- Looking beyond 2030 to 2050, many new initiatives and technologies will be required to realise a sustainable biomass potential.
- Algal biomass may be useful in the future, but based on the current situation, the costs are much too high for bioenergy. However, if future development of aquatic biomass would be successful, this type of biomass production could offer new possibilities. It should be realised that any number for its future potential is just a first guess. At this stage, feasibility studies and R&D support are the most obvious policy options.

Experience with biomass potential estimation in the United States

171. The original Billion Ton Report from the US was completed in 2005 to assess the sustainable biomass potential there (USDOE, 2005). An important conclusion from this earlier work was that the US

had the potential to sustainably produce a billion tons of biomass annually. The report was heavily criticised and an update was published in 2011 (USDOE, 2011b). A conclusion of the Billion Ton Update report remains the same: that the United States, depending on assumptions made, may be able to produce one billion tons of dry biomass per annum, thus substituting 30% of gasoline requirement with renewable biofuels.

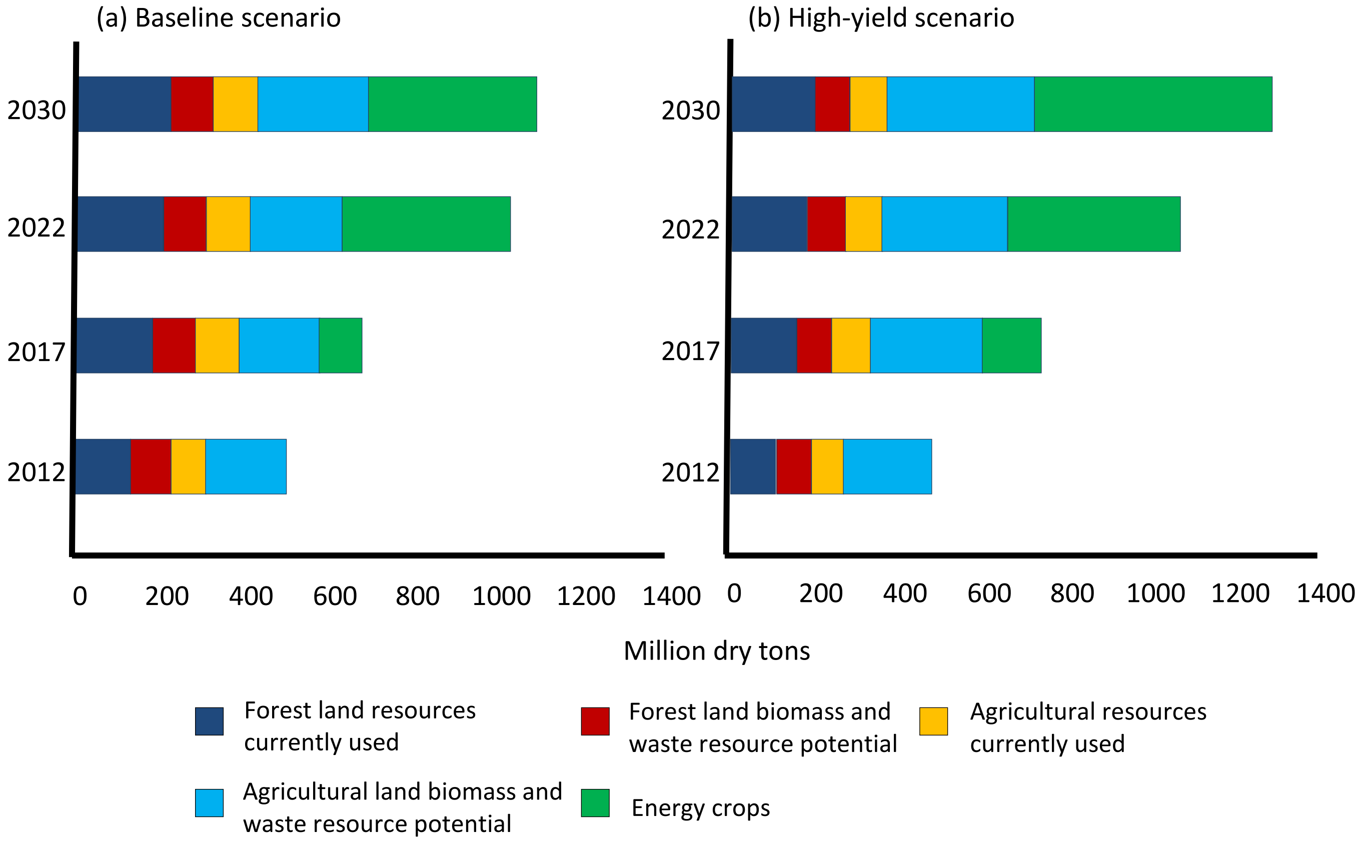
172. Like other biomass potential studies, it is based upon scenarios:

- *The baseline scenario*: Current combined resources from forests and agricultural lands total about 473 million dry tons at USD 60 per dry ton or less (about 45% is currently used and the remainder is potential additional biomass). By 2030, estimated resources increase to nearly 1.1 billion dry tons (about 30% would be projected as already-used biomass and 70% as potentially additional);

- The high-yield scenario: Total resource ranges from nearly 1.4 to over 1.6 billion dry tons annually of which 80% is potentially additional biomass. No high-yield scenario was evaluated for forest resources, except for woody crops.

173. The adopted methodology allowed estimation of the biomass potential of different sub-sectors (Figure 13). This is critical when developing future scenarios. Technological developments in one sub-sector may offset a lack of development in another. And as they change, this may alert governments to future policy needs.

Figure 13. Biomass potential in the baseline scenario (a) and high-yield scenario (b).



Source: Stokes (2014). The "billion ton update": methodologies and implications. Presentation at the OECD workshop "Sustainable Biomass Drives the Next Bioeconomy: a New Industrial Revolution?", June 10-11, 2014, Paris.

174. Stokes described ten principles that may be used by others when developing a methodology (Box 7). With this in mind, assessments should include:

- Adequate and verifiable data and information - Biomass should be considered a commodity just like other agricultural and forest products. Investments need to be made to provide such information;

- Yield – a significant variable in biomass supply is yield (e.g. geography and local climate alone create variability), either from residues and wastes or from energy crops. The literature, empirical studies, and expert opinion are used to develop yield estimates. Scenarios incorporated a range of annual yield increases;

- Supply curves – the underlying premise is that of estimating the biomass availability at different prices. Farm gate/roadside costs are developed for each feedstock and modelled to determine biomass availability at a given price;

- Sustainability – this is another important, underlying premise that had to be incorporated into the analysis. Different feedstocks require difference approaches. These include using multipliers and coefficients to model certain parameters such as soil carbon retention;

- Land availability and land-use change – land availability is important in estimating biomass production and land-use change is an important sustainability issue. Land competition between conventional crops and energy crops, and among energy crops are modelled.

Box 7. Ten principles for developing biomass potential methodology

1. Determine desired outcomes and probable uses; available data and analytical resources; and, then determined the "best" approach.

2. Use commonly accepted terminology and definitions of land use classes and other variables and functions Be consistent.

3. Use well- and consistently-defined feedstocks; from categories to a single feedstock.

4. Use various analytical tools dependent on availability of data and models; document and explain.

5. Use various data sources (mostly publically available for transparency) and document extrapolation; rely on many disciplines and professionals to have the technical depth required to understand and use the data appropriately.

6. Scenarios play an important role but require additional data and analyses, and experts, to be both realistic and useable.

7. Put other models to work to overcome specific issues such as sustainability criteria.

8. Work at the most appropriate spatial level based on data and models. Try to complete analysis for smallest spatial units and aggregate upwards to area, state, region, and national.

9. Provide and document all background work and assumptions.

10. Explain and document the details of the analyses and the outcomes and the application of the results.

Source: Stokes (2014). The "billion ton update": methodologies and implications. Presentation at the OECD workshop "Sustainable Biomass Drives the Next Bioeconomy: a New Industrial Revolution?", June 10-11, 2014, Paris.

A regional example in the US

175. Dedicated energy crops and crop residues are considered to be able to meet herbaceous demands for the new bioeconomy in the Central and Eastern US. Perennial warm-season grasses and corn stover are well-suited to the eastern half of the USA and provide opportunities for expanding agricultural operations in the region. A suite of warm-season grasses and associated sustainable management practices have been developed by researchers from the USDA Agricultural Research Service and collaborators associated with USDA Regional Biomass Research Centres. Second generation biofuel feedstocks provide an opportunity to increase the production of transportation fuels from recently fixed plant carbon rather than from fossil fuels. Although there is no "one-size-fits-all" bioenergy feedstock, crop residues like corn stover are the most readily available bioenergy feedstocks. However, on marginally productive cropland, perennial grasses provide a feedstock supply while enhancing ecosystems services. Twenty-five years of research has demonstrated that perennial grasses like switchgrass are profitable and environmentally sustainable on marginally productive cropland in the western corn belts and Southeastern USA (Mitchell et al., 2016).

Harmonising sustainable biomass potential

176. An important aspect of the Billion-Ton Update is that it may give leads on how to harmonise the approaches, which, as already highlighted, are variable in their underlying methodologies, assumptions, and analyses. It is very important to effectively estimate the sustainable capacities for biomass production for both domestic use and international biomass trade.

How to measure biomass sustainability: LCA, Environmental Footprint and alternative approaches

LCA in assessment of biomass sustainability

177. LCA methodology has unique advantages when analysing the environmental performance of products as it allows in theory – based on an accounting of all relevant material flows throughout the entire life cycle – to obtain a complete picture of certain environmental burdens associated with a product. This enables comparisons across technological boundaries and to identify relevant stages in the life cycle, as well as improvement options.

178. However, LCA methodology features fundamental shortcomings including dependency on numerous subjective choices, need for simplifications, lack of adequate data and limited precision. These limitations cannot be overcome by another layer of rules in addition to existing standards – they are inherent in the system of life cycle assessment. The lack of a standardised approach for accounting for the biogenic carbon storage in bio-based materials presents a key challenge to LCA practitioners (Pawelzik et al., 2013).

179. In addition, LCA is not the definitive tool to suitably characterise all environmental impacts. Many impacts cannot be reasonably related to reference flows because the effects are space-, time- and threshold-dependent. Sound environmental assessments require a mix of different tools (e.g. environmental impact assessment, human health and environmental risk assessment, technology assessment), taking due account of their strengths and weaknesses.

180. LCA is a suitable tool for orientation regarding certain aspects at the onset of indicator development or regulatory requirement setting. It delivers rough estimates rather than precise figures. However, suitable production, consumption or disposal indicators are typically more robust, are more meaningful or relevant, cheaper, they can be measured and are easier to verify (or to enforce).

181. Harmonised methodologies for the calculation of the environmental footprint (EF) of products have been developed. EF methodologies are by no means new; rather they constitute a remix of existing tools and related guidance. A key concept for improving comparability is the development of “Product Environmental Footprint Category Rules” (PEFCRs) (European Commission, 2016) for specific products. These are being developed in the EU with the cooperation of volunteering stakeholders and industry during a 3-year testing period which started recently[36]. The objectives of the EF pilot phase are:

- To set up and validate the process of the development of product group-specific rules (Product Environmental Footprint Category Rules – PEFCRs), including the development of performance benchmarks;

- To test different compliance and verification systems, in order to set up and validate proportionate, effective and efficient compliance and verification systems;

- To test different business-to-business and business-to-consumer communication vehicles for Product Environmental Footprint information in collaboration with stakeholders.

182. It would be useful to develop a framework for indicator development embedded in the system of political decision making, translating priority environmental concerns and broad target setting into specific quantified environmental demands at the country or region level (e.g. EU), as well as organisational and product level. A useful starting point to thus create a harmonised methodology would include a discussion of the pros and cons of current practices and, on this basis, identify needs for improvement covering all dimensions of the subject in question.

Policy implications

- LCA is an environmental tool which does not address economic and social impacts at all. However, these are crucial for policy decisions, particularly where such impacts are crucial. This seems to indicate the need for a fundamental review of its utility in biomass sustainability assessment.

- Social impacts especially are difficult to quantify and are therefore easily side-lined. This is an area for careful consideration to identify the most robust indicators. Qualitative indicators (e.g. compliance with organic farming standards) merit inclusion in environmental assessment.

- Possible complementing and/or alternative environmental assessment approaches using indicators which are tailored to specific product groups that are relevant, robust, verifiable and cost effective could be discussed.

- An adequate forum involving a broad range of stakeholders for the critical review of LCA methodology and possible alternative approaches for the assessment of product could be identified.

Is the market more able to provide a unified approach to biomass sustainability assessment?

183. The major limitation of the vast majority of methods is their inability to aggregate the different sustainability issues in an objective way. Aggregation requires making complicated trade-offs between sustainability aspects with different dimensions such as kilogrammes of CO_2 emissions and hours of child labour; such trade-offs are not intuitive. Currently, practitioners can only generate an overall sustainability

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36 http://ec.europa.eu/environment/eussd/smgp/pef_pilots.htm

number by using their own weighting factors when aggregating the different impact categories and this introduces an undesirable subjectivity. The failure to incorporate the social implications of biomass production further obfuscates the issue. In particular, this limits the usefulness of current methodologies for measuring the sustainability of biomass in international trade flows.

184. To take an ‘index’ approach requires that multiple input-output variables must be expressed using a common denominator. The index approach facilitates the integration and comparison of sustainability issues affecting human well-being at different temporal and spatial scales. A common denominator that the market understands is money. This would involve monetising the “good” and “bad” inputs and outputs. The analysis would have to *incorporate the several sustainability issues into a single measure of sustainability*.

185. Gaitán-Cremaschi et al. (2014) suggest the TFP approach to the problem. The general idea of TFP is that it reflects the rate of transformation of inputs (capital, labour, materials, energy and services) into outputs (biomass stock), where negative social and ecological externalities associated with different sustainability issues are included in terms of “bad” outputs (see Equation 1).

186. The TFP index would use prices that reflect the relative importance of input and output variables towards sustainability. In this solution, observed prices can be used for the marketable inputs and outputs and shadow prices need to be estimated for externalities that are non-tradable in conventional markets, and therefore, related price information does not exist. In other words, the TFP index would use (shadow) prices[37] to reveal the relative performance of a biomass production chain reflected in the form of price signals.

187. Thus, a biomass chain with the best sustainability performance, i.e. the highest TFP score, would be the one that produces the highest ratio of output to input where the “bads” are output penalties that lower the sustainability performance. Moreover, multiple chains with different sets of outputs and inputs could be compared using the TFP index.

Equation 1. The guiding principle of TFP

$$TFP = \frac{Aggregated\ Outputs\ ("goods" - "bads")}{Aggregated\ Inputs}$$

Purported advantages of the TFP approach

- It includes externalities (social and economic).
- Numerical harmonisation allows aggregation into a common metric.
- Inputs, outputs and bad outputs are converted to a common, universally understood unit: money.
- Access to market price data make policy negotiations easier – prices are tangible, qualitative indicators such as child labour are not.

[37] Shadow price is the opportunity cost of an activity or project to a society, computed where the actual price is not known or, if known, does not reflect the real sacrifice made.

Policy implications

- The acceptance of such a tool would require consulting with all stakeholders (policy makers, business stakeholders, NGOs) on:

1. The selection of sustainability issues (i.e. the inputs and outputs); and

2. The method for aggregating multiple input and output variables in the TFP index.

- The application of the TFP index would require a common base level of understanding of sustainability, which would have to be defined from regional, national and/or international biomass sustainability debates. In this way, the selection of inputs and outputs could be based on the issues of sustainability that are of established concern for expert scientist communities, policy makers and the well-being of society e.g. global warming, energy, innovation, human rights, equity, land use.

- The aggregation methodology would have to be agreed upon and accepted internationally. Aggregating sustainability issues using price information can be a benefit for the policy decision-making process in data-poor situations, where information about different sustainability issues is still lacking. Nevertheless, it requires making decisions about the importance of different sustainability issues expressed in the 'true' shadow price. These decisions imply incorporating social, political, and ethical values in monetary terms, which are often conflicting with each other, and could be deeply contentious in society. This would require careful handling and transparent stakeholder communication. Economic evaluation tools can be used to facilitate and support the estimation of shadow prices for decision making.

- The other approach to aggregation, using distance functions, allows easily integrating multiple environmental and social externalities without requiring (shadow) prices. Nevertheless, it requires a large set of observations for the multiple inputs and outputs to be included in the sustainability assessment.

ILUC: where food and non-food uses of biomass collide

188. Where previously uncultivated land is used to grow crops for industrial use, there is a direct land use change (LUC) and there are protocols to calculate the GHG impact of LUC. The protocols are used, for example, in the Renewable Energy Directive (RED). Perhaps the most controversial issue regarding bio-based production from biomass is indirect land use change (ILUC). Indirect land use change occurs when land used for food production is converted to grow a crop for non-food use. It is assumed that food production is essential and that the lost food production will be diverted elsewhere. If this requires the use of previously uncultivated land, this causes large initial increases in GHG emissions e.g. by encouraging deforestation. Since a primary purpose of biomass for industrial use is to reduce GHG emissions, it is important that the impacts of ILUC are considered.

189. As an example, the UK Government's Gallagher Review (Renewable Fuels Agency, 2008) stated that ILUC must be addressed for biofuel policy to have clear climate benefits. However, its measurement is extremely complex, and some contend that it is impossible to measure. Politically, the crux of the problem is that when ILUC enters policy under conditions of such uncertainty, there will be a lack of investor confidence.

190. Political progress on ILUC has been slow. Europe provides an example of divided opinion on ILUC. In both the RED and the FQD (Fuels Quality Directive) ILUC was considered to be inadequately

addressed. As a result, some biofuels may consequently have little environmental benefits compared with fossil fuels, and even result in an increase of GHG emissions rather than net savings. To address ILUC, in 2012 the European Commission proposed a Directive amending the RED and FQD which has since been adopted by the Council and Parliament and was published in September 2015 (Directive 2015/1513)[38]. In it, fuel suppliers and the European Commission are to report on emissions deriving from ILUC, but these are not included in the sustainability criteria for the biofuels or the GHG calculation methodology of the RED and FQD. Implementation of the ILUC Directive has been slow due to the short time since its publication, but also because of different positions of different EU member states (CE Delft, 2015).

Issues with ILUC

191. Models built to calculate GHG emissions have been adapted to accommodate ILUC. These models not only rely on the magnitude of specific mandates within a policy environment but also require a large number of inputs, the most important of which include: commodity pricings; projected crop yields; price elasticities; transformation elasticities (the ease with which land is converted from one to another use); and substitution elasticities (the ease in which comparable products, or co-products are substituted).

192. Many of these inputs require use of broad assumptions, which vary between studies, and the means by which elasticities are calculated is dependent upon the model used. It is not surprising that the estimated ILUC for biomass varies greatly in accordance with which model is used, and in which study it was used.

193. Co-product allocation represents a further controversial issue of ILUC modelling. Many crop-based biofuels are delivering significant GHG savings as well as a valuable food source in the form of high protein animal feed. This provides a stimulus to improved and sustainable agricultural productivity. Where biofuel production gives co-products that displace other animal feed crops, this will reduce the demand for these animal feed crops. This leads to a reduction in land use change that offsets the ILUC of the biofuel crop. The net ILUC impact may therefore be either a penalty or a credit in GHG emissions.

194. Whilst it is almost consensually agreed across the science community that biofuels can result in indirect emissions, despite a lack of agreement regarding the magnitude, there are many reservations about introducing ILUC into policy as it essentially represents a ‘best guess’ rather than an accurate measurement based upon empirical data. ILUC modelling, as it currently exists, is in no state to provide an accurate assessment of indirect emissions of biofuel production, especially for use in policy making, nor is it likely to be in the near future.

195. However, it is also clear that ILUC will not be dismissed. It is therefore imperative that the biomass industries begin to adopt a position on ILUC that will provide the most stable platform for growth of the bioeconomy.

What can be done ?

196. An alternative solution to the complexities of modelling ILUC emissions is to promote the uses of biomass that are unlikely to have a large impact on ILUC. This would provide a means of mitigating ILUC whilst avoiding the need for relying on controversial modelling results. In essence, for biomass to demonstrate that it has a low ILUC impact, it needs to prove that the feedstock has not come from land in competition with food production, or from carbon rich lands (forests, peat lands).

38 http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32015L1513

197. The development of mitigation options using supply chain certification schemes could provide a workable solution for addressing ILUC. Such a process could allow developers to provide evidence that their biomass for industrial uses has minimal ILUC impact (e.g. by using abandoned or degraded land, improving crop yields) and therefore should be exempt from application of any ILUC penalty, such as an ILUC factor. This concept could be built upon to provide a more satisfactory outcome to addressing ILUC in policy.

Policy implications

- ILUC modelling, as it currently exists, is in no state for use in policy making relating to biomass sustainability.
- All forms of biomass could be acceptable as feedstock for the bioeconomy; this could be mirrored in public debate and perception, as well as in specific policies.
- Biomass must meet established international sustainability standards covering GHG savings, sustainable land use and environmental protection. These criteria could be integrated into supply chain certification schemes.
- Public financial incentives should only be based on higher resource and land use efficiencies, sustainability and GHG savings and the lowest possible level of competition with food.
- Food or non-food biomass should not be taken as the sole acceptance criterion.
- Examine policies for the production of sugar for industry use. For example, sugar beet is a very attractive feedstock for the European chemical industry, with low impact on the food and feed sector as increasing yields are leading to decreasing areas under cultivation.
- Added value, employment and innovation speak in favour of supporting industrial use of biomass for materials and chemicals, rather than disproportionately allocating biomass to fuels and energy applications. Greater value added can only improve on ILUC calculations and implications relating to biomass sustainability.

Does the use of marginal land alleviate the complexities of the sustainability issue?

Sustainable biomass and marginal land

198. Large quantities of food and/or feed crops such as corn and soybean are directed toward the production of grain-based ethanol and biodiesel. While the cultivation of highly productive crops on prime agricultural land is able to produce large quantities of biofuels, this practice can have detrimental environmental effects and may contribute, along with other factors, to food prices rises (i.e. the food *versus* fuel debate).

199. An alternative approach is to grow lignocellulosic (or cellulosic) crops on ‘marginal lands’. Marginal land may be defined as follows: *land not used for food production because of some inherent limitation: low fertility, highly erodible, or otherwise not suitable for annual crops and not used for grazing*. Growing cellulosic feedstocks on such lands is advantageous due to the low management intensity required, increase in soil carbon stocks, and reduced soil erosion and GHG emissions.

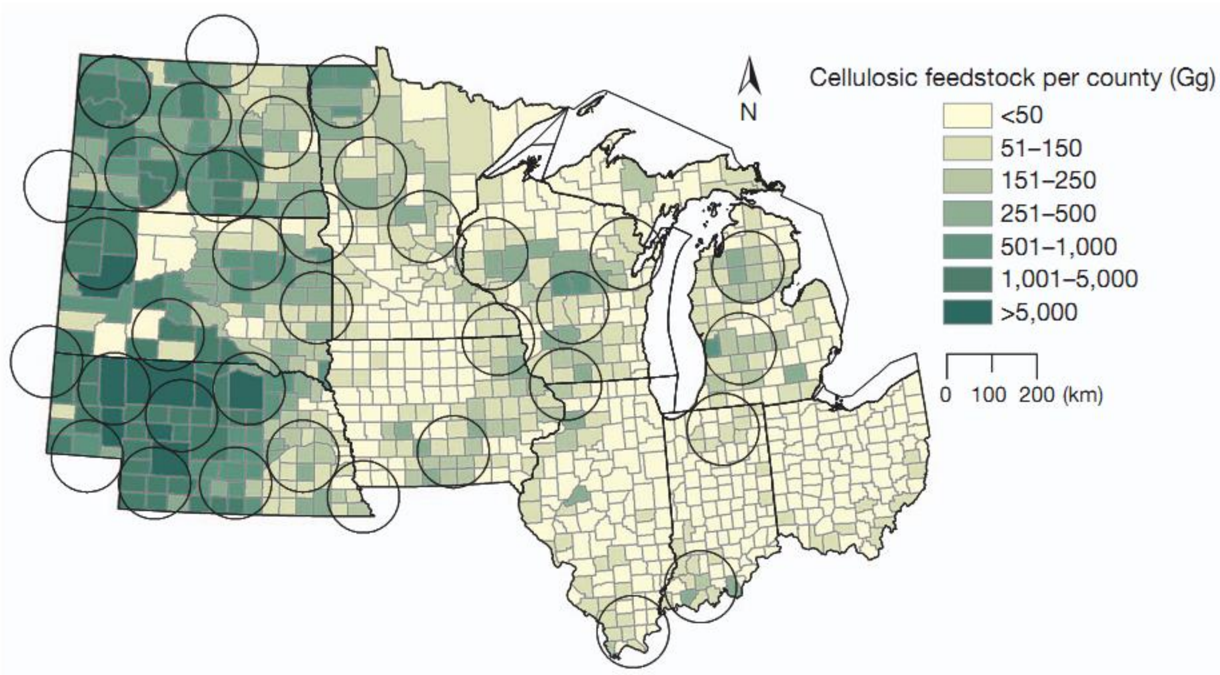
200. There are two main challenges to achieving this:

1. *Choosing the right crops to ensure sufficient productivity with environmental benefits*: To achieve sufficient yields on inherently unproductive lands requires the right choice of plants with characteristics that facilitate growth on marginal soils.

2. *Understanding the landscape dynamics that influence the supply and distribution of feedstocks*: Growing biofuel feedstocks on marginal lands may further amplify the complexity of feedstock supplies. Parcels of marginal lands might be spread across landscapes. They may or may not be connected by a suitable road network, or be of suitable size for successful harvesting and handling of biomass. Transport, management and biodiversity implications need to be understood.

201. Gelfand et al. (2013) identified 35 locations (Figure 14) across the North Central United States where biorefineries with production potential above 133 million litres could be built. These biorefineries could produce ~ 21 billion litres of cellulosic ethanol per year (equal to about 25% of EISA[39] mandate for 2022).

Figure 14. Potential for biofuel production from marginal lands.



Source: Gelfand (2013). Sustainable biomass and marginal land. Presentation at the OECD workshop “Sustainable Biomass Drives the Next Bioeconomy: a New Industrial Revolution?”, June 10-11, 2014, Paris.

202. However, before a sustainable biofuel economy can be established, three top priority questions need to be answered.

1. What are direct and indirect effects of land conversion on GHG emissions? As already explored, ILUC issues are complex and the models are not fit-for-purpose as yet to be used in policy or legislation.

39 EISA: The US Energy Independence and Security Act of 2007

2. What is the availability of marginal lands? In other words, suitability does not mean availability. In terms of understanding the availability of marginal lands for biofuel crop production, what is their potential productivity, and where are they located relative to potential biorefineries? How will this interact or interfere with social issues, such as tourism ? In addition, are landowners willing to grow biofuel crops in the first place?

3. What is the ideal biofuel feedstock? For example, what are the trade-offs associated with annual and perennial biofuel crops? Perennial feedstocks provide various ecosystem service such as: soil carbon sequestration and stabilisation in addition to the biomass produced; require a low input of agrochemicals; have a high ratio of energy return on investment; high climate mitigation benefits; and the potential to produce greater yields than annual plants on marginal lands. However, annual plants can be replaced by other crops if the demand changes, while perennial crops need to be grown for several years before harvesting is possible; and they cannot be rotated as often as annual feedstocks.

203. Clearly not only the biophysical aspects of biofuel production, but also the socio-economic impacts. An interdisciplinary approach is indicated for a better understanding of public and landowner perspectives, in relation to the use of existing landscapes for renewable energy production as part of the more general ecosystem services such as clean water and biodiversity.

Policy implications

- Yield alone is not sufficient justification for supporting an energy crop. Additional benefits through e.g. enhanced ecosystem benefits, such as those that foster biodiversity need to be assessed.

- Develop best management practices for biofuel feedstock production. Maximum environmental benefits are achieved by combining the right crop with the right location and the right cultivation practices.

  – Guidelines for sustainable feedstock production need to be developed and will require monitoring tools for assessment.

- Include the time dimension into assessment of the environmental impacts of biofuel feedstocks.

  – Harvesting of existing mature forests is not providing expected climate mitigation since forest will require decades to re-growth and to uptake CO_2 which will be released due to harvest and use of forest biomass as a biofuel feedstock.

- Using these best management practices, select suitable marginal lands and implement the growth of cellulosic feedstocks on them.

  – Although they are potentially less productive than high-input/high-yield crops, such feedstocks can provide more environmental benefits, which would need to be monitored.

- Support the development of breeding and selection programmes for new feedstock crops.

- Give high priority to the implementation of low-input cropping systems, such as grasses.

- Establish land-use guidelines. A spatial inventory of lands in areas suitable for biofuel production is needed to inform the development of such guidelines.

– Include land connectivity and assessments of potential yields. This must identify the existing land-use patterns at a small spatial scale, to be relevant for the growth of feedstocks, as an alternative land use (i.e. sub-kilometre).

– Include consideration of the fact that impacts of agricultural intensification are experienced domestically (i.e. direct land-use change) and globally (i.e. indirect land-use change).

Inter-relationships of bioeconomy and feed-food production

Industrial material use of biomass. Value added and sustainable feedstock, food or non-food: which agricultural feedstocks are best for industrial uses?

204. The absolute top priority for land use is for food and feed production i.e. food security. Consideration of the use of land for industrial purposes must take account of future population expansion and food trends. For example, increasing meat consumption accompanying higher living standards will generate additional demand for biomass. The projected growth rate of total world consumption of all agricultural products is 1.1% *per annum* from 2005/2007-2050. Since at the world level (but not for individual countries or regions) consumption equals production, this means global production in 2050 should be 60% higher than that of 2005/2007 (Alexandratos and Bruinsma, 2012).

205. In 2008, the 10 billion tonnes of biomass harvested worldwide were used as follows: 60% animal feed; 32% food; 4% material use, and; 4% energy use. Although agricultural yields can be significantly increased in many developing countries, and arable land can still be expanded by a few hundreds of millions of hectares worldwide without touching rainforest or protected areas, arable land and biomass are limited resources and should be used efficiently and sustainably.

206. The choice of biomass – food and non-food crops – should be dependent on how sustainably and efficiently these biomass resources can be produced. The only crucial issue is land availability, since the cultivation of non-food crops on arable land would reduce the potential availability of food just as much or even more. However, there has been increasing focus in recent years on cellulosic feedstocks from non-food crops.

207. This calls for an examination of the issue of whether using biomass for purposes other than food can be justified at all. Therefore the availability of arable land should be taken into account. In support of re-appraising the use of food crops for bio-based production, several factors should be considered:

- Several studies show that some arable land areas remain free for other purposes than food production even after worldwide food demand has been satisfied;
- These studies also show potential for further growth in yields and arable land areas worldwide;
- Recent studies have also shown that many food crops are more land-efficient than non-food crops;
- The long-time improvement of first generation process chains as well as the food and feed uses of by-products makes the utilisation of food crops in bio-based industries very efficient.

208. Growing more food crops for industry may, in fact, have several advantages:

- The farmers could win, with more options for selling stock and, therefore, more economic security;

- The environment could win, due to greater resource efficiency of food crops and the smaller area of land used;
- Food security could win, due to flexible allocation of food crops in times of crisis;
- Feed security could win, due to the high value of the protein-rich by-products of food crops;
- Market stability could win due to increased global availability of food crops, which will reduce the risk of shortages and speculation peaks.

209. Due to increasing demand for food and feed as well as bioenergy and industrial material use, the crucial question is how to increase the biomass production in a sustainable way. Two ways of achieving this are:

1. *Increasing yields*: Tremendous potential for increasing yields in developing countries is hampered by a lack of investment in well-known technologies and infrastructure, unfavourable agricultural policies such as no access to credits, insufficient transmission of price incentives, and poorly enforced land rights;

2. *Expansion of arable land (land extensification)*: Some 100 million hectares or more could be added to the current global 1.4 billion hectares without touching rainforest or protected areas. These areas would require a lot of infrastructure investment before they could be utilised. But there is a real possibility that land extensification leads to unfavourable outcomes, especially deforestation, with concomitant threats to biodiversity. Policy would have to be designed to avoid the unfavourable outcomes such that sustainability could be proven.

Policy implications

- All kinds of biomass should be accepted as feedstock for the bioeconomy. A comprehensive concept is required for feedstock allocation for food, feed, industrial material use and bioenergy.
- Potential political and financial measures should only be based on higher resource and land efficiency, sustainability, and a lower environmental footprint of the biomass, and the lowest possible level of competition with food.
- Using food crops should not be exempted from political thinking before the above are assessed - excluding them from industrial use could end up leading to a misallocation of agriculture resources.
- Examine if there are - in the country or region - free agricultural areas left, which are not necessary for the production of food and feed, domestic use or export.
- Research could be used to identify the most resource- and land-efficient crops and production pathways for specific regional conditions and applications.
- Political reforms and investment in agricultural technologies and infrastructure may be necessary.
- Reducing meat consumption would free up large amounts of arable land for other uses. Deriving protein from cattle requires 40 to 50 times more biomass input compared to protein directly obtained from wheat or soy;

- Reducing food losses would also decrease pressure on arable land. Roughly one-third of food produced for human consumption is lost or wasted globally, amounting to about 1.3 billion tonnes per year.

Lessons from history

Mediating global conflicts concerning biomass

210. In the 1980s a trade war over agricultural products was avoided because a measuring standard was developed by the OECD: the Producer Subsidy Equivalent, the forerunner to the current Producer Support Estimate (PSE). There may be lessons to be learned relating to possible concerns around flows of biomass needed for the global bioeconomy.

211. In summary the current situation pertaining to biomass sustainability is:

- There is a proliferation of sustainability standards, expensive procedures, subjectivity in application, possibility of trade conflicts and green tariffs;
- The current benchmarking tools, based on LCA methods, are limited;
- There is an inability to aggregate the different sustainability issues in an objective way;
- Suppliers of biomass use their own weighting factors, thereby introducing subjectivity.

212. This situation bears striking similarities to the 1980s situation in agriculture.

213. The Producer Support Estimate[40] is a commonly accepted benchmarking tool that is yearly adapted within the OECD framework.

History of the Producer Support Estimate (PSE)

214. Dumping of agricultural produce by the European Union and the United States on the world market caused not only problems to farmers in the EU and the US but understandably also elsewhere. In order to avoid trade wars the need was expressed for objective criteria to measure farm support. There are clear parallels with the current situation regarding biomass sustainability and the potential for biomass disputes.

215. The use of the Producer and Consumer Subsidy Equivalent (PSE/CSE) method to estimate assistance to agriculture had as a driver the necessity to capture in a single, all-inclusive measure the transfers to farmers from agricultural policies, implemented with a wide range of often complex and inter-related instruments. The calculation of PSEs and CSEs was perceived as being practically feasible given the availability of data and resources. The method had the potential to generate comparable results across countries, commodities and through time, which are easily understood by policy makers.

216. The Producer Support Estimate is an indicator of the annual monetary value of gross transfers from consumers and taxpayers to support agricultural producers. The nomenclature and definitions of this indicator replaced the Producer Subsidy Equivalent in 1999.

[40] https://stats.oecd.org/glossary/detail.asp?ID=2150

217. Specifically, the Producer Support Estimate incorporates explicitly all domestic agricultural policy measures directly or indirectly affecting trade which would not be captured by measuring trade barriers alone. The concept of measuring money transfers from governments to farmers has become an accepted indicator to compare producer support between various countries. The OECD has played a vital role in this.

ROLES OF MODERN BIOTECHNOLOGY IN CREATING A SUSTAINABLE BIOECONOMY: GENOMICS AND BIOTECHNOLOGY IN FOOD PRODUCTION

Introduction

218. Other chapters deal specifically with industrial production and bio-based products. Here, in relation to a sustainable bioeconomy, the focus is on biotechnology in food production and the future roles of marine biotechnology. Given the extensive discourse on the competing uses of biomass in food and industry, this is an important area for policy makers. If land extensification possibilities are limited, and agricultural productivity is declining, this would suggest limitations for the industrial use of biomass. As other forms of biomass as biorefinery feedstocks are being sought, it is still important to improve agricultural productivity as well as sustainability. The yield increase of the so-called green revolution in modern agriculture from the 1950s is flattening out. In addition, current agricultural practices with higher inputs, such as pesticides and fertilisers to ensure high yields, are not considered environmentally sustainable. Therefore the contributions of biotechnology to land extensification and intensification will be crucial in future. In addition, the marine environment remains a virtually untapped resource. Two overall messages from this chapter are:

1. Biotechnology, whether through genetic modification or not, is already making a huge impact on the sustainability of food production and this will continue to rise in importance as the human population increases and fossil dependence decreases. Despite apparent progress, the surface has merely been scratched. Biotechnology in agriculture still has a huge impact to make;

2. Marine biotechnology and the sustainable exploitation of the marine environment are in their infancy. Whether exploiting its biomass or genetic potential, the marine environment has a major role to play in a sustainable bioeconomy – it will reduce pressure on land and relieve the fears about the competing use of terrestrial biomass for food and industry. Nevertheless, the oceans also have to be exploited sustainably.

219. Although very powerful, it should be stressed that genomics does not necessarily involve genetic modification (GM) or synthetic biology, and the negative societal issues that have haunted GM in many applications can be avoided. Rather, -omics technologies can be applied to animal and plant breeding to greatly improve the efficiency of selection of traits. In the case of trees, this is especially important given the long timescales needed for tree growth and trait expression.

220. To use the full potential of genomics there is a need to link genomics information to phenotypic characteristics. The availability of well-defined linkage maps and the extent of genetic studies conducted on them vary among different crops, and this influences the feasibility of any Marker Assisted Selection (MAS)[41] -related activity. MAS allows to reduce the breeding cycle time significantly (e.g. for cassava from five to two years) and is much more accurate (Ly et al. 2013).

Genomics and biotechnology in food production

221. Increasing incomes in developing economies have contributed to a large increase in meat and milk consumption. From the beginning of the 1970s to the mid-1990s, the increase on consumption of

41 Marker assisted selection or marker aided selection (MAS) is a process whereby a marker (morphological, biochemical or one based on DNA/RNA variation) is used for indirect selection of a genetic determinant or determinants of a trait of interest (e.g. productivity, disease resistance, abiotic stress tolerance, and quality).

meat in developing countries was almost triple the increase in developed countries, and the increase in consumption of milk was more than twice the increase in developed countries (Delgado, 2003). Naturally, this creates strains on a bioeconomy as yet less biomass can be devoted to industrial uses. Therefore there is clearly a need to find new ways of increasing food production efficiency in these areas.

222. Chinese Taipei offers a good example of this shift in dietary pattern as development proceeds. In the 30 years from 1959-1989, per capita consumption of rice halved, while meat consumption (chicken, beef and pork) quadrupled, fruit consumption quintupled, and fish consumption doubled (Huang and Bouis 1996). Similar patterns were seen in Japan and Korea as household incomes increased.

223. From a bioeconomy point of view, this trend is negative. Large amounts of crop production are dedicated to feed for animal production, and ruminant production has notoriously high GHG emissions (Table 4) and water consumption.

Table 4. The GHG emissions associated with various meat production systems

Product	**CO_2 (eq. per kg)**
Beef	44.80
Idaho + Nebraska beef	33.50
Idaho lamb	44.96
Swedish pork	3.3-4.4
Michigan pork	10.16
Chicken	2.0-4.6
Poultry (United States)	1.4
Cod	3.2
Farmed salmon (United Kingdom sea-based)	3.6
Farmed salmon (Canada sea-based)	4.2
Farmed salmon (Norway sea-based)	3.0
Farmed trout	4.5
Capture fish (global average)	1.7

Source: OECD (2015a)

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Beef production

226. The Australian beef industry today sees "*unprecedented demand from the entire Asia Pacific as well as the Middle East*" (Kondo 2014), whereas before the demand was mostly from Japan, and then later

China. But beef production is resource intensive in terms of land, feed, water. It also creates large GHG emissions. Therefore measures that improve beef production efficiency are being sought. Genomics offers some solutions.

227. Genomics has been propagated as a “paradigm shifting” innovation in livestock production during the last decade. The possibility of predicting breeding values using genomic information has exerted major changes within the dairy cattle industry. This technology is now being implemented in beef cattle. A challenge in the development of genomic tools for beef cattle selection, however, is in the diversity of breeds represented in the industry.

228. There is large scope for the development of novel applications in the livestock sector, such as selection tools for new traits (meat quality, diseases resistance, feed efficiency, heat tolerance), animal traceability and parentage verification (e.g. McClure et al., 2013). Efforts in sequencing important animals in the global beef industry are underway to identify variants and to associate those variants with the genetic variation observed across beef populations.

229. Beef cattle selection for protein production requires appropriate emphasis placed on economically relevant traits (ERT). Most ERT are quantitative traits. Examples of traits that fit these criteria are early life growth traits and carcass quality attributes. These traits are output ERT which impact revenue. There are many ERT that are left out of breeding objectives because the capacity to collect data in the field does not exist or the cost of data collection is too high to do so in the quantity needed to support a national evaluation programme. Many of these ERTs affect input costs of production such as animal health, feed efficiency and adaptability. These traits are fertile ground for the application of genomics technology. There is also great scope for increased international collaboration in all livestock species (Pollak et al., 2012).

230. It is also feasible to postulate that in the near future the artificial reproductive technologies (ART), such as artificial insemination, embryo transfer and in vitro fertilisation, combined with genomic evaluation (GE) approaches will be the driving forces to lead cattle breeding to a finer process than it is nowadays. On the one hand, GE-improved methods will make it possible to know which gene alleles are the exact ones desired for a given type of animal.

231. On the other hand, ART will enable checking for the presence of these favourable alleles in early stage in vitro produced embryos, making the whole selection and breeding process much more accurate. It is also foreseen that the development of specific “genomic-audited” lineages, carrying specific and interconnected alleles selected inside the traditional breeds, will offer better chances to the livestock industry to produce the animal required for each type of application, fostering quantity and quality parameters.

232. The Department of Agriculture, Food and the Marine of the Irish government has a *Beef Data and Genomics Programme* (BDGP) for 2015 – 2020.[42] The EUR 300 million programme is addressing the widely acknowledged weaknesses in the maternal genetics of the Irish suckler herd, and will make a positive contribution to farmer profitability and reduce the greenhouse gas intensity of Ireland’s beef production. An objective of the programme is to place Ireland at the forefront of climate friendly agriculture and further the positive environmental image of Irish beef production, which is considered to have added value to Irish beef in high value markets around the world.

42 https://www.agriculture.gov.ie/farmerschemespayments/beefgenomicsschemebeefdataprogramme/beefdataandgenomicsprogrammebdgp2015-2020/

Milk production

233. Genomics studies of milk have varied goals, underlining the significance of milk as a human food. Topics include: the capacity of milk to manipulate the gut microbiota; manipulation of bovine milk fat; genetic selection for economically important traits; and diagnostics. The dairy industry has been revolutionised by genomics (for a review, see Hayes et al., 2009), where genetic tests are used to select every bull that sires milk-producing cows. Traditionally, a breeder would have to breed the bull with a cow, wait nine months for calves to be born, then wait another three years until the calves begin lactating to know whether the bull produces higher milk-yielding offspring. Genetic testing doubles the speed of achieving those same milk production gains (Darcé, 2010).

234. Molecular mechanisms responsible for variations in the components of milk require further investigation given the importance of these processes for human nutrition. A very important economic trait is protein content. In dairy cattle, the heritability of milk protein yield has been estimated to be approximately 23%. If the polymorphisms contributing to milk traits were identified, this information could be used in breeding programmes to increase milk protein yields, with obvious economic and societal benefits. Furthermore, identification of the gene pathways involved would contribute to the understanding of the mechanisms that regulate lactation and to the development of new approaches to improve milk production and the value of milk proteins for human nutrition.

235. Raven et al. (2013) produced evidence supporting a role for the RNASE5 pathway in milk production, specifically milk protein percent (and not other traits such as fat content or fertility). The evidence indicated that polymorphisms in or near these genes explain a proportion of the variation for this trait. Moreover, the gene set method that they applied to the RNASE5 pathway could be used to rapidly assess the role of other emerging pathways and functions with a genetic validation relevant *in vivo*.

236. An important application of bacterial genomics is to improve control of the microbiological safety and quality of food products. This is particularly relevant to milk to ensure that it is free from pathogenic bacteria and that the concentration of spoilage microorganisms is as low as possible (Marco and Wells-Bennik, 2008). Human pathogens that have been detected in raw milk include *Campylobacter jejuni*, enterohaemorrhagic *Escherichia coli*, *Salmonella* spp., *Listeria monocytogenes*, *Bacillus cereus* and *Yersinia enterocolitica*.

237. Non-pathogenic bacterial species determine the milk quality and limit the shelf-life by the production of off-flavours, unwanted acidification, and structure defects. Culture collection and model strains are instrumental for gaining knowledge on the behaviour of food-associated bacteria. However, the behaviour of “wild” strains in a dairy environment can differ significantly from the laboratory-adapted reference strains. Therefore, it is important to obtain genome sequences of additional dairy isolates, to better understand their survival, persistence, and pathogenic potential.

238. The International Milk Genomics Consortium[43] aims to accelerate the understanding of the biological processes underlying mammalian milk genomics. It organises the annual International Milk Genomics and Human Health Symposium to promote the advancement of milk genomics, proteomics, metabolomics and bioinformatics knowledge tools. The symposium facilitates communication between scientists, sponsors and others to accelerate progress and identify commercial opportunities.

43 http://milkgenomics.org/

Chicken as a food source in a bioeconomy

239. Chickens are a major source of protein in the world, with around 20 billion birds alive today, producing around 1.2 trillion eggs[44]. It was the first livestock species to be sequenced and so leads the way for others (Burt, 2005). It is an excellent food source in bioeconomy terms as its production is relatively low in GHG emissions (Table 4), and is cheaper to produce and less energy intensive than rearing lamb, beef or pork.

240. In parallel with the chicken genome sequencing project (Hillier et al., 2004), a consortium set about identifying single nucleotide polymorphisms (SNPs[45]). When a large number of these are verified, the availability of a standard set of 10 000 or more SNPs holds much promise towards the identification of genes controlling quantitative trait loci (QTL), including those of economic interest.

241. During the past 80 years, modern selective breeding has made spectacular progress in both egg and meat production traits. Associated with these successes have been a number of undesirable traits. These impose added costs on the industry which it is striving to control. The consumer wants high-quality products, such as increased egg shell strength. With an increased requirement for food safety, there will be a need to reduce the use of chemicals and antibiotics and increase genetic resistance to pathogens. These new traits are difficult and costly to measure by conventional genetic selection, and the developments in poultry genomics in the last few years promises new solutions to these problems. Therefore genomics research may be expected to be directed at these 'sustainability' criteria.

242. One of the key traits improved every year through selective breeding is feed efficiency (Figure 15) – the number of kilos of animal feed needed to produce a kilo of poultry meat (Technology Strategy Board, 2010). Genomic technologies are expected to enhance this trend. Since animal breeding is cumulative, even small enhancements to the rate of improvement can multiply into huge differences for commercial customers over time and have very large impacts. The result of this is that more people can be fed from the same land resources or land resource can be freed up – for example for biomass production for industrial use.

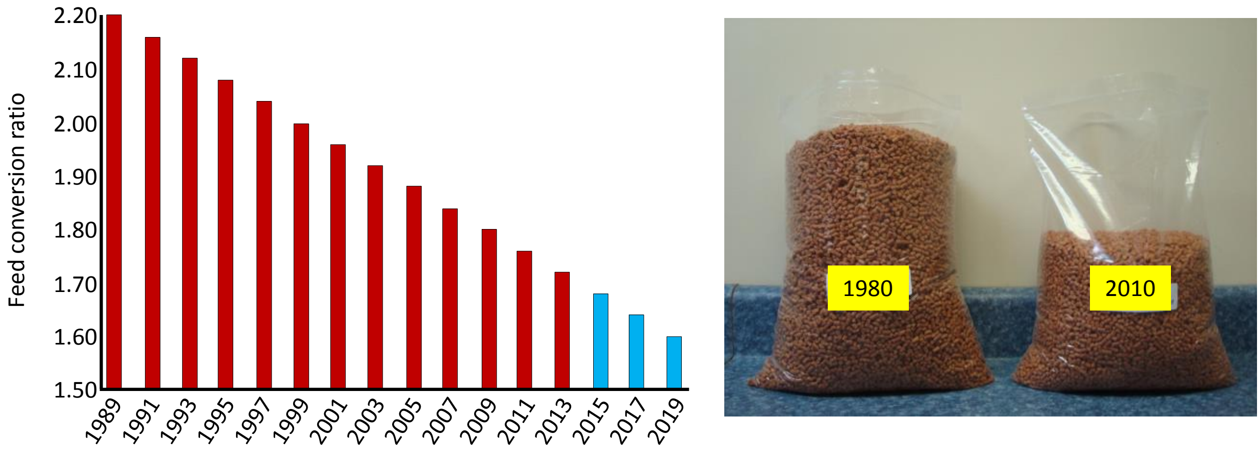
44 http://www.bbsrc.ac.uk/news/food-security/2013/130404-f-what-lives-inside-a-chicken.aspx

45 A SNP represents a difference in a single DNA building block, called a nucleotide. http://ghr.nlm.nih.gov/handbook/genomicresearch/snp

Figure 15. Selective breeding of poultry for higher meat production and more efficient feed conversion

(a) Feed conversion ratio over 30 years in meat-producing broilers at 42 days

(b) Broiler feed to produce a 2.5 kg chicken at 42 days



(a) (b)

Source: Jimenez-Sanchez, G. (2015). Presentation at the OECD workshop "Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry"

243. The Aviagen[46] genomics project, for example, is concerned with identifying naturally occurring markers within the genome of elite birds and using those markers to help breed stronger and more productive birds through the current selective breeding programme, a completely natural process. Aviagen became the first company to include genomic information as a critical additional source of information in a R&D breeding programme.

Fish and food security

244. Between 1998 and 2008, global exports of fish products doubled to a value of over USD 100 billion. It is estimated that over 20 000 species of fish are used for food. Of a total global fishers (i.e. excluding aquaculture) of over 34 million in 2008, over 8.25 million were in China alone, and over 2.25 million in Indonesia (compare this to just under 13 000 in Norway). Per capita consumption of fish continues to rise – from 10 kg in the 60s to more than 19 kg in 2012 (UN FAO, 2014).

245. From the bioeconomy perspective, fish protein relieves pressure on land as the source of biomass for both agricultural and industrial uses. Given the health benefits and the lower GHG emissions associated with fish (Table 4), then increased fish consumption would appear to be desirable for a future bioeconomy.

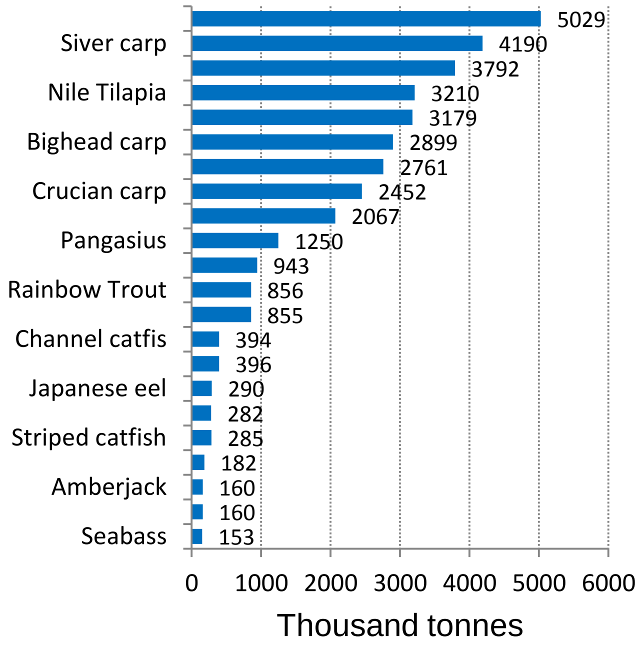
246. Overfishing has reduced some fish stocks to near extinction, and destructive fishery practices, such as bottom trawling, have damaged the habitat of the ocean floor. Coastal development and the resulting domestic and industrial wastes continue to perturb marine ecosystems and to threaten coastal habitats in some areas. In extreme cases, agricultural pollution has resulted in hypoxia, which weakens established ocean ecosystems and sometimes leads to permanent 'dead zones'.

46 http://en.aviagen.com/research-development/

247. About 90% of global wild fish stocks are already at capacity or are in precipitous decline[47], with 60% of wild stocks fully fished, 30% overfished (UN FAO, 2014). Wild fisheries should therefore be regarded as 'not necessarily renewable'. Well-reported universal difficulties associated with wild fisheries are related to fish species identifications e.g. species with limited diagnostic morphological features, cryptic species, juvenile identification, or unavailability of adequate drawings and descriptions.

248. Aquaculture has continued to grow in volumes and species (Figure 16) as a consequence of deeply troubled wild fishing and increasing demand for fish, with a total of 66.6 million tonnes in 2012 (compared to 91.3 million tonnes for wild fish).

Figure 16. Top 20 finfish from aquaculture species and tonnages.



Source: UN FAO, 2012.

249. However, more instructive is the rate of growth of aquaculture. From 2007-2012, the aquaculture industry grew by 33.5%, whereas capture fishing grew by a mere 0.6% (thus is effectively static). Continuing future increases in demand are likely as the global middle class explodes (D'Hondt et al., 2015), and it is most likely that most of the future growth will have to come from aquaculture.

250. The benefits arising from the rapid growth in aquaculture have been accompanied by serious environmental, social and production challenges. Reliance on fish feeds remains an issue in most countries as they are often derived from scarce wild resources. There are also constant challenges in terms of fish health, rearing and containment. To grow and fulfil the promise of a 'blue revolution', aquaculture will need to balance its long-term environmental sustainability with its present goal of growing large fish rapidly. Marine biotechnology offers some solutions.

47 http://www.bbc.com/news/business-33068446

Biotechnology in the capture fish and aquaculture industries industry

251. The increased availability of hardware, software and genetic information in the last decade has opened up possibilities for biotechnology to contribute to both capture fishing and aquaculture. Many of these applications are not related to GM technologies and therefore are unlikely to cause public resistance.

Triploid oyster and mussel

252. Since the early 1970s attempts have been made to produce triploid clams, salmon or rainbow trout. Triploid organisms have three sets of chromosomes instead of the usual two. Triploids are generally sterile, which makes them grow faster because they do not have to put energy into reproduction. Triploid, therefore sterile, shellfish also have the advantage that spawning after harvesting is prevented (spawning makes them unsuitable for the market).

253. Triploid oysters are available throughout the year and the fact that they grow more rapidly also make them more resistant to pathogens. The generation of triploid seed is done in restricted sites in hatcheries. These natural oyster triploids were after only nine months of growth as much as 50% larger than normal diploid oysters, and a third larger than induced triploids. Now most of the oyster seed supplied by commercial hatcheries for cultivation is triploid, produced using various methods in the US. In France in 2008 triploid oyster cultivation took about 30% of market share. The market share of triploid oysters in the Netherlands is also increasing and in addition also triploid mussels are finding their way to the market.

254. Triploid shellfish have a clear economic and environmental advantage. Once production methods and resulting products have been approved for use and consumption, the technology used should not be the determining factor for acceptance or rejection. The power of biotechnology is that it can accelerate breakthroughs to deal with diseases or other stress factors and increase yields, thereby ensuring environmental and economic sustainability. In particular, access to genome editing is opening new ways.

Capture fishing: traceability is becoming an urgent issue

255. Almost 34% of the world's fisheries catch from 1950–2002 lacked species level identification. The use of DNA barcodes for species delimitation, and the availability of a standardised and globally accessible database (Barcode of Life Data System, BOLD)[48], facilitates numerous related applications, including issues relating to traceability, eco-labelling, illegal fishing and fish fraud (Costa et al., 2012), and more fundamental information such as migration and dispersal behaviour (Box 8). A common fraudulent practice is species substitution, which can be unintentional or intentional for tax evasion, for laundering illegally caught fish or for selling one fish species for a higher-priced species. Illegal, unreported and unregulated (IUU) fishing remains a major threat to marine ecosystems (UN FAO, 2014). Traceability is becoming an increasing urgent need.

48 www.barcodinglife.org

Box 8. Atlantic herring identification through genomics

Herring has been an important food source for hundreds of years over a very wide distribution. For many decades, it has been in dramatic decline. The Pacific herring, however, has sustained low abundances even after reductions of fishing pressure. Offered reasons include: climate-induced ecological changes in distribution of predators and prey; disease; overfishing, and; the rebound of marine mammal populations that prey on herring (McKechnie et al., 2014). A study of Atlantic herring on the Gulf of Maine – Georges Bank indicated that predation mortality rates were relatively low during the 1960s, when Atlantic herring were abundant, but increased in the late 1970s and early 1980s, when Atlantic herring declined. Predation mortality rates declined in the 1990s as Atlantic herring abundance increased. Sustainable fisheries management for herring is therefore extremely complicated. In addition, herring are generally highly migratory (Overholtz et al., 2008). This further complicates fish stock management, which requires precise and accurate data on the population identity of harvested fish to maximise long-term fisheries yield at minimal risk to population viability.

The risk associated with failure to identify individual populations in herring stock assessments is well known. Weak levels of differentiation among populations have prevented accurate assignment of individual fish to specific origins. Genomic resources, especially single nucleotide polymorphisms (SNPs) heralded the identification of Atlantic herring to unprecedented levels of geo-localisation in this weakly structured fish.

Bekkevold et al. (2015) extended the utility of the existing genetic techniques for herring. They demonstrated the applicability of Genetic Stock Identification (GSI) and showed that the approach can be used as an adaptive tool to address biodiversity indicators applicable to natural resource management, and also to address control of illegal fishing and mis-labelling.

The practical advantages of DNA-based identification include the ability to use a range of fresh, preserved, or highly processed material, hence allowing samples to be collected by non-experts with relatively little cost and effort. The method is also transferrable across laboratories and SNP genotyping platforms, and can readily be extended for additional populations and (or) genetic markers.

256. About 70% of the global tuna fish catch is taken from the Pacific. Most of the 23 tuna stocks are either over-exploited or depleted. Bluefin tuna are unrivalled in popularity, especially in sushi, and the economic value per fish is unmatched by any other species. However, its over-exploitation seriously threatens its future, and some advocate that consumers should avoid eating Bluefin tuna altogether. Moreover, prices of yellowfin tuna and Pacific bluefin tuna are drastically different. But if they are used in cooking, it is difficult even for experts to distinguish between them. DNA barcoding therefore holds out promise for various policy goals: to reduce fraud, to play a role in cultivating conscientious consumerism (by helping threatened species conservation) and to effectively regulate by eliminating market ambiguity (Lowenstein et al., 2009).

257. To date, no one technique is perfect in its ability to identify species at the molecular level. However, DNA barcoding analysis is a significant advancement upon previous DNA techniques because it is based on a universal methodology (Hanner et al., 2011). It has been argued that linking DNA barcoding to a universally accessible, expert-authenticated database of species identification data would address many of the problems that plague the current system of species authentication (Clark, 2015).

Monitoring invasive species

258. Invasive species are introduced organisms outside their natural (past or present) range of distribution, and outside their natural dispersal potential, which might survive and subsequently reproduce. They can have enormous and long-lasting impacts on a region in terms of biodiversity (Darling and Piraino, 2015), and hence on economic impact if they damage or displace economic species populations.

259. The combination of reductions in the cost of acquiring genetic data and the rapid recent technological and analytical developments has resulted in molecular methods becoming increasingly important in investigations of biological invasions, from simple biodiversity assessment to historical reconstruction of invasion histories.

260. For example, Comtet et al. (2015) described how high throughput sequencing (HTS) enables the expansion of DNA barcoding to DNA "meta-barcoding", which rapidly and inexpensively characterises entire biotic communities. This creates unique opportunities for describing, potentially in great detail, changes in marine biodiversity associated with biological invasions. In practical terms, meta-barcoding may be used at multiple stages of the invasion process, to enable early detection of introduced high-risk marine pests, and tracking the effectiveness of control strategies in a more cost-effective manner. The authors see this as "*crucial in the implementation of early warning strategies*".

Aquaculture and genomics

261. Aquaculture production has continued to grow annually at around 6-8%. Today, farmed seafood production (around 60 million tonnes) exceeds that of wild fisheries and has significant potential for future growth. World aquaculture is heavily dominated by the Asia–Pacific region, which accounts for roughly 90% of production, mainly due to China. In 2008, 85.5% of fishers and fish farmers were in Asia, compared to 1.4% in Europe and 0.7% in North America (FAO/WHO, 2010). However, much remains to be done in productivity in Asia: fish farmers' average annual production in Norway is 172 tonnes per person, while in China it is 6 tonnes and in India only 2 tonnes.

262. High priority traits for farmed fish are the development of single sex populations and improving disease resistance. Production of mono-sex female stocks is desirable in most commercial production since females grow faster and mature later than males. Understanding the sex determination mechanism and developing sex-associated markers will shorten the time for the development of mono-sex female production, thus decreasing the costs of farming.

Tilapia

263. Nile Tilapia is one of the most important farmed species with a production exceeding 2.8 million metric tonnes in 2010. Tilapia farming is increasingly important in Asia, with (at least) Bangladesh, China, Indonesia, Malaysia, Myanmar, the Philippines, Thailand and Vietnam all producing significant tonnages. Most Asian countries do not export significant amounts of Tilapia, demonstrating its role in food security.

264. Tilapia is unusual in that intensive commercial production generally requires all-male stocks, not only because males grow faster but also to avoid uncontrolled reproduction before harvest. A restriction associated DNA (RAD) sequencing study by Palaiokostas et al. (2013b) identified a reduced candidate region for the sex-determining gene(s) and a set of tightly sex-linked SNP markers. Although they could not identify the causative gene(s), no female was mis-assigned using their sex-associated SNPs. This means that those SNPs could be of high practical value towards the production of all male stocks for the Tilapia aquaculture industry.

Halibut: a high value fish to diversify aquaculture

265. Atlantic halibut (*Hippoglossus hippoglossus*) aquaculture began in the 1980s but many challenges had to be overcome. It is white-fleshed fish with high market value and demand, and is an excellent species to complement and diversify the aquaculture industry[49]. In addition, the shelf-life of fresh, head-on gutted halibut is up to three weeks on ice, much longer than most fish.

266. In common with some other commercial fish, female halibut are preferred for farming as they mature quicker, thus are faster to reach market size (3-5 kg) than males. With daily feeding required for 24-36 months, sex sorting for exclusively female populations therefore saves money. Like the strategy for

49 http://www.aquaculture.ca/files/species-halibut.php

producing male Tilapia, Palaiokostas et al. (2013a) described assays for sex-associated DNA markers developed from RAD sequencing analysis to help implement single-sex female halibut production.

Salmon genomics: a very special case

267. Salmonids, in particular Atlantic salmon, are amongst the most important aquaculture species. In 2010, approximately 1.5 million tonnes of Atlantic salmon were produced from farms worldwide, corresponding to a value of just over USD 7.8 billion (UN FAO, 2010). It is an important bioeconomy species due to the low GHG emissions associated with farming salmon. There are still outstanding challenges to the industry that cost hundreds of millions of dollars in lost production, such as reducing unsustainable fish losses, and controlling or eradicating sea lice and salmon Rickettsia septicaemia.

268. The genomic resources for Atlantic salmon are amongst the most extensive of all aquaculture species, and include several genetic maps, a physical map, an extensive EST database of approximately 500 000 tags and several microarrays (Gonen et al., 2014). In June 2014, the International Cooperation to Sequence the Atlantic Salmon Genome (ICSASG) announced completion of a fully mapped and openly accessible salmon genome[50], which is housed at its own website[51]. Some of the expected outcomes of this research are: understanding the attacks by viruses and pathogens on salmon and to produce new vaccines to reduce losses through disease; applications for food security and traceability and brood-stock selection for commercially important traits; and better understanding of the interactions of farmed salmon with wild counterparts.

269. Selective, marker-assisted breeding (possible due to access to the genome) of salmon will be more targeted and efficient. This could, for example, select for individuals that are more resistant to disease and parasites, and select fish that grow more quickly whilst being adapted to new feed types. In the longer term, genomic knowledge should help streamline the aquaculture industry while providing consumers with healthier farmed salmon, produced with as little environmental impact as possible.

270. The power of marker assisted breeding is illustrated with the success in breeding salmon resistant to sea lice infection[52] or Infectious Pancreatic Necrosis (IPN) virus.[53] Not only can the use of pesticides and antibiotics be omitted, but losses are also greatly decreased. Survival rates of salmon in aquaculture of just a few per cent higher translate into major earnings for the Norwegian aquaculture industry, where the annual turnover is NOK 45 billion (approximately EUR 5.6 billion, or USD 7.6 billion).[54]

271. In the case of salmon, then, the power of relatively small public research funding of genomics to transform an industry is illustrated. In this case, many of the problems of the industry can be addressed through a single tool, which makes genomics unique as a solution provider.

Vaccines and the end of the antibiotic era

272. Marine biotechnology, in the form of new vaccines and molecular-based diagnostics, has already helped to increase production, reduce the use of antibiotics and improve fish welfare (Sommerset et al., 2005). In many places, the use of antibiotics has plummeted. In Norway 99% of farmed salmon are

50 http://www.genomebc.ca/news-events/news-releases/2014/scientific-breakthrough-international-collaboration-has-sequenced-atlantic-salmon-genome/

51 http://www.icisb.org/atlantic-salmon-genome-sequence/

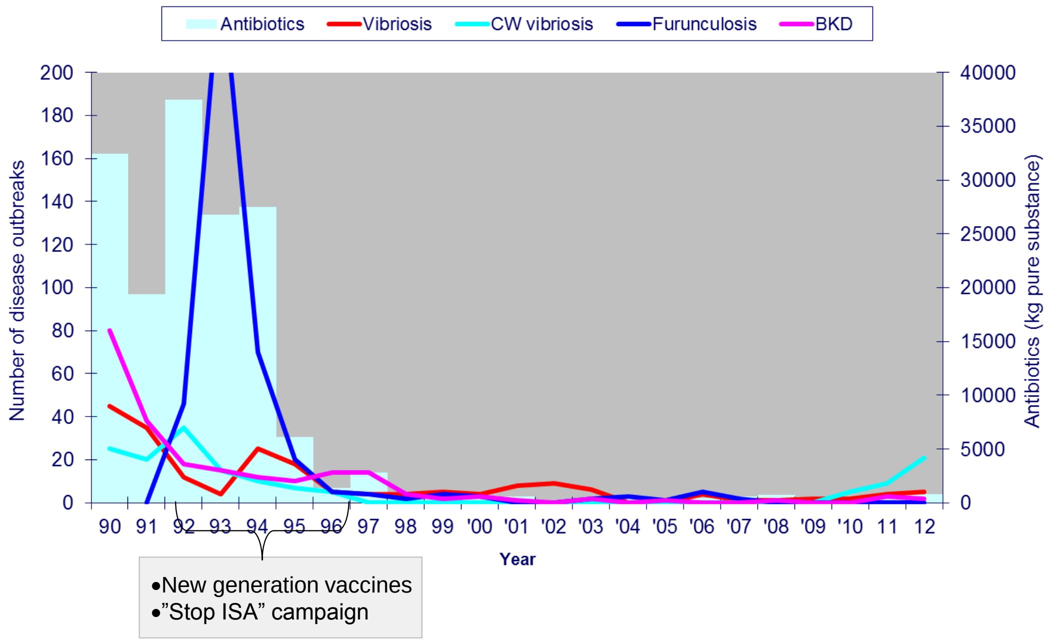
52 www.gla.ac.uk/news/headline_416474_en.html

53 www.worldfishing.net/news101/industry-news/aquagen-identify-ipn-resistance-gene

54 www.sciencedaily.com/releases/2014/06/140611093238.htm

produced without the use of antibiotics (Figure 17). In other countries, however, especially developing countries without access to molecular-based tools and technologies, use of antibiotics remains widespread (Cabello, 2006).

Figure 17. The end of the antibiotic era in Norwegian salmon farming.



Source: Magne Rødseth (2015)

273. Genomic and related technologies have also been used to create new DNA-based vaccines for economically important diseases (e.g. Apex®-IHN, Novartis, for the treatment of infectious hematopoietic necrosis in farmed salmon) and highly sensitive specific tools for disease detection (Cunningham, 2002).

Molecular aquaculture

274. The application of new genomic knowledge and technologies to the practice of aquaculture is termed "molecular aquaculture" to help to distinguish it from the more production-oriented activities in aquaculture such as improved feeding systems, cage design and husbandry. Molecular aquaculture is characterised by the incorporation of new omics knowledge, high-throughput genomics technologies and recombinant DNA technology. These technologies have facilitated selective breeding for economically important traits such as body shape or disease resistance.

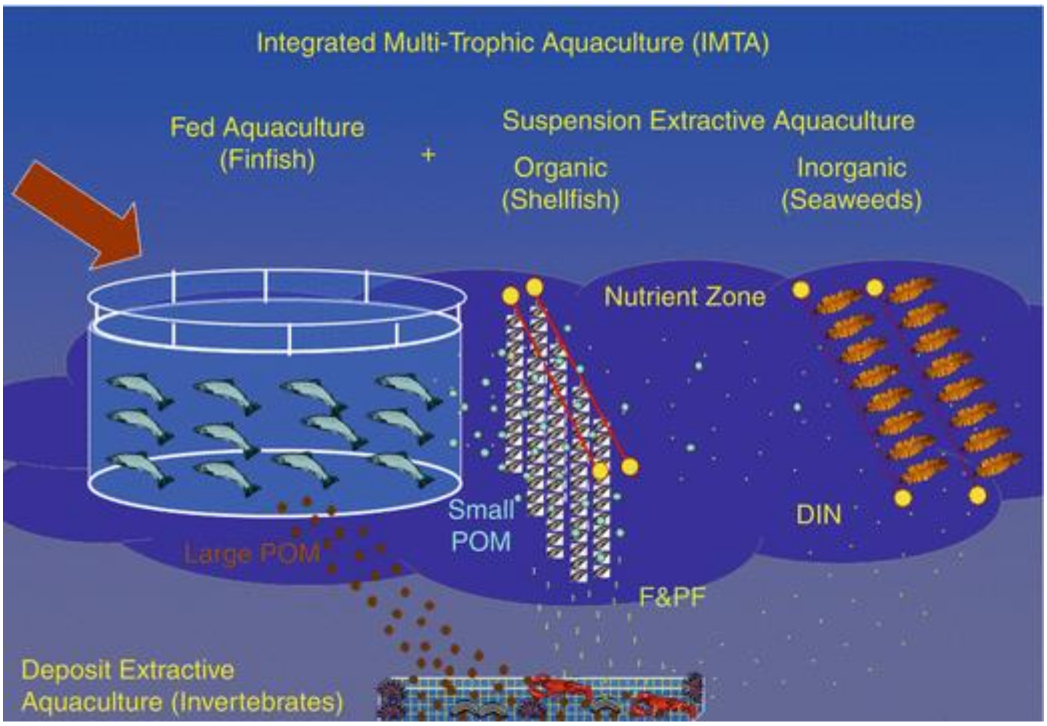
275. Molecular aquaculture holds great potential for increasing sustainable food production to meet anticipated increases in global demand through the culture of species such as salmon, Tilapia, shrimp and oysters. However, molecular aquaculture is developing and diffusing at different rates in different countries, potentially limiting the productivity gains and sustainability of the endeavour.

Integrated Multi-Trophic Aquaculture (IMTA)

276. While molecular aquaculture is key to the development of new approaches to maximise yields and minimise input while guaranteeing environmental sustainability, new production methods will further contribute to this. Integrated Multi-Trophic Aquaculture (IMTA) is a promising aquaculture approach that, by integrating the culture of fed species (such as finfish and crustaceans), inorganic extractive species

(such as seaweeds), and organic extractive species (such as suspension- and deposit-feeders), can minimise the negative effects of aquaculture on natural ecosystems (Figure 18). IMTA has been proposed for mitigating aquaculture waste release, and has advantages that may include a reduced ecological footprint, economic diversification and increased social acceptability of culturing systems (Sorgeloos et al., 2011).

Figure 18. Conceptual diagramme of an integrated multi-trophic aquaculture (IMTA) operation combining fed aquaculture (finfish) with organic extractive aquaculture (shellfish), taking advantage of the enrichment in particulate organic matter (POM), and inorganic extractive aquaculture (seaweeds), taking advantage of the enrichment in dissolved inorganic nutrients (DIN).



Source: Barrington et al. (2009)

Hybrid technologies for aquaculture/agriculture

277. The possibility has been discussed of building solar-powered desalination plants in hot, sunny climates (Palenzuela et al., 2015). A hybrid system combining solar-powered desalination with a "floating farm" has been described in concept (Moustafa, 2016). Construction of such a system (a 'bluehouse' rather than greenhouse) offshore would relieve pressure on land as this concept envisages growing crops that need freshwater rather than seawater. In other words, it is about moving terrestrial crop production offshore.

Genetic modification in aquaculture

278. Much more controversial than genomics and traditional vaccine development, GM technology has already been applied to salmon breeding. GM technology varies widely in its acceptability in different countries. In the US, the Food and Drug Administration (FDA) has approved the first GM salmon, which contains a growth hormone gene from a related species which allows the salmon to grow to market size in 16 to 18 months rather than three years. As a result, it consumes at least 25% less feed over its lifetime than conventionally farmed salmon, thus saving money, which could mean, if it reaches the market, lower prices for the consumer.

279. The US FDA began its review of this technology (AquAdvantage[55]) in 1993. In 2012, it concluded that AquAdvantage was safe for human consumption and was unlikely to damage the environment. A lengthy public consultation ensued[56], during which the salmon was not available to consumers. Finally, on 19 November 2015 it became the first genetically engineered animal to be approved for human consumption in the US (Ledford, 2015).

Feeding the fish that feed humans

280. Well-described benefits of eating oily fish come from the long-chain polyunsaturated fatty acids (LC-PUFA) commonly referred to as omega-3 fatty acids. They are, however, not synthesised by the fish themselves; rather, the synthesis is done by single-celled algae and the molecules then pass up the food chain to small, herbivorous fish and thence to large, carnivorous ones (*The Economist*, 2015).

281. Paradoxically, farmed fish such as salmon are fed fish meal, made from wild-caught oceanic species such as anchovies that are not in great demand as human food, in order to boost their levels of the two critical omega-3 fatty acids, docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA). The aquaculture industry needs to find new fish food sources, particularly to replace or supplement these high-quality inputs currently derived from fishmeal and oil, as this is increasingly seen as a limitation for future growth in aquaculture production (McAndrew and Napier, 2011).

282. More than one strategy to do this is being is investigated. First, there exists the possibility of genetically engineering plants to modify seed oil composition[57] to include omega-3 PUFAs, and the collective data available (e.g. Usher et al., 2015) confirm the promise of transgenic plants. However, while levels of EPA achieved are equivalent to marine sources, DHA still represents a challenge.

283. Rather more controversial would be to engineer the fish to make omega-3 fatty acids directly. One study in which zebrafish were transformed with a salmon desaturase, led to modestly increased tissue levels of EPA and DHA (Alimuddin et al., 2005). While zebrafish is a model organism, Tilapia is an aquaculture species. Work at the of the Institute of Cellular and Organismic Biology in Chinese Taipei is examining the possibility of metabolic engineering in Tilapia to express high levels of omega-3 PUFA biosynthesis genes in the liver.

Crop genomics and precision crops

284. Feeding the nine billion people on the planet by 2050 is a major food security issue. Moreover, the demand for biomass for bio-based production of fuels, chemicals and plastics will further stress land availability and productivity. The effects of climate change will exacerbate the difficulties facing conventional agriculture. Although seldom acknowledged in discussions of agricultural genetic resources, soils are the critical life-support surface on which all terrestrial biodiversity depends. Meanwhile, world-wide soil is being lost at a rate 13 to 80 times faster than it is being formed. It takes in the regions of 500 years to form 25 mm of soil under agricultural conditions, and about 1 000 years to form the same amount in forest habitats.[58] In the face of soil destruction, more crops will have to be grown more efficiently, while methods are also explored to halt or limit soil destruction.

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55 http://aquabounty.com/

56 http://www.businessinsider.com/this-salmon-will-likely-be-the-first-gmo-animal-you-eat-2014-6?IR=T

57 Over 400 different fatty acids have been identified in seed oils although, remarkably, none have been found to contain the very long chain omega-3 fatty acids.

58 Food and Agriculture Organisation (FAO), www.fao.org/sd/epdirect/epre0045.htm

285. There are many applications of genomics to crop production that will be utilised in the future bioeconomy e.g. pest resistance, more “efficient” plants that use less water, resistance to environmental stresses, the development of crops that can fix nitrogen to replace synthetic fertilisers. Heat and drought stress are used as examples of the potential of the application of genomics to agriculture. On the other hand, too much water in the case of rice can also lead to crop destruction.

286. The examples of crops used here are not typically crops of the advanced economies. The front line in food security is elsewhere, and the crops described here – rice, banana and oil palm – are vital to food security.

Heat and drought stress: an increasingly important problem associated with global warming

287. Agricultural productivity is ultimately defined by crop yield. Recent agronomic and economic studies indicate that yield losses most significantly attributable to environmental stresses such as drought and heat occurred over the growing season of many staple crops such as corn, soybean, rice, and wheat. Independent drought or heat stress make measurable negative impact on their eventual yields. However, combined stresses of heat and drought trigger multiple-folds of higher damage in crop productivity than a single stress. Therefore, improvement of dual stress tolerance to heat and drought in crop plants has become a top priority for the development of agricultural biotechnology for both food and bioenergy markets.

288. Performance Plants, a Canadian company, has identified and completed functional studies of a subset of target genes that constitute a novel regulatory cascade that controls plant responses to the combined stress. In laboratory conditions, *Arabidopsis* and canola plants with missense expression of these regulatory genes were able to tolerate independent higher temperature or drought treatment. More importantly, these plants produced higher seed yield comparing to their controls when both stresses were applied simultaneously. The dual stress tolerance and yield enhancement properties of the transgenic plants were further confirmed by large-scale, multiple season and location field trials. These results represent a significant breakthrough in crop improvement and technologies derived from this research could enable farmers around the world to maintain higher yield and productivity over variable and adverse environmental conditions.

Rice, the iconic crop of Asia

289. Rice is the major staple food for almost half of the world’s population. Perhaps more than any other, rice is a defining crop of Asia. It has naturally been the model cereal for genetic, breeding and agronomic research. This is a fortuitous choice: rice has a small genome, it is easily transformed and there are similarities of its gene order and gene sequence with other cereals (Upadhyaya and Dennis, 2010).

290. Conventional breeding over the last three decades has resulted in a doubling of rice production. However, breeders are in need of new tools and resources with which they can address the major production constraints such as pests, pathogens, submergence, salinity and drought in order to provide the required increase in the rate of production. Rice genomics has the potential to provide such tools and resources in the form of molecular markers for genes and gene control sequences determining the desired traits or as genes and gene control sequences *per se* for use in transformation breeding.

291. Regarding climate change and other abiotic threats to crop production, a major challenge is identifying genes involved in complex traits of agronomic significance. It is likely that there will be many genes with some effect in abiotic stress, and pinpointing critical genes will require inputs from all aspects of genetics and genomics. These characteristics will be of critical importance in altered environments caused by changing climate.

292. Major success has been achieved in using genomics to select rice strains to tolerate submergence, an abiotic effect of increasing importance due to increasing instances of flooding as a consequence of climate change.

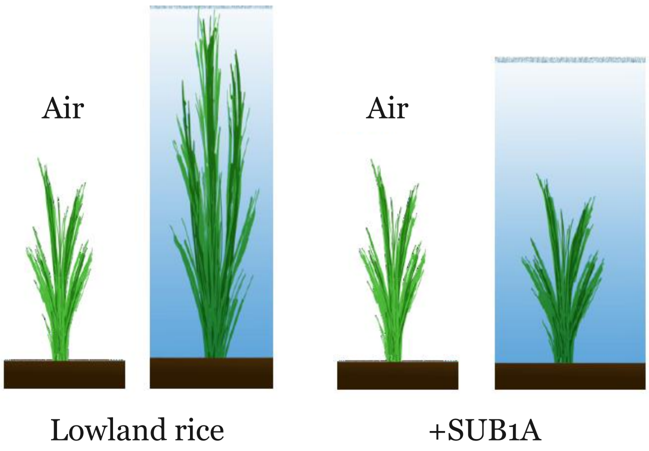
Rice and submergence tolerance

293. Rice is a crop well adapted to wet, monsoon climates and allows farmers to produce food in flooded landscapes. Of the lowland rain-fed rice farms worldwide, over 22 million hectares are vulnerable to flash flooding, representing 18% of the global supply of rice. In total, some 30-40 million hectares get submerged, and this happens roughly every three years. Most rice varieties can tolerate only a few days of submergence and die after about a week.

294. Success in fine mapping of SUBMERGENCE 1 (SUB1), a robust quantitative trait locus (QTL) on chromosome 9 from the submergence tolerant FR13A landrace, has enabled marker-assisted breeding of high-yielding rice capable of enduring transient complete submergence (Bailey-Serres et al., 2010). It provides protection from complete submergence for 3-18 days. SUB1 belongs to the Ethylene Responsive Family (ERF) transcription factors (Xu et al., 2006). It functions by slowing down growth, preserving chlorophyll and conserving energy reserves.

295. With traditional lowland rice, when flooded the plant reacts by spurring growth to get above the water, continues to grow when the flooding continues, and finally runs out of nutrients and dies (Figure 19). Variety SUB1A does not grow while flooded and starts growing again after the flooding has subsided. In this case a single mutation is involved in tolerance.

Figure 19. Submergence tolerance in SUB1A



Source: Ismail, S. (2015). Presentation at the OECD workshop "Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry"

296. The success of the SUB1A variety is graphically illustrated in Figure 20.

Figure 20. SUB1 enhances recovery after severe flooding damage

Immediately after flooding — Three months later

Source: Ismail, S. (2015). Presentation at the OECD workshop "Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry"

297. SUB1 has been introduced into several mega-varieties of rice through marker assisted selection (MAS) and backcrossing[59] (MABC). Under submergence for 7-14 days these tolerant cultivars have an average yield advantage of 1.5 tonnes per hectare over intolerant cultivars, with no reduction in yield under non-submerged conditions. SUB1 is gradually being introduced to all varieties developed for lowland ecosystems by the International Rice Research Institute (IRRI)[60], and several national programmes are also introducing the gene into locally-adapted varieties. To date, over 4 million farmers have been reached with seeds of SUB1 varieties with the cooperation of the private sector.

Social impacts

298. About 90% of the world's rice is produced and consumed in Asia. Over 70% of the world's poor are in Asia. In Asian countries with subsistence rice farming, when submergence occurs and the rice crop fails, the first most obvious effect is that the farmers' income decreases. Almost the first knock-on effect is that the farmers attempt to save money by taking their children out of school. They may be forced to sell land. Continuing poverty leads to people migrating off the land to find jobs in cities. So the cycle of poverty in the countryside continues.

299. One of the difficult issues encountered is to convince farmers to switch from their traditional varieties to the submergence resistant rice varieties. The strategy taken by IRRI was to convince single farmers to use the sub resistant varieties on one field and when flooding happened the result of this is so convincing (Figure 20) that most farmers around were convinced to switch.

300. There is evidence that the introduction of submergence tolerant rice strains is now decreasing these negative social effects, and efforts are underway in the International Rice Research Institute to try to quantify these effects.

59 Backcrossing is a crossing of a hybrid with one of its parents or an individual genetically similar to its parent, in order to achieve offspring with a genetic identity which is closer to that of the parent.

60 www.irri.org

How governments can help

301. Some of the critical steps that governments can take of are:

- To characterise stress-prone areas and share information with central and state governments for targeted dissemination;
- To map domains to predict seed needs of a particular variety and feedback to partners in the seed chain;
- To monitor progress to identify gaps and needs for process adjustments;
- To assess impacts on farmers' livelihoods and social conditions.

302. There are, of course, other threats to rice crops, and some of these will be complex factors that are not addressable through single gene mutations. Rice is subject to many bacterial, viral and fungal diseases. Without resorting to GM technologies, governments should ensure effective international communication so that advances can be shared where possible.

303. Genomics will only make a difference when closely tied to breeders, and ultimately the involvement of the farmers is needed. Empowering subsistence farmers in this way is likely to optimise the process from discovery to field deployment. By doing so in a timely manner, farmers may be spared from subsequent flooding events and disease episodes.

Banana: a critical crop with many threats

> "*The* Musa *genome sequence is therefore an important advance towards securing food supplies from new generations of* Musa *crops*…"
>
> D'Hondt et al. (2012).

304. Banana as a crop for food security is often overlooked and yet it is the fourth most important food crop in the world. It is a staple in many diets. A large number of people in East Africa consume 1 kg or more per person per day. India and Uganda are the largest producers, but none are exported: the whole crop is required for food security. More than 70 million people in West and Central Africa are estimated to derive more than one-quarter of their food energy requirements from plantains. Banana is the most popular fruit in industrialised nations (Lescot, 2011). But this is all from one variety – Cavendish – and in global terms it is relatively minor. In 2012 the volume of global gross banana exports reached a record high of 16.5 million tonnes, but this represents only some 15–20% of total banana production.

305. However, various pathogens and pests threaten banana crops and its attendant food security (De Lapeyre de Bellaire et al., 2010; Dita et al., 2010). The race against pathogen evolution is particularly critical in clonally propagated crops such as banana. For example, *Fusarium* wilt, known as Panama disease, is a lethal infection caused by the fungus *Fusarium oxysporium*. Once infected, the plant is effectively doomed (Figure 21). *Fusarium* destroyed the Gros-Michel banana plantations in Central America in 1950s. A new strain, Tropical Race 4, identified first in Malaysia, has spread to other South East Asian countries. It is now also in the Middle East and southern Africa. In Queensland, Australia, it threatens to make the AUD 600 million banana industry extinct.

Figure 21. Fusarium wilt

Source: Volkaert, H. (2015). Presentation at the OECD workshop "Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry"

306. Tropical Race 4 attacks not only the Cavendish cultivar, but also many other cultivars grown widely in subsistence farming systems in Africa. What is worse, *Fusarium* spores can persist in soil for many years, so eradication of TR4 will require an approach similar to Ebola outbreaks – tracing all possible infection paths and quarantine.

307. Pest control is also expensive. Up to 50 pesticide treatments a year are required in large plantations against black leaf streak disease (also known as Black Sigatoka), a recent pandemy caused by *Mycosphaerella fijiensis*. The situation is not helped by monoculture: every Cavendish is genetically identical, and all have the same susceptibility to disease. Other major threats for banana include banana bunchy top virus (BBTV), burrowing nematode and banana weevil. More recently, banana *Xanthomonas* wilt (BXW) has emerged as an important bacterial disease that apparently originated in Ethiopia and caused a major disease epidemic in much of East Africa in the last decade. Breeding for resistance to these diseases and pests is one of the major goals in Africa and Asia.

The banana genome and breeding

308. Due to several reasons banana breeding is exceptionally difficult. Very few new varieties have been obtained by crossing (e.g. FHIA-01 Goldfinger, FHIA-03 Sweetheart). A few new varieties have been obtained by mutational breeding (e.g. GCTCV-218 Formosana). But acceptance of the new varieties has been low because of different taste, ripening, cooking qualities. Among the difficulties are:

- Banana is seedless and most clones are also pollen sterile;
- It is very difficult to obtain seed from cultivars;
- It is very difficult to germinate viable seedlings;
- They are relatively large plants with long cycles;
- Inadequate germplasm collection, and vitally;

- The understanding of the genetic mechanism of parthenocarpy[61] and unreduced gametogenesis is completely lacking.

309. The reference *Musa* genome sequence is considered a major advance in the quest to unravel its complex genetics. Having access to the entire *Musa* gene repertoire is a key to identifying genes responsible for important agronomic characters, such as fruit quality and pest resistance (D'Hont et al., 2012). In Southeast Asia, at its origin, wild *Musa* still remains, although the global gene pool information is still missing. Access to wild varieties could lead to identification of resistance markers that can be used against pest attacks through breeding or breed more nutritious hybrids.

310. The potential of natural resistance is very well illustrated in the banana variety Yangambi km5 (Hölscher et al., 2013). This variety is resistant to the nematode *Radopholus similis*, a roundworm that infects the root tissue of banana plants. This roundworm infects banana crops worldwide. The nematodes are invisible to the naked eye, but they can penetrate the roots of banana plants by the thousands. Once infected, these plants absorb less water and nutrients, resulting in yield losses of up to 75%. Lesions in the roots also make the plant more susceptible to other diseases. Eventually, the roots begin to rot. In the final stage of the disease, the plant topples over, its fruit bunch inexorably lost. Analysis of Yangambi km5 indicated this variety produced nine metabolites that are toxic for nematodes. The popular Grande Naine is very susceptible to the nematode infection although it also produces these metabolites, be it much more slowly and in lesser quantities. These findings open new perspectives to use in plant protection.

More information is needed

311. Genomic information on its own is not going to solve problems with bananas, and this should be a general point for policy makers – a large amount of background knowledge is needed before the benefits of genomics can be unleashed. With banana, the issues are:

- There is still an outstanding need to find the relevant populations in the wild;
- Thorough phenotyping is still lacking;
- Making crosses among seeded bananas still has to be done;
- A thorough search for interesting segregating variants is yet to be done e.g. disease resistance, drought resistance, improved yield, unreduced gametes, parthenocarpy.

312. Only then is it useful to apply molecular tools to understand the genetics and developmental mechanisms. Together these measures create the toolbox to create new banana cultivars. This is important intelligence to maintain food security with banana. The tools of genomics are an enormous step forward, but alone they cannot solve the specific problems of the banana crop. It is the marriage of the new and the old that is all-important – the new genomics and the ages-old breeding technologies.

Oil palm genomics and significance to the Malaysian bioeconomy strategy

313. Oil palm illustrates a classic bioeconomy dilemma. It is the most productive oil-bearing crop, accounting for one-third of all vegetable oil and 45% of edible oil worldwide. Although it is planted on only 5% of the total world vegetable oil acreage, increased cultivation competes with dwindling rainforest reserves. Global production of palm oil more than doubled between 2000 and 2012 (UN FAO, 2013). Thus

61 In botany and horticulture, parthenocarpy (literally meaning virgin fruit) is the natural or artificially induced production of fruit without fertilisation of ovules. The fruit is therefore seedless.

the competing imperatives of a bioeconomy are clear to see: creating economic growth while reining in detrimental environmental effects to create a future economy that is sustainable.

314. Palm oil production is central to the economy of Malaysia, employing close to half a million people. Historical statistics indicate that Malaysian palm oil yields have typically appreciated over time, until 2009, when an unexpected break in the long-term national growth pattern occurred which has persisted to the present day. Explanations for the abrupt change are varied, which include a combination of adverse weather, ageing trees and plant disease (USDA Foreign Agriculture Service, 2012).

315. Data indicate that the vast majority of trees have already reached or passed through their peak yielding years. A small but growing problem is a lethal fungal disease. *Ganoderma* has the capacity to cause significant yield losses well before it has actually killed an oil palm, while its spores can spread to ever increasing areas of a plantation once it has been introduced. Therefore very obvious targets for genomics applications would be increasing oil yield and disease resistance. With growing needs for edible and biofuel uses, increasing yield would reduce the rainforest footprint of oil palm.

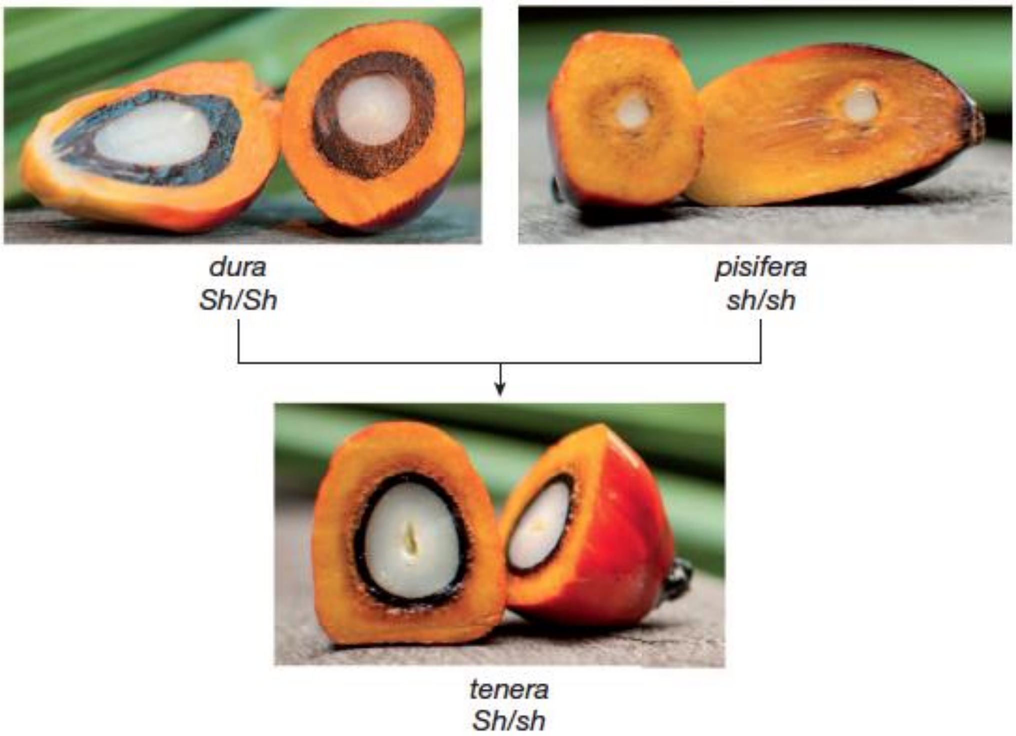
The oil palm genome and oil yield

316. The oil palm is a crop at the front line of the bioeconomy and its sustainability. Many of the economic, social and environmental concerns that are defining concerns for a bioeconomy are seen with this crop. An incident in 2015 exemplifies the seriousness of the concerns. In August 2015 four large groups of Asian companies were excluded from the Norwegian sovereign wealth fund over instances of deforestation in Indonesia (*Financial Times*, 2015).

317. The oil palm genome sequence was published by Singh et al. (2013b). The sequence enables the discovery of genes for important traits as well as alterations that restrict the use of clones in commercial plantings. The oil palm is largely undomesticated and is an ideal candidate for genomic-based tools to harness the potential of this remarkably productive crop. The authors claim that the dense representation of sequenced scaffolds on the genetic map will facilitate identification of genes responsible for important yield and quality traits.

318. The modern oil palm tree *Elaeis guineensis* has three fruit forms: *dura* (thick-shelled); *pisifera* (shell-less); and *tenera* (thin-shelled) (Figure 22). The *tenera* palm yields far more oil than *dura*, and is the basis for commercial palm oil production in all of South East Asia. In 2013 a remarkable discovery was made. The *Shell* gene has proven extremely challenging to identify in oil palm, given the large genome, long generation times and difficulty of phenotyping in experimental populations. Singh et al. (2013a) identified the gene and determined its central role in controlling oil yield. Regulation of the *Shell* gene will enable breeders to boost palm oil yields by nearly one-third, which presents excellent news for the industry, the rainforest and its champions worldwide, and also for bioeconomy policy makers.

Figure 22. Oil palm tree fruit forms



Note: The Shell gene is responsible for the oil palm's three known shell forms: dura (thick); pisifera (shell-less); and tenera (thin), a hybrid of dura and pisifera palms. Tenera palms contain one mutant and one normal version, or allele, of Shell, an optimum combination that results in 30% more oil per land area than dura palms.

Source: Singh et al.(2013a)

319. Seed producers can now use the genetic marker for the *Shell* gene to distinguish the three fruit forms in the nursery long before they are field-planted. Currently, it can take six years to identify whether an oil palm plantlet is a high-yielding palm. Even with selective breeding, 10 to 15% of plants are the low-yielding *dura* form due to uncontrollable wind and insect pollination, particularly in plantations without stringent quality control measures (Cold Spring Harbor Laboratory News, 2013).

320. Accurate genotyping such as this has a critical implication for a bioeconomy. Enhanced oil yields will optimise and ultimately reduce the acreage devoted to oil palm plantations, providing an opportunity for conservation and restoration of dwindling rainforest reserves (Danielsen et al., 2009).

Decoupling agriculture from fossil fuels

321. Nitrogenous compounds in fertilizers are major contributors to waterway eutrophication and GHG emissions, and the Haber-Bosch process for making fertilizers is very energy-intensive. It consumes 3 to 5% of the world's natural gas production and releases large quantities of CO_2 to the atmosphere (Licht et al., 2014). When the price of Brent crude oil rose from around USD 50 per barrel to about USD 110 by January 2013, the prices for ammonia in Western Europe and the Mid-Western corn belt in the US roughly tripled over the same period.[62]

62 http://marketrealist.com/2013/02/brent-oil-moves-nitrogenous-fertilizer-prices/

322. Several efforts are on-going in a tantalising research area – creating plants that make their own fertilizer. A collaborative project with UK and US scientists aims to design and build a synthetic biological module that could work inside a cell to perform the function of fixing nitrogen (National Science Foundation Press Release, 2013). This project aims to re-engineer the cyanobacterial machinery to fix nitrogen using solar energy as a first step towards transferring the machinery into plants themselves. This has the potential to revolutionise agriculture, and significantly decouple it from the fossil fuels industry.

Gene editing could make a paradigm shift in agricultural biotechnology

323. As of early 2015, the EU has granted its member state governments greater power in deciding whether to plant GM crops[63], which are highly restricted in Europe. The new directive may have split the EU policy landscape, with those states clearly opposed, and others in favour (Rabesandratana, 2015). This has come at a time when precision crops are becoming easier to produce through advances in gene editing techniques such as CRISPR/Cas9. Such gene editing techniques are being hailed as low-cost and simple to perform. They are also applicable across all breeding programmes, from large scale row crops to local and minor species (Von Essen, 2016).

324. A regulatory shift may bring the application of gene editing techniques to crop production under less regulatory scrutiny. Regulators often classify these as the product of ‘new breeding techniques’ (NBTs) that are sometimes distinct from classical GM varieties (*Nature*, 2016). Some mutations that are edited into the genome already exist in wild plant relatives in nature, and the argument is then whether crops produced in this way should be treated differently (less stringently) from GM crops by the regulator (Box 9). The implications are being examined in Europe and the US.

Box 9. CRISPR/Cas9 edited mushroom can be cultivated and sold without further oversight in the US

The common white button mushroom (Agaricus bisporus) has been modified to resist browning using CRISPR/Cas9, and can be cultivated and sold without further oversight in the US. The USDA will not regulate a mushroom modified with the gene-editing tool CRISPR/Cas9. The decision means that the mushroom is the first CRISPR-edited organism to be approved by the US government.

Source : Waltz (2016).

325. More controversial still could be the use of gene editing in domesticated animals. Experimental ‘double-muscled’ pigs have been created by scientists in Korea and China by editing a single gene, a change that is much less dramatic than those made in conventional, transgenic genetic modification (Cyranoski, 2015). It is reported that the pigs provide many of the benefits of the double-muscled cow, e.g. the Belgian Blue, such as leaner meat and a higher yield of meat per animal – important targets for food security in a bioeconomy. It may also be that government agencies will view this more leniently than they do conventional forms of genetic modification; no ‘new’ DNA has been inserted.

326. China may be the first to adopt this technology in animals, and this pig could be among the first genetically engineered animals to be approved for human consumption. However, the technique has also been proven to work experimentally in creating double-muscled cows and sheep (Proudfoot et al., 2015).

Policy implications

- Overall, the most important message for policy makers is that a biotechnology revolution in food production is not something of the future. It has already started. Production of virtually all animals and crops can benefit from genomics. This includes some critical economic

63 http://www.bbc.com/news/world-europe-30794256

considerations, such as feed efficiency and disease resistance which benefit food security now and into the future. But the benefits are also environmental, although this is even more in its infancy. This message is not well understood at the political level, and the benefits of biotechnology in food production are under-valued and under-reported.

- Governments could better see the advantages of genomics in agriculture, and could more efficiently steer research programmes, by sponsoring programmes that train farmers in genomics. The Irish *Beef Data and Genomics Programme* is a good example. Gathering relevant field data has been a past limitation. Incentivising farmers to gather the data could relieve this limitation.

- As genomics is a means of speeding up breeding and making it more efficient without genetic modification, then this should cause less public resistance. Campaigns that make this clear could remove public resistance.

- The examples given here are only the very start. The costs of genomic studies have tumbled through the revolution in next generation sequencing. Bringing genomics testing to the farms will increase the range of applications as these are clearer to farmers than to researchers. Education and information programmes throughout the agricultural production chain would demystify genomics in agriculture.

- Genetic modification and gene editing have many other applications to offer, but here the level of public resistance is greater. However, GM salmon is now cleared in the US for human consumption. Its performance in the market may influence consumers in positive or negative ways. Governments could promote the benefits of such GM foods after their safety is guaranteed.

- An explosion in gene editing of crops and animals is starting. There is a serious danger that the science runs ahead of policy and the latter blocks beneficial applications of value in food security. There is a pressing need for regulatory clarity of whether the products of techniques such as CRISPR/Cas9 are to be treated differently in regulation than classical GM crops and animals.

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ANNEX 1. RESULTS OF WAGENINGEN RESEARCH PROJECT ON MEASURING SUSTAINABILITY BY MEANS OF AN INDICATOR BASED-APPROACH

Benchmarking the sustainability performance of the Brazilian non-GM and GM soybean meal chains: An indicator based-approach

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ABSTRACT
A commonly accepted approach for measuring the sustainability of agricultural products is the first step towards treating traded products differentially according to their sustainability. If we were able to measure sustainability, business stakeholders could optimize food production chains, consumers could demand products based on reduced environmental and social impacts, and policy makers could intervene to meet the growing demand for food in a context of environmental conservation, population growth, and globalization. We proposed to measure profitability adjusted for the negative externalities of food production as a single metric for benchmarking products in terms of their sustainability. In addition, the adjusted profits differences between different products are then be assessed by means of the Bennet price and quantity indicator to highlight areas for potential sustainability improvement. To illustrate the usefulness of the approach, we assessed the relative sustainability of two Brazilian conventional soybean meal chains, non-genetically modified (non-GM) and genetically modified (GM) chains. Based on the results, we indicated potential areas for sustainability improvement. Sustainability issues included in the assessment were profitability, global warming potential, eutrophication potential, environmental toxicity, farmworker toxicity, consumer toxicity, deforestation, and loss of employment. Results showed that the non-GM soybean meal chain is slightly more sustainable than the GM chain. However, both chains require joint efforts to address their economic, environmental, and social deficiencies. These efforts should focus on providing technical and high quality assistance to reduce biocide use, and improving transportation. The analysis in this study could be extended by undertaking a comparative assessment of the sustainability performance of major soybean meal producers, i.e. United States, Argentina, China, and Brazil.

The proposed approach proved to be a promising benchmarking tool for agricultural trade flows. It allows an integrated assessment of the dimensions of sustainability along food chains that is sufficiently flexible to compare the sustainability level of various biomass stocks that are produced in different locations and in a variety of environmental and socio-economic contexts. Nevertheless, it requires consensus on which components of sustainability are to be assessed.

1. Data and Methods

1.1 Indicator based-approach

The Brazilian soybean meal chain, for both non-GM and GM, is defined in this study as a set of four product life cycle stages integrated in an input-output system: agricultural, processing, transport to port, and transoceanic transportation. The chain is modelled up to the destination port (Rotterdam Port). At each stage, multiple inputs, denoted by vector x, are transformed into multiple outputs, denoted by vector y. As side effects of production, multiple environmental and social externalities are produced, expressed by vector b, such as waste, pollution and loss of biodiversity. The social or adjusted profit (SP) of the soybean meal chain is defined as the difference between the value of the aggregated good outputs and the aggregated inputs and externalities:

$$SP = p'y - r'b - w'x \qquad \text{(Eq. 1)}$$

where *p, r* and *w,* are vectors of (shadow) prices of outputs, inputs and externalities, respectively (prime indicating the transpose of the vector).

To assess the relative sustainability performance, the Bennet quantity indicator and the Bennet price indicator are computed:

$$B_{1,2} = \left[\frac{1}{2}(p'_2 + p'_1)(y_2 - y_1)\right] - \left[\frac{1}{2}(w'_2 + w'_1)(x_2 - x_1)\right] - \left[\frac{1}{2}(r'_2 + r'_1)(b_2 - b_1)\right]$$
$$+ \left[\frac{1}{2}(y_2 + y_1)(p'_2 - p'_1)\right] - \left[\frac{1}{2}(x_2 + x_1)(w'_2 - w'_1)\right] - \left[\frac{1}{2}(b_2 + b_1)(r'_2 - r'_1)\right] \quad \text{(Eq. 2)}$$

The sum of the Bennet quantity indicator and the Bennet price indicator reveals in monetary terms the adjusted profit difference of a particular chain relative to the benchmark. The Bennet quantity indicator (first line of equation 2) captures changes in quantities of outputs, inputs and externalities, i.e. the Total Factor Productivity (TFP) component. The Bennet price indicator (second line of equation 2) captures changes in the prices of outputs, inputs, and externalities, the Total Price Recovery (TPR) component. A positive (negative) value of the TFP and TPR components indicate higher (lower) sustainability performance of the assessed observation relative to a benchmark.

1.2. Selection of outputs, inputs, and externalities

To assess the relative sustainability performance of the non-GM and GM soybean meal chains, the main outputs, inputs, and externalities along the product life cycle were selected. The process of selecting the variables consisted of three steps. (i) A generic set of sustainability issues, i.e. topics that are of public concern, such as land use, health, energy, biodiversity, profitability, and water, was provided to a group of stakeholders involved in chain sustainability. Stakeholders were asked to assign a score to each of the issues using a five-point Likert scale, where 1 represented “not at all important” and 5 “extremely important” for the given dimension of sustainability, either economic, environmental, or social. The group of stakeholders consisted of eight academic researchers and eleven practitioners (NGO’s, certifying organizations and firms in the agri-food sector). (ii) Once answers were received, the percentage of participants who gave a score of 4 or 5 was calculated for each issue. The issues for which at least 65% of the participants gave a score of 4 or 5 were selected as being of utmost importance. A total of seven sustainability issues were selected. Four issues were selected for the dimension of environmental sustainability: *water*, *materials*, *atmosphere*, and *biodiversity*. *Economic performance* was selected for the economic dimension, and *labor practices* and *product responsibility* for the social dimension.

For each of the selected issues, data on quantities and (shadow) prices for outputs, inputs and externalities were collected. Prices were expressed in 2011 US dollars (US $). We computed the adjusted profit for each observation to identify the “best” performer from the observed data (in terms of highest adjusted profit). Next, adjusted profit differences and its components (TPR and TFP) were computed.

2. Adjusted profits of the selected non-GM and GM soybean meal chains in Brazil

Table 1 (a-c) shows the adjusted profit estimated for each of the observations of the non-GM and the GM soybean meal chains, as well as the average adjusted profit for the non-GM and the GM soybean meal chains.

Table 1a. Adjusted profit for the observations of the non-GM soybean meal systems in Brazil (US$ per soybean meal ton). In the column headings, y = vector of outputs, x = vector of inputs, b = vector of externalities, p = vector of prices of outputs, w = vector of prices of inputs, r = vector of prices of externalities; thus, ($p'y$) = value of production, ($w'x$) = value of inputs, ($r'b$) = value of externalities, and adjusted profit = $p'y - w'x - r'b$ (consistent with Eq. 1).

	($p'y$)	($w'x$)	($r'b$)	Adjusted profit
Guarapuava	449	262	43	144
Campos Novos	449	276	44	129
Andirá	449	273	50	126
Campo Mourão	449	273	51	125
Londrina	449	280	49	120
Marialva	449	278	50	121

Anahy	449	292	53	104
Arapoti	449	313	40	96
Cafelândia	449	314	55	80
Sorriso	449	342	76	31
Pedro Afonso	449	369	66	14

Table 1b. Adjusted profit for the observations of the GM soybean meal system in Brazil (US$ per soybean meal ton). For explanation of column headings, see above.

	$(p'y)$	$(w'x)$	$(r'b)$	Adjusted profit
Guarapuava	420	258	44	118
Campos Novos	420	277	42	101
Campo Mourão	420	275	52	93
Londrina	420	284	49	87
Marialva	420	287	49	84
Cruz Alta	420	297	44	79
Anahy	420	295	52	73
Passo Fundo	420	305	61	54
Cafelândia	420	314	55	51
Araguari	420	320	53	47
Palmeira das Missões	420	315	60	45

Table 1c. Average adjusted profit for the non-GM and the GM soybean meal systems in Brazil (US$ per soybean meal ton). For explanation of column headings, see above.

	$(p'y)$	$(w'x)$	$(r'b)$	Adjusted profit
Average non-GM chain	449	297	52	99
Average GM chain	420	293	51	76

The highest adjusted profit was calculated for the non-GM observation in the municipality of Guarapuava, equal to $144 per ton of soybean meal. This observation was used as the benchmark observation for the computation of the Bennet quantity indicator and the Bennet price indicator.

Table 2. ***Differences in the adjusted profit between observations of the non-GM and GM soybean meal chains and the benchmark at each product life cycle stage, expressed in US $ per soybean meal ton. Stage 1 = agricultural production, stage 2 = processing, stage 3 = transport to port, and stage 4 = transoceanic transportation. The adjusted profit difference is decomposed into TPR and TFP in each of the four stages (consistent with Eq. 2).***

Non-GM chain	**Stage 1**		**Stage 2**		**Stage 3**		**Stage 4**		**Adjusted profit difference**
	TPR	*TFP*	*TPR*	*TFP*	*TPR*	*TFP*	*TPR*	*TFP*	
Guarapuava[a]	0	0	0	0	0	0	0	0	0
Campos Novos	3	-13	0	0	0	-5	0	0	-15
Andirá	0.4	-14	0	0	0	-6	-0.2	0.7	-19
Campo Mourão	-3	-7	0	0	0	-10	0	0	-20
Londrina	-1	-16	0	0	0	-6	0	0	-23
Marialva	3	-19	0	0	0	-7	0	0	-24
Anahy	-3	-21	0	0	0	-15	0	0	-39
Arapoti	-32	-29	0	0	0	12	0	0	-48
Cafelândia	-32	-19	0	0	0	-14	0	0	-64

	Stage 1		Stage 2		Stage 3		Stage 4		Adjusted profit difference
	TPR	*TFP*	*TPR*	*TFP*	*TPR*	*TFP*	*TPR*	*TFP*	
Sorriso	-18	-14	0	0	0	-82	-0.2	0.7	-113
Pedro Afonso	-34	-57	0	0	0	-40	-0.2	0.7	-130
GM chain	**Stage 1**		**Stage 2**		**Stage 3**		**Stage 4**		**Adjusted profit difference**
	TPR	*TFP*	*TPR*	*TFP*	*TPR*	*TFP*	*TPR*	*TFP*	
Guarapuava	8	-4	-0.7	0	0	-0.4	-29	0	-26
Campos Novos	1	-9	-0.7	0	0	-5	-29	0	-43
Campo Mourão	-4	-7	-0.7	0	0	-10	-29	0	-51
Londrina	-4	-17	-0.7	0	0	-7	-29	0	-57
Marialva	-6	-17	-0.7	0	0	-8	-29	0	-60
Cruz Alta	-12	-15	-0.7	0	0	-6	-29	-2	-64
Anahy	-5	-22	-0.7	0	0	-15	-29	0	-71
Passo Fundo	1	-49	-0.7	0	0	-11	-29	-2	-90
Cafelândia	-31	-18	-0.7	0	0	-14	-29	0	-93
Araguari	-15	-37	-0.7	0	0	-16	-29	1	-97
P. das Missões	-12	-46	-0.7	0	0	-10	-29	-2	-99
GM chain vs. benchmark= non-GM chain	5	-7	-0.7	0	0	6	-29	-0.6	-25

A positive value indicates higher performance relative to the benchmark.
a Benchmarking observation

The decomposition of the aggregate difference in the adjusted profits between the average GM and non-GM soybean meal chains highlights five main differences in price effects (TPR) and quantity effects (TFP) for the inputs, output, and externalities.

3. Conclusions

Results show that the non-GM soybean meal chain is more sustainable than the GM chain, i.e. it has a higher adjusted profit. Quantity differences (TFP component) include a lower use of biocides, i.e. pesticides, fungicides, and herbicides, in the non-GM chain. The main price difference (TPR component) is associated with the price premium paid per ton of non-GM soybean meal. In contrast, the GM soybean meal chain has a lower emission of GHGs at the transport to port stage due to a lower amount of fossil fuel used in transportation. This is because GM soybean production is mainly found in the southern Brazilian states that are closer to the ports. Our study highlights areas for improving the sustainability of the GM and non-GM chains. Externalities arising from soybean meal production could be reduced by introducing technical assistance in GM soybean production to reduce the application of biocides and by improving the transport infrastructure matrix, especially in remote non-GM soybean production areas of Brazil. These efforts would also reduce production costs.

Although our study focused on the assessment of the relative sustainability performance of the soybean meal chain, the indicator based-approach has a much wider applicability. It is sufficiently flexible to allow aggregation of different sustainability issues and therefore can be used to analyze the sustainability of trade flows at different locations and in a variety of socio-economic contexts. Further development and acceptance of this approach as a benchmarking tool in trade negotiations could assist in the future imposition of trade preferences for sustainable commodities and provide an incentive to switch production towards better economic, environmental, and social practices throughout production chains.

ANNEX 2: GLOSSARY OF SUSTAINABILITY-RELATED TERMS AND TERMINOLOGY

Note: The terms presented here are not internationally agreed and are only examples taken from a wide range of definitions in common usage.

Advanced biofuels. Usually referred to as produced from lignocellulosic sources, these biofuels are produced through the application of advanced conversion processes to crops and novel feedstocks such as algae.

Advanced energy manufacturing tax credit. A tax credit awarded to firms for qualifying investments in renewable and advanced energy projects to support new, expanded or re-equipped domestic manufacturing facilities. For example, the Section 48C tax credit of the American Reinvestment and Recovery Act of 2009 (ARRA) is equal to 30% of the basis of qualifying investments used to manufacture property that will reduce greenhouse gas emissions or air pollutants.

Agenda 2030 for Sustainable Development. The Heads of State and Government and High Representatives met at the United Nations Headquarters in New York from 25-27 September 2015 and decided on new global Sustainable Development Goals. The 17 Sustainable Development Goals (SDGs) and 169 targets announced are far-reaching in their scale and ambition – this is the "*new universal Agenda*".

Agricultural residues. The by-products from crops, such as wheat straw and seed husks, as well as other agricultural wastes including slurry and manure.

Aliphatic. Relating to organic compounds whose carbon atoms are linked in open chains, either straight or branched, rather than containing a benzene ring. Alkanes, alkenes, and alkynes are aliphatic compounds. They are important molecules in petrochemistry. The alkanes are very significant components of liquid transport fuels. The short-chain alkenes, such as ethylene and propylene, are at the heart of the petrochemicals industry.

Aromatic. The term was coined simply because many of the aromatic compounds have a sweet or pleasant odour. Aromatic hydrocarbons contain six carbon atoms in a ring structure known as a benzene ring, after the simplest one, benzene. Aromatic compounds have many uses. The aromatic ring can be found in rubbers, lubricants, dyes, detergents, drugs, explosives, pesticides, among others. Apart from their widespread utility, many are toxic to very toxic, and some are known to cause cancer. Bio-based versions are very difficult to manufacture.

Bio-based chemicals tax credit. The US Renewable Chemicals Act of 2015 would create a 15 cent-per-pound production tax credit for eligible renewable chemicals manufactured from biomass feedstock. Alternatively, the bill would allow producers to elect to take a 30% investment tax credit for qualified investments for new renewable chemical production facilities in lieu of the production tax credit. The Qualifying Renewable Chemical Production Tax Credit Act of 2012 would provide renewable chemical and bio-based products access to tax credits that are available to other industries.

Bio-based content. The amount of bio-based carbon in the material or product as a percent of weight (mass) of the total organic carbon in the material. This is an important indicator of renewability but not necessarily of sustainability. Bio-based products need not be composed entirely of bio-based carbon. The emerging bio-based manufacturing industry produces large quantities of products that contain mixtures of bio-based and fossil-derived materials, *e.g.* first generation bio-polyethylene terephthalate (bio-PET, the material commonly used to make drinks bottles).

Bio-based product. A product made partially or entirely from substances derived from living matter. It may include common materials such as wood and leather, but typically means modern materials that have undergone more extensive processing. Bioproducts or bio-based products include materials, chemicals and energy derived from renewable biological resources. Bio-based materials are often but are not necessarily biodegradable. The term is typically applied only to materials containing carbon.

Biodegradable. Capable of being decomposed by biological agents, especially bacteria and fungi. Biodegradable has proven a controversial term as it does not necessarily mean biodegradation to its mineral components although marketing may imply this. Partial biodegradation can in fact result in a stable intermediate compound that is more toxic than the original molecule. *Mineralisation* means the ultimate conversion of the material or compound to its mineral components (CO_2 and H_2O under aerobic conditions). *Biodegradability* usually refers to the testing regime under which a compound or material is judged to be biodegradable or not.

Biodiesel. Biodiesel is an alternative to fossil diesel fuel in transport. It is similar in composition, but can be produced from straight vegetable oil, animal oil/fats, tallow and waste cooking oil. A biodiesel of the future will be derived from algae. Biodiesel can be used alone, or blended with petro-diesel in any proportions. Indeed, many renewable energy policies depend on blending. Biodiesel blends can also be used as heating oil.

Biodiversity. The variety of all life on Earth, including all species of animals and plants, and the natural systems that support them. There are on-going studies on the links between climate change and biodiversity from at least two perspectives: impacts of climate change and climate policy on biodiversity and ecosystem services, and the role of biodiversity and ecosystem services in climate change mitigation and adaptation.

Bioeconomy. Since a landmark publication of the OECD, bioeconomy definitions have varied, and as yet there is no consensus. From a broad economic perspective as envisaged by the OECD, the bioeconomy refers to the set of economic activities relating to the invention, development, production and use of biological products and processes. However, it has come to include agriculture, forestry, pulp and paper and other sectors. Some countries include health. Therefore estimates of the size of the bioeconomy vary enormously.

Bioenergy. Energy generated by combusting solid, liquid or gas fuels made from biomass feedstocks which may or may not have undergone some form of conversion process.

Bioethanol. Bioethanol is the principal fuel used as a petrol substitute for road transport vehicles and is generally produced from crops such as sugar cane, corn and wheat. It can be made from virtually any biomass source (grass, wood, biodegradable elements of municipal solid waste), but the technologies for doing so are still under development.

Biofuel. A fuel produced from biomass feedstocks. Strictly speaking, fossil fuels fit this definition, but biofuels are distinguished from fossil fuels in that they are produced from renewable biomass, *i.e.* crops that can be harvested for refinement to biofuels, and replanted and reharvested on a continuing basis.

Biofuels sustainability criteria. In the EU, to be considered sustainable (and therefore qualify for government support), biofuels must achieve greenhouse gas savings of at least 35% in comparison to fossil fuels. This savings requirement rises to 50% in 2017. In 2018, it rises again to 60% but only for new production plants. All life cycle emissions are taken into account when calculating greenhouse gas savings. This includes emissions from cultivation, processing, and transport. Other criteria include:

- Biofuels cannot be grown in areas converted from land with previously high carbon stock such as wetlands or forests;
- Biofuels cannot be produced from raw materials obtained from land with high biodiversity such as primary forests or highly biodiverse grasslands.

Biogas. Biogas typically refers to a mixture of different gases produced by the breakdown of organic matter in the absence of oxygen. Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste. It is typically depicted as a mixture of methane and carbon dioxide with traces of many other gases possible in some sources e.g. landfill gas.

Biomass. This is the biological raw material used to make fuels or other bio-based products. It includes solid biomass such as wood, plant and animal products, gases and liquids derived from biomass, and the biodegradable components of industrial and municipal wastes.

Biomass potential. Biomass potential refers to the amount of biomass that can be grown. In the modern policy setting, this will refer to the sustainable biomass potential. Several biomass potential studies have been done in the last decades. Their approaches have been very different and their results difficult to compare and interpret. They can be done at local, regional, national levels or above. Without standardised criteria for measuring biomass potential, future estimates will continue to be uncomparable and variable.

Biomass sustainability. The meaning of biomass sustainability depends on what is meant by sustainability. The latter has come to be associated with safeguarding the future by not taking out more from the planet than necessary. This responds to the habit of rapid population growth and development being accompanied by a 'throw-way'mentality when resources are finite. Therefore it calls for using renewable resources and higher levels of recycling.

Bioplastic. There is no universally agreed definition of a bioplastic. Bioplastics were first introduced as biodegradable plastics for use in simple packaging applications. The bio-based plastics that are now increasing in the market are not necessarily biodegradable, but they contain carbon that is partially or entirely derived from renewable biomass.

Bio-principled cities. The integration of biological principles into urban planning and city life. It calls for higher levels of self-sufficiency of cities and more recycling to reduce waste and close energy and material loops.

Blending tax credit. Biofuels blenders are eligible for an income tax credit per litre or gallon. For example, under the US Biodiesel Production and Blending Tax Credit, qualified biodiesel producers or blenders are eligible for an income tax credit of USD 1.00 per gallon of pure biodiesel (B100) or renewable diesel produced or used in the blending process. For the purpose of this credit, biodiesel must meet ASTM specification D6751, and renewable diesel is defined as a *renewable, biodegradable, non-ester combustible liquid derived from biomass resources that meets ASTM specification D975*.

It can suffer the criticism that it does not keep out foreign biofuels, where a producer's credit would support domestic production more. On the other hand, proponents of the blender's credit say that a producer only credit increases profits for a limited number of producers while reducing the overall availability of fuels.

Business ecosystem/ecology. A system-level view of the relationships and interdependencies evident in organisations, markets, or industries, including their components, actors, resources, and stakeholders. Inspired from nature, this is a similar approach to understanding biological ecosystems in their fullest sense.

Cap and trade. A cap is placed on the total amount of allowable emissions, it is distributed among the total number of polluters, and a marketplace is created where owners of the permits can trade with each other. The intention is to incentivise a reduction in emissions and penalise those who fail to comply.

Carbon Capture and Storage (CCS). This is a technology that involves capturing CO_2, transporting it and storing it in secure spaces such as geological formations, including old oil and gas fields and aquifers under the seabed.

Carbon dioxide equivalents (CO_2e). The internationally recognised way of expressing the amount of global warming of a particular greenhouse gas in terms of the amount of CO_2 required to achieve the same warming effect over 100 years.

Carbon footprint. The total emissions of greenhouse gases (in carbon equivalents) from whichever source is being measured – be it at an individual, organisation or product level.

Carbon neutral. Carbon neutrality makes or results in no net release of carbon dioxide into the atmosphere, especially as a result of carbon offsetting.

Carbon offsetting. The process of reducing greenhouse gas emissions by purchasing credits from others through emissions reductions projects, or carbon trading schemes. The term often refers to voluntary acts, arranged by a commercial carbon offset provider.

Carbon price and carbon tax. A carbon price, is the amount that must be paid for the right to emit one tonne of CO_2 into the atmosphere. Carbon pricing usually takes the form either of a carbon tax or a requirement to purchase permits to emit, generally known as cap-and-trade. Carbon pricing has proven extremely controversial politically. As a consequence of not being priced, there is no market mechanism responsive to the costs of CO_2 emitted. Classically, emissions should be charged at a price equal to the monetary value of the damage caused by the emissions. This should result in the economically optimal (efficient) amount of CO_2 emissions. However, the price of the damage has remained elusive.

Carbon trading. Any trading system designed to offset carbon emissions from one activity (such as burning fossil fuels in manufacturing, driving, or flying) with another (such as installing more efficient technologies, planting carbon-reducing plants, or establishing contracts with others not to partake in carbon-releasing activities). When activities that reduce or capture carbon are paired successfully with those that produce it, these are said to be carbon neutral or climate neutral.

Cascading use. This usually refers to the cascading use of biomass. The theory goes that the highest value products, generally in the lowest volumes, are extracted from biomass first. Then the same biomass cascades towards the lowest value products, often the highest volume materials. Recycling is applied as often as possible before the biomass and its products reach the end of their life, perhaps by burning to generate electricity. In theory, in this manner the maximum value is extracted from the original biomass. It has been estimated that cascading can lead to an almost 30% reduction in European greenhouse gas emissions by 2030 compared with 2010.

Certification schemes and labels. In certification schemes, independent organisations test materials or products and if the results are satisfactory they issue a certificate stating that the material or product meets the requirements (prescriptions) of a particular standard. Certification of bio-based products informs users about the nature of the material or product. Certification is often accompanied by a label that may be placed on certified materials and products.

Circular economy. This is strongly associated with recycling. It refers to closed loops of energy and material use in that the residues and byproducts of one process can be used in another. The ultimate goal of a circular economy would be ‘zero waste’. A strong relationship to cascading use will be evident.

Clean production. Manufacturing processes designed to minimise environmental impact by using the minimum amount of energy and raw materials possible and producing limited waste or emissions.

Clear cutting. A process where all trees in a selected area are felled in a logging operation. This can be extremely destructive to the environment, whilst being the most cost-effective means known to harvest high yields of timber rapidly.

Climate change. Climate change has come to be associated with global warming as a result of human activities since the Industrial Revolution, but it is also caused by factors such as oceanic processes, variations in solar radiation, plate tectonics and volcanic eruptions. The term is now almost universally used to describe impacts resulting from human activity.

Combined Heat and Power (CHP). A system in which the heat associated with electricity generation is used for space heating or process heat. It considerably increases the overall efficiency of the fuel used in the process. Energy generated by the incineration of waste at local combined heat and power facilities can support district heating schemes.

Composting. In the context of sustainability this refers to a regulated industrial-scale process for converting decomposable organic materials into useful stable products through biochemical processes. Industrial-scale composting through in-vessel composting, aerated static pile composting, and anaerobic digestion is now used in most Western countries and is often legally mandated. Composting is one of the very few ways to revitalise soil in which the phosphorus is depleted.

Conventional biofuels. These are transport biofuels typically derived from crops and waste using current conversion processes. Examples include bioethanol from sugar cane and biodiesel from oilseed rape and used cooking oil. These are also known as first-generation biofuels.

CO_2 economy. A CO_2 ecoonomy encompasses both carbon capture and storage (CCS) and carbon capture and utilisation (CCU). For example, hot, pressurised CO_2 can be used not only for generating power, but also for higher-value, carbon-negative products, such as synthetic gasoline and diesel fuel, thereby ushering in an era of possibilities: clean, reliable baseload energy; a cost-effective means to capture greenhouse gases; and the affiliated production of potent carbon-negative, fossil-fuel substitutes. But the CO_2 economy can also be associated with a low carbon economy (due to the renewable and recyclable elements of the theory).

Cradle-to-Cradle. A design protocol that advocates the elimination of waste by recycling a material or product into a new or similar product at the end of its intended life, rather than disposing of it.

Cradle-to-Gate. An assessment of a partial product life cycle from manufacture (‘cradle’) to the factory gate i.e. before it is transported to the user or consumer. The use phase and disposal phase of the product are usually omitted. Cradle-to-gate assessments are sometimes the basis for environmental product declarations. They are of greatest use to manufacturers, who cannot foresee what customers will do with their products.

Cradle-to-Grave. A manufacturing model which describes the process of disposing of a material or product via a recognised route, such as landfill or incineration, at the end of its presumed useful life.

Dedicated energy crops. These are crops grown to be used for energy generation. Examples include fast-growing trees (such as short rotation coppice willow) and grasses with a high lignocellulosic content (such as *Miscanthus*).

Deforestation. This is the clearing of the planet's forests on a massive scale, often resulting in damage to the quality of the land, and reducing the capacity of the planet to absorb CO_2. An estimated 13 million hectares of forests were lost each year between 2000 and 2010 due to deforestation.

Direct land use change (DLUC). The conversion of land from one use to another, *e.g.* from unmanaged forest to cropland, or from one crop type to another. The tillage of unmanaged land exposes large amounts of soil organic carbon to the atmosphere and produces large amounts of CO_2. It can take a long time to pay back this CO_2 debt.

Eco-label. An environmental label or declaration that provides information about a product or service in terms of its overall environmental character, a specific environmental aspect or number of environmental aspects. The information can be used to influence or inform purchasing decisions. Eco-labels may take the form of a statement, symbol, or graphic and be found, in part, on products or packaging and in product literature or advertising.

Emission. The release of any gas, particle, or vapour into the environment from a commercial, industrial, or residential source including smokestacks, chimneys, and motor vehicles.

Emissions trading. This refers to the trading of permits which allow emissions of set amounts of greenhouse gases. It is therefore a market mechanism for controlling pollution. By creating tradable pollution permits it attempts to add the profit motive as an incentive for good performance, unlike traditional environmental regulation based solely on the threat of penalties.

End-of-life options. This refers to the step in the life of a chemical or material after its primary intended purpose has been fulfilled. The chemical or material may then be used for another purpose. Often it becomes a waste product. Here the options typically are discarding to landfill, incineration (with or without energy capture and electricity production), composting (for biodegradable wastes) and recycling for further use.

Energy density. In terms of fuels, energy density means the amount of energy stored in a given liquid, per unit volume (litre or gallon, normally). Ethanol has a higher energy density than methanol, meaning a vehicle can be drive further on a litre of ethanol than a litre of methanol. Biomass is also described as being of low energy density, making it inefficient to transport over long distances.

Energy intensity. There are two meanings in common use. First, it can be a measure of the energy efficiency of a national economy, calculated as units of energy per unit of GDP. Second, it can be the entire amount of energy required to produce a product as a ratio of that product.

Energy recovery. This is obtaining energy from waste. It is accomplished through a variety of processes, and is also known as 'waste-to-energy'. Traditionally, this meant burning waste products, but now gasification and anaerobic digestion are also playing a role.

Energy security. At its core energy security is the concept of physical security (avoiding involuntary interruptions of supply). It can include elements of price security (*e.g.* avoidance of excessive price volatility). In the context of sustainability and affordability and as a result of volatility of fossil fuel prices many countries seek to improve energy security through diversification of supply, *e.g.* biofuel production, offshore and onshore wind energy, solar power.

Feed-in tariff. A feed-in tariff (FIT), or advanced renewable tariff or renewable energy payments is a policy mechanism designed to accelerate investment in renewable energy technologies. It achieves this by offering long-term contracts to renewable energy producers, typically based on the cost of generation of each technology. Producers may be generating companies of any size, all the way down to the individual home. It is effectively a scheme that pays people for creating their own green or renewable electricity. For governments, FITs help increase the level of renewable energy being produced to meet national targets on renewable energy and therefore for greenhouse gas emissions reductions.

Feedstocks. Crops or products that can be used to produce bioenergy or bio-based products.

Fermentation. The use of microorganisms (*e.g.* yeasts, bacteria) to break down organic substances to create other organic substances. The classic fermentation is the anaerobic conversion of sugars into ethanol by the yeast *Saccharomyces cerevisiae*. In strict scientific terms, fermentation is an anaerobic process, but in practice the term is also used for aerobic biological conversion processes.

Flex fuel vehicle (FFV). A vehicle that operates with more than one fuel or fuel blend. For example, the Ford Model T, produced from 1908 to 1927, was fitted with a carburetor with adjustable jetting, allowing use of petrol or ethanol, or a combination of both. FFVs have been designed for modern use with petrol or ethanol, and blends thereof, in many countries as a means of reducing emissions, most notably in Brazil and Sweden.

Food security. Food security refers to the availability of food. In the bioenergy context it relates to the food *versus* fuel debate about diverting farmland from food crops to bioenergy feedstocks and the perception that this leads to higher food prices and decreased food supply worldwide. The origins of the recent food price spikes, however, are complex and include other issues such as the price of fossil fuels.

Forestry and forest residues. These forest sector by-products include residues from thinning and logging (*e.g.* treetops, limbs) and secondary residues such as sawdust and bark from wood processing. Forestry and forest residues also include dead wood from natural disturbances, such as fires, biomass grown in forests that is not required for timber production, and biomass from dedicated plantations, *e.g.* short- and long-rotation forestry.

Fossil fuel. Coal, oil and gas are called fossil fuels because they were formed from the fossil remains of plants and animals millions of years ago. As fuels they offer high energy density but making use of that energy requires burning the fuel and the oxidation of the carbon to CO_2 and H_2O. Unless they are captured and stored, these combustion products are released and return carbon sequestered millions of years ago to the atmosphere.

Fossil fuel subsidies. These are any government actions that lower the cost of fossil fuel energy, that raise the price received by energy producers or lower the price paid by energy consumers. There are a lot of activities under this simple definition - tax breaks and giveaways, but also loans at favourable rates, price controls, purchase requirements and more. The global value of these subsidies is vast, by most calculations of the order of half a trillion USD per annum. They therefore have the global effect of distorting the fossil fuel markets. For example, the price of petrol in a Western European country can easily be more than one hundred times the price in Venezuela at a given time.

Genetically modified. An organism is genetically modified if it contains genetic material that has been artificially altered so as to produce a desired characteristic. The term has become extremely political and societally devisive, with the result that there are multiple interpretations of its meaning. The greatest controversy is with food. Genetically modified (GM) foods are foods derived from organisms whose genetic material (DNA) has been modified in a way that does not occur naturally, e.g. through the introduction of a gene from a different organism.

Genome. A genome is the complete set of DNA, including all of the genes, of an organism. Each genome contains all of the information needed to build and maintain that organism. In humans, a copy of the entire genome—more than 3 billion DNA base pairs—is contained in all cells that have a nucleus.

Genomics. Now a rather broad term, it is the branch of molecular biology concerned with the structure, function, evolution, and mapping of genomes.

Global warming. The gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, CFCs, and other pollutants. Scientific consensus is now overwhelmingly that global warming is caused by human activity.

Green bank. A green bank is a public or quasi-public financing institution that provides low-cost, long-term financing support to clean, low-carbon projects by leveraging public funds through the use of various financial mechanisms to attract private investment so that each public dollar supports multiple dollars of private investment. An early example is the UK Green Investment Bank. Typical projects could include offshore and onshore renewable energy, offshore wind, solar, energy efficiency, waste and bioenergy.

Green chemistry. The design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. Hazardous now has come to include greenhouse gases, in particular CO_2, and there is now an emphasis on the link between green chemistry and climate change/global warming.

Green engineering. Engineering with environmentally conscious attitudes, values, and principles, combined with science, technology, and engineering practice, all directed toward improving local and global environmental quality.

Green growth. This is a term to describe a path of economic growth that uses natural resources in a manner that is sustainable. It is used globally to provide an alternative concept to typical industrial economic growth. A green growth strategy would bring together the three pillars of sustainable development: economic, environmental and social; and incorporates technological and development aspects into a comprehensive framework.

Greenhouse effect. The greenhouse effect is the process by which radiation from the atmosphere of the planet warms its surface to a temperature above what it would be without its atmosphere.

Greenhouse gas (GHG). Any atmospheric gas (either natural or of human origin) which absorbs thermal (infrared) radiation emitted by the Earth’s surface. This traps heat in the atmosphere and keeps the surface at a warmer temperature than would otherwise occur. The primary greenhouse gases in Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide, and ozone.

Greenwashing. A term merging the concepts of ‘green’ (environmentally sound) and ‘whitewashing’ (to conceal or gloss over wrongdoing). Greenwashing is any form of marketing or public relations that links a corporate, political, religious or non-profit organisation to a positive association with environmental issues for an unsustainable product, service, or practice.

Gross Domestic Product (GDP). A measure of economic production (and often standard of living) of a country. GDP calculates a nations total economic output of products and services. The GDP is problematic as a sustainability indicator because it considers the amount of money spent in a country in isolation, assuming more money spent means a healthier economy.

Gross National Product (GNP). The total value of newly produced products and services produced in a year by a country's companies (including profits from capital held abroad). Transactions in existing goods, such as second-hand cars, are not included, as these do not involve the production of new goods.

Hydrocarbon. A compound of hydrogen and carbon, such as any of those which are the chief components of petroleum and natural gas.

Hydrogen economy. The term refers to the vision of using hydrogen as a low-carbon energy source – replacing, for example, petrol as a transport fuel or natural gas as a heating fuel. However, its 'green' credentials are questioned if the hydrogen is generated by steam reformation of hydrocarbons. Other means of generation, such as water electrolysis, require large energy inputs. Bio-based hydrogen to date suffers from poor production and therefore applications at large scale are still evanescent.

Incineration. Incineration of waste materials converts the waste into ash, flue gas and heat. The flue gases should be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere. In some cases, the heat generated by incineration can be used to generate electric power. Incinerators reduce the solid mass of the waste by 80–85% and the volume by 95-96%. Incineration does not completely replace landfilling but significantly reduces the volume to be disposed of.

Indirect land use change (ILUC). Indirect land use change occurs when land used for an existing activity (*e.g.* food or timber production) is converted to grow a bioenergy feedstock or when a food crop is used for bioenergy (*e.g.* diversion of maize for ethanol production). It is assumed that food production is essential and that the lost food production will be diverted elsewhere.

Industrial biotechnology. Industrial or white biotechnology uses enzymes and micro-organisms to make bio-based products in sectors such as chemicals, food and feed, detergents, paper and pulp, textiles and bioenergy (such as biofuels or biogas).

Industrial ecology. A field of study and practice that focuses on how industry can be developed or restructured to reduce environmental burdens throughout the product life cycle (extraction, production, use, and disposal). In applying this perspective, companies seek to shift industrial processes from open loop systems that produce waste materials to closed loop systems where wastes become inputs for new processes. Perhaps the best-known example is Kalundborg, Denmark.

Industrial metabolism. The total use of materials and energy throughout an entire industrial process, such as manufacturing. This includes the source, transportation, use, reuse, recycling, and disposal of all industrial nutrients (materials) as well as the energy needed at each step.

Irrigation. Irrigation becomes an issue of sustainability because about 70% of fresh water use is for agriculture. Much of this is used for irrigation. Irrigation is the artificial application of water to the land or soil. It is used to assist in the growing of agricultural crops, maintenance of landscapes, and revegetation of disturbed soils in dry areas and during periods of inadequate rainfall. Methods vary greatly in their efficiency. One of the drives in plant genomics is to produce crop varieties that are heat and drought tolerant to reduce the use of water in agriculture, thereby improving water security.

Integrated biorefineries. In the integrated biorefinery model, multiple products are made at the same facility or complex – biofuels, bio-based materials and bioenergy. Often the economics of bio-based chemicals production will be superior to those of biofuels production (this is also the case in petro-production). Integration is widely accepted as the most sustainable form of biorefining for the future.

Kyoto Protocol. Adopted in 1997 as a protocol to the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol placed a legally binding commitment on participating countries to reduce their greenhouse gas emissions by 5% relative to 1990 levels over the period from 1998 to 2012. Gases covered by Kyoto Protocol are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), hydroflurocarbons (HFCs) and perfluorocarbons (PFCs).

Landfill. In the sustainability context, landfill refers to ground filled in with waste materials; in other contexts it can refer to rocks. Landfill is the most common organised waste disposal technology. As waste is buried in landfill, the site rapidly becomes anaerobic, with the result that materials that biodegrade produce methane, which can be captured and burned for heat or electricity production. If the methane production is not controlled it contributes to GHG emissions. Decades of concern over the declining number of suitable sites for landfilling has led to legislation to limit materials that are landfilled.

Lifecycle analysis (LCA). This is a numerical technique to assess environmental impacts associated with all the stages of the life of a product, typically from cradle-to-grave (*i.e.* from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). There are several variants of cradle-to-grave in common use.

- Cradle-to-factory gate assesses the product life cycle from resource extraction (cradle) to the factory gate *i.e.* before it is transported to the consumer. This variant is often favoured by the manufacturer which does not control the use and disposal of the product by the consumer.
- Cradle-to-cradle (also known as open loop production) is a cradle-to-grave assessment for which recycling is the end-of-life option.
- Well-to-wheel is a specific LCA used for transport fuels and vehicles.

Lifecycle emissions. The emissions generated by a product, system or service over its lifetime.

Lignocellulosic feedstock. Woody feedstocks with significant cellulose and hemi-cellulose content. Advanced conversion processes are required to break down the cellulose and hemi-cellulose for conversion to liquid biofuels or bio-based products. The biorefining of these feedstocks involves a high cost.

Loan guarantee. A loan guarantee in finance is a promise by one party (the guarantor) to assume the debt obligation of a borrower if that borrower defaults. A guarantee can be limited or unlimited, making the guarantor liable for only a portion or all of the debt. This has become a major finance instrument for the construction of high-risk and flagship (first-of-kind) biorefineries.

Managed forests. In a managed forest, trees are re-planted as they are felled. Wood products that come from well-managed forests offer the most benefits in terms of combating climate change. Well-managed woodlands also generally store more carbon than stands that are not harvested.

Market failure. A market's inability to create maximum efficiency, by not properly providing goods or services to consumers, not efficiently organising production, or not serving the public interest. The term does not refer to the collapse or demise of a market.

Materials audit. The process of investigating the costs and effects of materials used in manufacturing in order to determine more efficient, less costly, less toxic (or dangerous), and more sustainable options.

Metabolic engineering. The use of genetic engineering to modify the metabolism of an organism. It can involve the optimisation of existing biochemical pathways or the introduction of pathway components, most commonly in bacteria, yeast or plants, with the goal of high-yield production of specific molecules for medicine or biotechnology. It has many applications in bio-production of chemicals, plastics, textiles and other materials.

Net Present Value (NPV). The value, in the present, of an investment or financial transaction that will pay-off in the future, minus the cost of the investment up until the time of that pay-off. NPV represents the profit or loss, in present worth, of future transactions so they are comparable against other investments. Large, time-consuming construction projects are managed on this basis e.g. developing an oilfield.

Non-renewable energy. Energy derived from sources that cannot be replenished in a short period of time relative to a human life span. Non-renewable sources of energy are typically divided into two types: fossil fuels and nuclear fuels. Fossil fuels include oil, natural gas, and coal. Nuclear involves uranium.

Open-loop recycling. The conversion of material from one or more products into a new product, involving a change in the inherent properties of the material itself e.g. recycling plastic bottles into plastic drainage pipes. This is also referred to as downcycling or reprocessing.

Paris Agreement, 2015. The Paris Agreement is an agreement within the framework of the United Nations Framework Convention on Climate Change (UNFCCC) governing greenhouse gases emissions mitigation, adaptation and finance from 2020. The agreement was negotiated during the 21st Conference of the Parties of the UNFCCC in Paris and adopted by consensus on 12 December 2015, but has not entered into force. In the 12 page Agreement, the members promised to reduce their carbon output "*as soon as possible*" and to do their best to keep global warming "*to well below 2 degrees C*".

Peak oil. A controversial concept, peak oil is the hypothetical point in time when the global production of oil reaches its maximum rate, after which production will gradually decline (some models envisage precipitous decline). It has political dimensions that pertain to sustainability as it can be used as an argument for greater deployment of renewable energy and materials production.

Precautionary principle. An approach to determining whether a given process or policy should be pursued or continued based on an analysis of the social, economic, or environmental risks associated with that activity. Not all risks are known when a new practice is introduced or a current one is re-examined, and the ethical approach in light of implied or expected (but not confirmed) negative impacts is to stop such practices as a precaution until more is known about the impacts.

Pollution prevention. Any activity to reduce or eliminate any number of pollution types or quantities from personal, corporate, or governmental activities. These activities seek to create more efficient procedures or practices that reduce pollution or use it in the manufacturing process of some other activity. In policy pollution prevention and control have been integrated in many countries. The European Union has the *Integrated Pollution Prevention and Control Directive* (the IPPC Directive) that requires industrial and agricultural activities with a high pollution potential to have a permit. This permit can only be issued if certain environmental conditions are met, so that the companies themselves bear responsibility for preventing and reducing any pollution they may cause.

Production (biofuels) mandate. Under the US Renewable Fuel Standard (RFS), first established in 2005, Congress mandated biofuels use for the US. The US Energy Independence and Security Act (EISA, 2007) superseded and greatly expanded the biofuels mandate to 36 billion gallons by 2022. This was very substantial biofuels policy as it set minimum usage requirements for various road transport biofuels to guarantee them a market irrespective of their cost.

Public-private partnership. Widely used in science and technology policy, public-private partnership (PPP) models of various varieties exist. The general idea is that public (taxpayer's) money pump-primes greater financial support from the private sector. This signals policy stability from governments and de-risks private investments when the private sector is unwilling to shoulder the risk alone. PPPs are especially suited to the high risk associated with biorefinery projects, especially the integrated biorefineries of the future.

Public procurement. This can be a powerful market-making measure. It involves mass purchasing of commodities by the public sector. Obvious examples might be: military procurement of biodiesel; public procurement of fleet vehicles, such as flex-fuel vehicles for police forces or the post office to encourage the uptake of renewable fuels. PP affects a substantial share of world trade flows. For example, in the EU this accounts for roughly 18% of GDP.

Recycling. The processing of used waste materials into new products to reduce waste production, reduce the consumption of fresh raw materials, reduce energy usage, reduce air and water pollution and lower greenhouse gas emissions as compared to virgin production. Many materials, such as thermoplastics and glass, are recyclable. Although typically an alternative to landfilling, there is some debate about whether recycling is economically efficient. The costs and energy used in collection and transport compared to the costs and energy saved in the production process have been debated.

Renewable. In sustainable development, this relates to a commodity or resource, such as solar energy or firewood, that is inexhaustible or replaceable by new growth. The opposite is finite resources, such as fossil fuels, which are definitely exhaustible. The meaning is extended by including emissions. By dint of being replaceable within a relatively short time frame, renewable resources are more likely to be carbon-neutral as the emissions from their use can be negated by CO_2 capture during growth. As fossil resources take millions of years to develop, the emissions generated are considered 'permanent' as the timeframes nullify the original carbon capture (millions of years ago) in relation to the human lifespan.

Renewable Energy Directive (RED). Officially titled as 2009/28/EC, is a EU directive which mandates levels of renewable energy use within the European Union. The directive was published on 23 April 2009 and amends and repeals the 2001 *Directive on Electricity Production from Renewable Energy Sources*. It requires the EU to fulfil at least 20% of its total energy needs with renewables by 2020 – to be achieved through the attainment of individual national targets. All EU countries must also ensure that at least 10% of their transport fuels come from renewable sources by 2020. A new *Renewable Energy Directive* for the period after 2020 is in preparation.

Renewable energy tax credit. A renewable energy credit is any tax credit offered by a local or federal taxation authority as an incentive for the installation and operation of renewable energy systems such as solar or wind power. Renewable power generation creates power in the form of electricity, and environmental benefits to society from 'green' power production – such as minimising pollution and slowing the rate at which finite fuel resources are used. The electricity is sold into the local grid, and the societal benefits are sold in the form of Renewable Energy Credits (RECs), sold separately as a commodity into the marketplace. For each REC purchased the customer is able to claim the equivalent MWh of energy reduction as on offset to their conventional energy use.

Renewable feedstock. This can be defined as any renewable, biological material that can be used directly as a fuel, or converted to another form of fuel, energy or bio-based material product. Biomass feedstocks are the plant and algal materials used to derive fuels like ethanol, butanol, biodiesel, and other hydrocarbon fuels. Organic wastes are assuming greater importance politically as renewable feedstocks.

Renewable Fuels Standard (RFS). The RFS is a US federal programme that requires transportation fuel sold in the US to contain a minimum volume of renewable fuels. The RFS originated with the Energy Policy Act of 2005 and was expanded and extended by the Energy Independence and Security Act of 2007 (EISA).

Salination. Soil salinity is the salt content in the soil; the process of increasing the salt content is known as salination or salinisation. Salts occur naturally within soils and water. Salination can be caused by natural processes such as mineral weathering or by the gradual withdrawal of an ocean. Salinity from irrigation can occur over time wherever irrigation occurs, since almost all water contains some dissolved salts. Soil salinity has detrimental effects on plant growth and yield.

Small to medium enterprise (SME). In the EU, an SME can be defined as a firm with revenues of EUR 10–50 million or a balance-sheet total of EUR 10–43 million. In general, an SME has up to about 250 employees. SMEs are very common in biotechnology, especially in research-intensive firms. Many firms are involved in industrial biotechnology and attempt to make sustainable alternatives to fossil-derived goods.

Soil destruction. Soil destruction can include soil erosion. Soil can also be destroyed by salination, over-fertilisation and industrial pollution. If, for example, a soil becomes so contaminated with heavy metals from industry that it cannot be used in agriculture, it would be considered ‘destroyed’, although the soil itself remains.

Soil erosion. Soil erosion is defined as the wearing away of topsoil. Topsoil is the top layer of soil and is the most fertile because it contains the most organic, nutrient-rich materials. Therefore, this is the layer that farmers want to protect for growing their crops and animals. Soil erosion can have several causes. A prime concern in sustainability is erosion caused by deforestation.

Solvent. This is a liquid, typically other than water, used for dissolving other substances. Often solvents are non-polar liquids that are toxic to humans and pose threats to the environment if released accidentally. Another major function of solvents is to clean surfaces, and biodegradable solvents have been developed as potential replacements for more harmful solvents in such applications.

Supply chain. A network of individuals or organisations that: performs the functions of procurement of materials; transformation of these material into intermediate and finished products; and distribution of these finished products to customers.

Sustainable development goals (SDGs). These are an inter-governmental set of 17 aspiration goals with 169 targets. The goals are contained in paragraph 54 of the United Nations Resolution A/RES/70/1, of 25 September 2015. They are officially known as *Transforming our world: the 2030 Agenda for Sustainable Development*. They include ending poverty and hunger, improving health and education, making cities more sustainable, combating climate change, and protecting oceans and forests.

Sustainability. This term is in common use but is hard to define. Human and ecological sustainability have become intermingled with the emergence of climate change as a major societal challenge. Defining sustainability as a part of the concept of sustainable development, the Brundtland Commission of the United Nations in 1987 stated that: “*sustainable development is development that meets the needs of the* *present without compromising the ability of future generations to meet their own needs*". It reflects the realisation that economic growth has to be achieved with minimal environmental damage if the effects of climate change are to be controlled.

Sustainability indicators. Ecological and environmental indicators have been intermingled in assessing sustainability. One subset of environmental indicators is ecological indicators which include physical, biological and chemical measures such as atmospheric temperature or the concentration of ozone in the stratosphere. These are also referred to as "state" indicators as their focus is on the state of the environment or conditions in the environment. A second subset is indicators that measure human activities or anthropogenic pressures, such as greenhouse gas emissions. These are also referred to as "pressure" indicators, *i.e.* they measure the pressures that humans place on the environment. Finally, there are indicators, such as the number of people served by sewage treatment, which track societal responses to environmental issues.

Synthetic biology. The application of science, technology and engineering to facilitate and accelerate the design, manufacture and/or modification of genetic materials in living organisms. It aims to bring an engineering approach to biotechnology by design and engineering of biologically-based parts, novel devices and systems as well as redesigning existing, natural biological systems. It has clear and current applications to bio-production of chemicals, plastics, textiles and other materials.

Value-added. The additional value, in customer terms, created at a particular stage of production.

Value chain. The value chain identifies the various value-adding activities of an organisation or network. It is often used as a tool for strategic planning because of its emphasis on maximising value while minimising costs.

Waste. This means any substance or object which the holder discards or intends to, or is required to, discard. This narrow definition avoids the implication that the material or object serves no further use. In the context of sustainability, waste minimisation is an important concept. Billions of tonnes of organic waste materials are produced worldwide every year, and a great deal of these waste materials could be used as a source of biomass for the production of bio-based materials.

Waste hierarchy. Waste disposal legislation has introduced a hierarchy of options for managing wastes. It gives top priority to preventing waste in the first place. When waste is created, it gives priority to preparing it for re-use, then recycling, then other recovery such as energy recovery, and last of all disposal, *e.g.* landfill.

Waste-to-energy. The practice of processing waste products to generate steam, heat, or electricity.

Wastewater and wastewater treatment. Wastewater is any water that has been adversely affected in quality by human influence. Wastewater can originate from a combination of domestic, industrial, commercial or agricultural activities, surface run-off or stormwater, and from sewer inflow or infiltration. Wastewater treatment is the process whereby wastewater is treated to render it innocuous and/or reusable. Biological wastewater treatment plants, known more widely as sewage treatment plants are more sustainable than non-biological processes and are deployed worldwide. Wastewater treatment and reuse is considered essential to future water security.

Water security. The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems.

Zero waste. The goal of developing products and services, managing their use and deployment, and creating recycling systems and markets in order to eliminate the volume and toxicity of waste and materials and conserve and recover all resources. Implementing zero waste eliminates all discharges to land, water, or air that may be a threat to planetary, human, animal or plant health.