

Looking at Possible Future Change

Biochar Deployment Scenario for UK in 2030

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1 Context

Future use of biomass is expected to be hugely uncertain as their use and growth has conflicting interests in terms of associated land-use change, food security, climate change, biodiversity and other environmental impacts, and can be further complicated by rising demand for them by different competing uses (ranging from traditional uses to bioenergy systems), and changes in policy drivers on the national, EU and global scale. In recent times, scenarios have emerged as means of characterizing the future and its uncertainties through structured, imaginative yet self-consistent storylines to look beyond conventional wisdom for many applications including socio-economic and environmental change assessment (MA, 2005; EEA, 2007; Shackley and Deanwood, 2003; Rounsevell and Metzger, 2010). Therefore, the aim of this scenario exercise is twofold. Firstly, to limit exploring the uncertain future decision-making context for biochar deployment potential in Europe through constructing storylines/ narratives; secondly, to translate these storylines to examine the availability level of biomass and scale of biochar deployment potential in the UK under a discrete number of possibilities ('constrained uncertainty').

2 What is a scenario and why we need them

According to Millennium Ecosystem Assessment report, 2005, Scenarios have been defined as- '... plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships' (MA, 2005). In recent times they are preferred over predictions or forecasts in environmental studies. This is because environmental systems are considered as complex systems that have the characteristics of radical sensitivity to initial conditions and branching behaviours at critical thresholds due to emergence and chance events, therefore, contains 'many futures' that single predictions can hardly accommodate (Raskin et al., 2002; Van Vuuren et al., 2012). Scenarios thus became popular to assess environmental systems, for not being predictions rather as explorative analysis tools that try to communicate visions to examine arrays of development pathways or key branches that the future might unfold. The purpose is not to explicitly identify future events, rather to explore possible forces that can be in place to alter the future in different directions. Thus scenario analysis is usually designed to offer fresh perspectives, critical thinking that can help in identifying uncertainties and challenges we will face in the future. Creating contrasting scenarios has become popular as creative structured scenarios can work as 'learning space' to explore potential outcomes from different assumptions and potential strategies or policies (Volkery, et al., 2006).

Modern day scenario techniques came firstly through Herman Kahn and colleagues at the Rand Corporation in the 1950s for the US Air Defence System Missile Command, which were later applied to social forecasting and public policy after Kahn formed Hudson Institute. Their methods were later adopted by business communities, initially by Royal Dutch Shell in the 1970s in Europe, to understand uncertainties of the global oil market, and then building strategic contingency plans accordingly for better stable business management (Wack 1985a,b). Depicting human-environment interactions driven by concern about climate change, SRES storylines by the Intergovernmental Panel on Climate Change (IPCC) (Nakicenovic et al 2000) has brought the role of scenario storylines at the front-line in environmental change assessment, policy, planning and strategy making. SRES scenario has been the most widely used scenario analysis framework and were followed in similar or modified form in numerous studies (e.g. Arnell et al., 2004; Gaffin et al., 2004; Grübler et al, 2007; Hoogwijk

et. al., 2005, 2009; Lorenzoni et al, 2000, Van Lieshout et al., 2004; Rounsevell et al., 2006; Shackley and Deanwood, 2003). Around the time SRES was published, two more genres of scenarios emerged. Great transitions Scenario by the Global Scenario group (Raskin et al., 2002) was mostly qualitative of nature while UNEP's Global Environmental Outlook (GEO3) took the middle stance-relied equally on storylines and quantifications (UNEP, 2002).

3 Data and methods: developing the biochar deployment scenario

Principally the methodology used for this scenario exercise has been adopted from Shackley and Deanwood, 2003, and it is further structured in the light of extensive literature survey of relevant scenario studies. It is worth mentioning here that since scenarios become more widely used these days, various scenario typologies have been suggested but there is no consensus on the right typologies (e.g. Tapio and Hietanen, 2002; Inayatullah, 1990; Marien, 2002; Börjeson et al., 2006; Van Notten et al., 2003). But broadly it has been suggested that future studies should explore possible, probable and preferable futures that provided three principle branches namely predictive, explorative and normative scenario respectively (Börjeson et al., 2006).

But the typology by Van Notten et al. (2001) is arguably thought to receive wider acceptance as a valid starting point to categorise scenarios based on project/ research goal (why?), process design (how?) and scenario content (what?). Subsequently this has been adopted for this study to further structure the methodology adopted (figure 1).

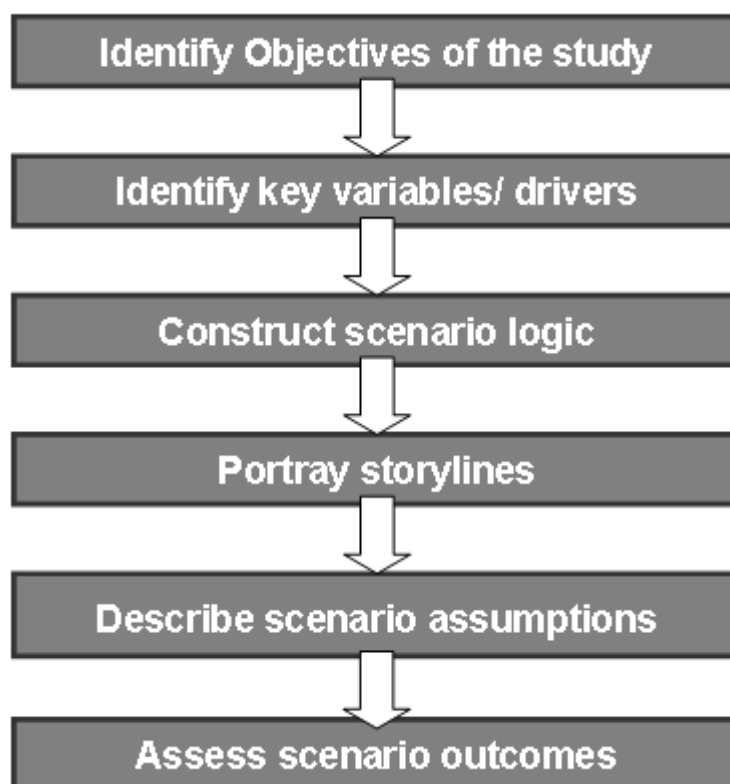


Figure 1: Stages of scenario development (adopted from UKCIP, 2000; Shackley and Deanwood, 2003; Rounsevell & Metzger, 2010)

The goal is to create descriptive exploratory scenarios instead of normative scenarios based on intuitive logic in which different assumptions about arrays of development pathways under different drivers lead to potentially different outcomes for a snapshot in the future (i.e. the year 2030). Drivers are assessed and assumptions are made primarily qualitatively while scenario outcomes are assessed quantitatively. Data are modified or adopted based on desk research while scenario logic and storylines are created and modified through group discussions/ workshops.

Thus the key steps followed can be structured as follows: identifying the key objective, key drivers; defining the scenario logic/framework and storylines; describing scenario assumptions based on the scenario logic, storylines and drivers identified; and finally assessing the scenario outcomes in terms of biomass availability and deploy-ability of biochar. These are further detailed in the next section.

4 Scenario Analysis

4.1 Key objective:

Key objective of this scenario exercise is to explore biochar deploy-ability or development pathways based on a variety of perspectives i.e. to accommodate profound structural social environmental changes and to explore consequences of different strategic or policy decisions so that awareness or uncertainties on the possible future of biochar can be raised, and thus some critical creative thinking can be instilled into its future research.

4.2 Key drivers:

Influences by and interactions amongst the drivers are key to direct different pathways for the outcomes from scenario analysis. These are mostly drawn from the broad continuum of drivers, commonly known as STEEP (i.e. Social, Technological, Economic, Environmental, and Policy drivers) (Bradfield et al, 2005). Key driving factors considered while developing storylines for biochar scenarios are relevant environmental policies (e.g. sustainability criteria for biomass, Common Agricultural Policy), competition for biomass from other uses, level of imports, price of oil and gas and market logic for biochar, land-use/ diversification of land, carbon market, technological development pathways which will lead to different level of biomass availability for biochar and different number of production units.

4.3 Scenario logic:

Storylines and assumptions for different drivers are structured and based on the framework which is called 'scenario logic'. Such structure can help in organising divergent issues through making internally consistent assumptions. The SRES matrix by IPCC is the most common place for constructing scenario logic in environmental issues. The aim is also to create a mix of contrasting or peripheral scenario instead of surprise-free or trend-line business-as-usual scenarios.. The IPCC SRES framework as adopted in the REGIS project (or a more detailed version as adopted in the UK Climate Impacts Programme report on socio-economic scenarios) has been fast-tracked here to create four

main narratives: World Markets, Global Sustainability, Regional Enterprise and Local Stewardship (Shackley and Deanwood, 2003) (fig. 2).

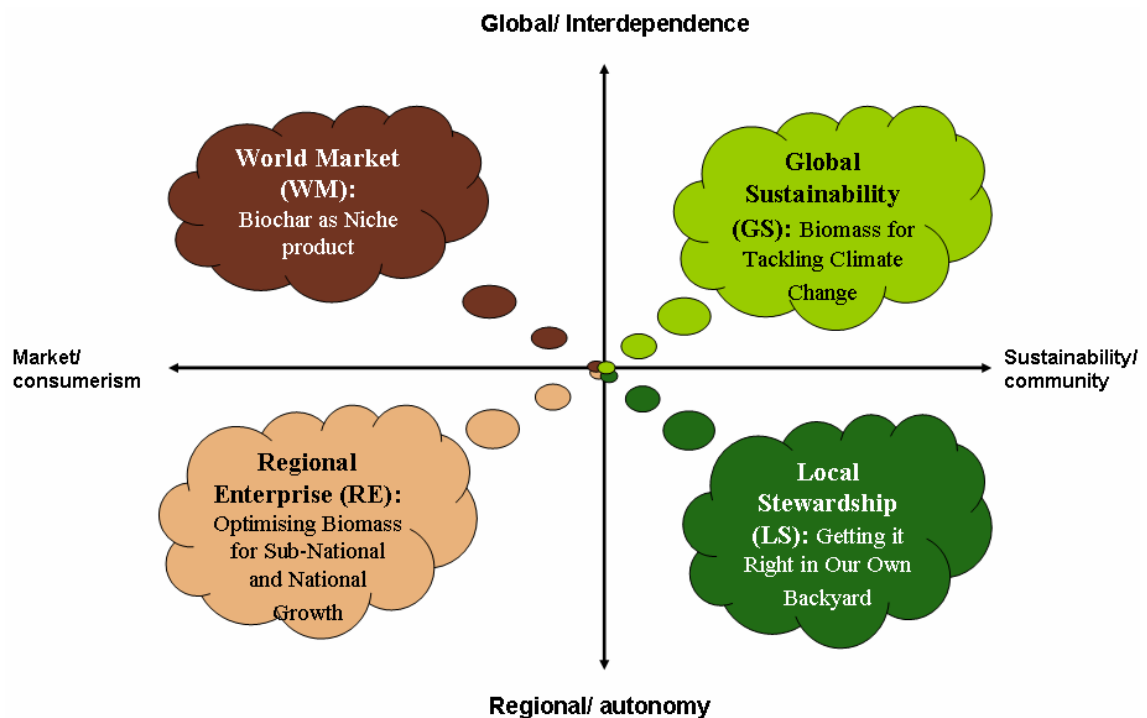


Figure 2: Scenario logic for biochar deployment in the UK in 2030

4.3 Storylines

A storyline (often called as a *narrative*) is the main component and starting point for constructing a scenario. It is qualitative in nature, and provides the description about different future development pathways based on assumptions on the influence of drivers, consequences or outcomes. It is important in the sense that it is an effective way of disentangling complex relationships between different drivers which are difficult to model or quantify due to limited knowledge or higher uncertainty, and it helps to constrain the unlimited possibilities of the future through a few stylized story lines that represent the main branches (Nakicenovic et al 2000; UKCIP, 2000; Raskin et al., 2002; Shackley and Deanwood, 2003; MA, 2005; Rounsevell et al., 2006). Detailed description of the narratives for the four scenario markers is provided below.

4.3.1 World Markets (WM): Biochar as a Niche Product

This is the global capitalism scenario and is most similar of all the four scenarios to the neo-liberalist inspired contemporary world that has emerged from processes of late capitalist globalisation and modernisation over the past 30 years. The market logic rules and promotes the most cost-effective use of biomass resources – i.e. in terms of what makes most money most quickly. Climate change has gone down on the political agenda and is discounted by most financial institutions and governments. Oil and gas prices do not rise as highly as many feared due to the continued discovery of new

supplies, such as shale gas, and the continued innovation around enhanced oil and gas recovery. Technologies for converting coal into gas and liquids also improve relieving pressure on oil supplies for transport fuels. This greater supply of fossil fuels tends to depress investment in renewables, slowing down R&D and innovation.

In this scenario, competition for biomass is high because innovation promotes a range of biochemical / biotechnological and thermo-chemical conversion routes. Biorefineries have developed in response to innovation and demand for more organic-based materials and products. In general, criteria for evaluating the sustainability of feedstocks are relaxed in this scenario. Trade in biomass is encouraged and regulations left to countries from which biomass is extracted (which are frequently lax).

In this scenario, biochar is largely a niche technology and option. It does quite well as an addition to chemical fertilisers and incorporated with compost in organic agriculture. Biochar also has a niche role in horticulture and in the domestic sector, where it appeals as a more sustainable growing media. Organic foods is a strong niche sector in this scenario, but it never really expands beyond the c. 10% level and remains a preserve of the more wealthy sections of society. This scenario is a world of uneven wealth distribution, inequalities and disparities in opportunities.

The pyrolysis units (PU) developed will be determined purely on efficiency grounds. They will generally be bespoke biochar PU facilities and not have the ambition of producing bioenergy by-products – in general fossil fuels remain the fuel of choice for energy generation.

Carbon markets do exist but the market does not value carbon abatement very much, hence this is not a major driver of innovation on low-carbon technologies. It remains, as at present, something of a voluntary and low-level policy driver.

The general philosophy behind nature conservation / protection is that it should 'pay for itself' rather than being a burden on the general tax payer. This tends to prioritise the more spectacular, visible and prominent nature conservation areas and lends less support to areas that are predominantly of local and regional interest.

4.3.2 Global Sustainability (GS): Biomass for Tackling Climate Change

In this scenario, biomass resources at the global scale are mobilised to tackle the global challenge of climate change. Wherever biomass can be utilised to reduce CO₂ emissions to atmosphere, or to draw down CO₂ from atmosphere, then this is prioritised over other users of biomass. In version (a) of the scenario, this will tend to prioritise bioenergy CO₂ capture and storage – BECCS. BECCS is able to achieve a higher net carbon abatement than biochar and can work at the large scale typical of existing electricity power generating facilities. Fit into existing power generation and distribution networks is a distinct advantage in this scenario. Hence, most of the biomass is diverted to BECCS, meaning that pyrolysis-biochar (and other biomass technologies) are limited in extension and development. Non-BECCS utilisation of biomass is typically small-scale.

In version (b) of the GS scenario, BECCS does not take off, may be because CCS itself is not found to be effective. Hence, there is a lot more biomass around that can be used for other bioenergy

technologies, including district heat, AD, biochar, 2nd & 3rd generation fermentation, biorefineries, etc.

An international regime / treaty for climate change and greenhouse gas emission controls has been successfully negotiated, implemented and enforced. Some serious natural disasters have taken place that are widely considered to be attributable to anthropogenic climate change. This has spurred countries, initially reluctant to take decisive action, to become much more engaged and to sign-up to ambitious deep carbon emission reductions. This has fostered a lot of serious investment in a whole range of low-carbon energy technologies, though there is a tendency towards larger-scale options and of readily scaleable options.

Carbon markets are one of the key policy incentive mechanisms and are international in scope. Governments work together to remove carbon emission allocations from markets in tranches, hence driving up the carbon price. This provides the single strongest incentive for low-carbon innovation.

There are comprehensive sustainability constraints on biofeedstock supply with a focus on avoiding carbon debt from land-use change / indirect land-use change and protecting major biodiversity resources. The degree of control on what is added to soils is similar to the level of control experienced today. The level of protection of natural areas is similar to that today and does not increase except in the case of nature conservation areas that are of importance internationally.

The organic foods sector has expanded from current levels, based upon large-scale organic farming efforts in agricultural regions which brings down prices. Furthermore, conventional agri-produce is priced more highly due to the greater inclusion of the external environmental costs of food production in agricultural systems – i.e. environmental taxes on fertilisers, pesticides, higher costs of water irrigation, further restrictions on nitrates and phosphates, etc.

4.3.3 Regional Enterprise (RE): Optimising Biomass for Sub-National and National Growth

Global trade is reduced in this scenario. This limits imports from outside of Europe. The partial disintegration of the global market means that fossil fuel trade is reduced compared to today. This puts the onus on more efficient recovery and use of available regional fossil fuels – predominantly Norwegian and Russian. Political tensions with Russia are an issue for gas and oil imports but the presence of good pipeline infrastructure and the sheer economic value of the trade for Russia means that solutions can be found. Nonetheless, the lack of a global trade pushes up fossil fuel prices and volatility significantly, incentivises the exploitation of indigenous coal reserves and encourages the innovation in renewable energy supplies.

The European region becomes generally self-sufficient in its utilisation of biomass. This means that supply over all is constrained and prices therefore increase. In turn, this results in more efficient recovery and re-use of organic resources. Most of the spare biomass in Europe comes from Scandinavian timber production and, to a lesser extent, from central and eastern Europe. Trade with Russia is possible but somewhat sporadic and uncertain due to on-going political tensions.

Controls on biomass imports are quite strict, this being due to trade barriers. Failure to meet sustainability criteria is one of the rationales for limiting biomass trade from outside Europe (i.e. used as a trade barrier), though these same criteria do not apply to biomass trade within Europe. In this scenario, there is less concern about protecting nature conservation areas and only the most highly

valued designated areas are maintained. Policy on what is added to soils is a bit more relaxed than today. The size of the organic foods sector is somewhat larger than today, this being due to the concerns of some wealthier consumers about food quality and the less readily available supply of interesting or exotic foods from other parts of the world.

In RE, some digestates from sewage sludge processing and AD are available for thermo-chemical conversion into biochar. Likewise organic wastes from biorefining type operations.

There is a focus in this scenario on local and regional solutions to power and heat production, e.g. local, neighbourhood and district CHP schemes using wood chips. Despite the increasing costs of biomass feedstocks, these options are still attractive at the small- to district-scale due to the high costs of fossil fuel alternatives, especially where reasonable local biomass supplies exist. However, the availability of sufficient feedstock resources typically limits the scale and extent of deployment.

4.3.4 Local Stewardship (LS): Getting it Right in Our Own Backyard

The LS scenario is the typical green vision of strong sustainable local communities. Countries have finally woken up to the threat of climate change and have worked through the UN to come up with stringent carbon reduction targets. This is devolved to the national level, which in Europe has further devolved the responsibility to the sub-national scale. This means that sub-national states and regions are given carbon tax-raising powers. The revenues from carbon taxation are then recycled to pay for low-carbon R&D, innovation and incentive schemes, such as Feed-in-Tariffs for renewables. The sub-national scale is also given the power to determine what low-carbon technologies and options are incentivised and by how much. Carbon markets are not widely used and are generally not trusted.

Global trade is limited due to a move away from material consumption as the main objective of policy making. The ‘wealth beyond prosperity’ argument (e.g. Jackson and UN’s Inclusive growth Index¹) has been widely accepted. Stringent sustainability criteria are also used to regulate trade and investment and meeting these criteria has tended to restrict import and export, encouraging a shift to local self-sufficiency. These criteria are applied equally stringently for biomass that is sourced domestically. There has been a large increase in community-owned and managed woodlands and more active woodland management – changes which have resulted in more arboricultural arisings, prunings and wood wastes becoming available for producing biochar. There is an onus on protecting the integrity and ‘health’ of soils and stringent controls on what can be used as a soil amendment.

Extensification of agricultural production and consumption of organic food has become the norm. Taxation on fertilisers and other chemical inputs, as well as demand-side shifts against intensive agri-food systems, has greatly restricted intensive agriculture. There has also been a shift away from eating meat and dairy products, so freeing up large amounts of land that was previously used for producing meat and animal fodder. Many communities have taken up local food production with enthusiasm and food miles have plummeted.

In the LS scenario, there are very efficient and creative uses of organic wastes. Small-scale AD plants are developed for use at the household and village / small community scale. Small-scale biochar production fits well into this, utilising small arisings of timber, arboricultural arisings and other dry

¹ <http://www.ihdp.unu.edu/article/read/iwr>

<http://www.mindfulmoney.co.uk/12689/knowledge-bank-/beyond-gdp-measuring-natural-wealth.html>

organic wastes, AD digestates, etc. Small scale units tend to be stand-alone biochar producing facilities, though heat is recovered for the purposes of feedstock drying and, where feasible, e.g. where a district heating system already exists, for space heating.

Fossil fuels are very expensive in the LS scenario, this being due to the very high carbon taxes which are imposed upon their use for the purposes of limiting climate change. The eventual aim of the carbon taxation approach is to keep fossil fuels in the ground rather than being extracted, used and contributing to carbon dioxide emissions. CCS is not a technology which receives any support in Europe in the LS scenario – this being because it is not regarded as a long-term sustainable option, but rather one which literally buries the problem. Summary of these narratives are provided in the following text box.

:: Summary from storylines ::

❖ World Markets (WM): Biochar as a Niche Product

- Promotes the most cost-effective use of biomass resources.
- Climate change has gone down on the political agenda and sustainability criteria for biomass is relaxed than today. Only globally recognized areas of conservation (i.e. Natura 2000 sites²) will be protected with much less concern over local and regional ones.
- Oil and gas prices is stable enough.
- Investment in R&D and innovation in renewables is slow.
- Less focus of carbon markets on carbon abatement and low-carbon technologies.
- Competition for biomass is high.
- Higher import and trade is allowed.
- Biochar production remains small or medium scale³, given its role as sustainable growing media targeted to niche market (like organic agriculture).
- These are char dedicated PUs as fossil fuels remain the fuel of choice for energy generation.

Global Sustainability (GS): Biomass for Tackling Climate Change

- Climate change will go high on the political agenda and sustainability criteria for biomass is strictly followed at all scales.
- Underutilized biomass resources at the global scale are mobilised rapidly (e.g. bamboo, sugarcane bagasse, rice husk etc.) to tackle the global challenge of climate change (GHG abatement) which leads to two versions of scenarios under GS.

With BECCS	Without BECCS
BECCS go large scale and use lion share of the	BECCS does not take off (due to different

² The Natura 2000 network consists currently of nearly 26 000 protected areas and has a total area of more than 850 000 sq. km, representing approximately 18% of the total EU terrestrial area

³ Small scale~2000 odtpa; medium scale~16000 odtpa and large scale~ 185000 odtpa (Shackley et al., 2011)

<p>available biomass while biochar and other biomass technologies stay in similar scales as depicted for WM.</p>	<p>socio-economic and political barriers), other bioenergy technologies (i.e. AD, District heat, PBS, biorefineries) can go medium to large scales along with the smaller ones.</p>
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- Investment in R&D and innovation in renewables will remain high.
- Higher focus of carbon markets on carbon abatement and low-carbon technologies, leading to high carbon price.
- Market for sustainable growing media has increased due to larger organic market.

Regional Enterprise (RE): Optimising Biomass for Sub-National and National Growth

- Climate agenda similar to WM. But trade on biomass and fossil fuels is limited to Europe means higher price of biomass and fossil fuels than that in WM and GS.
- Due to constrained resource availability and stricter trade barriers, better use of organic waste, and better extraction, logistics and management of residues (i.e. forestry residues from Norway and Sweden along with Central Europe are coming to markets across Europe).
- Protection of conservation areas are same as WM and GS. Sustainability criteria over biomass strictly applies outside Europe.
- Organic market is larger than WM but lower than GS. Digestate and other by-products from bio refineries to make better use of resources along with higher demand for sustainable growing media in organic market will put demand and supply for biochar ahead of WM.
- On efficiency ground all Bioenergy technologies (i.e. AD, District heat, PBS, bio refineries) will flourish but stay medium to small scale due to constrained availability of resources.

Local Stewardship (LS): Getting it Right in Our Own Backyard

- Climate change agenda has reached maximum outreach and managed to set stringent carbon reduction targets at national and sub-national scales.
 - Along with similar trade barriers like RE, LS employ stricter sustainability criteria on domestic biomass.
 - Due to less material consumption (e.g. wealth beyond prosperity' argument (e.g. Jackson and UN's Inclusive growth Index)), waste generation and agri-produce will be lower which means lower biomass availability than GS, but higher demand for sustainable growing media than LE due to tight environmental taxes imposed on other agricultural inputs.
 - Biochar along with other bioenergy technologies is operating in small and medium scales with attention on recovering and using by-products for energy production due to higher prices of fossil fuel than other scenarios.
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4.4 Scenario assumptions

Common Agricultural Policy (CAP):

In 2030, Cap still is kept as the biggest share of the EU's annual budget and the two-pillar system stays. In the WM and RE scenario, CAP has not changed a lot or remained BAU as direct payments and price support (pillar one) still account for more than 70% of the CAP budget (approx. 43 billion euros), while rural development (pillar two) gets less than a quarter. Large agri-businesses and big land-owners receive more from the CAP in these scenarios. But in the GS and LS scenario, only 30% of the 'direct payment', as income support payments, are received by farmers. To qualify, arable farmers have to grow at least three different crops, to promote biodiversity. Farmers have to leave 7% of their land fallow, to encourage wildlife, keep soil healthy which promotes use of sustainable growth media/ soil amendments, particularly biochar. This policy driver will have a radical role in the LS scenario, boosting stronger multifunctionality of land than in any other scenarios.

Sustainability constraints:

In the WM scenario, current sustainability criteria is relaxed to some extent which means 2G biofuels can still use majority of the domestic and international supply of biomass with laxer GHG abatement efficiency compared to fossil fuels. In this scenario, the policy makers consider modern biomass as an attractive business worldwide. Therefore, more rigid sustainable requirements are considered not practical. Over-regulation of the bioenergy market is thought to impede rather than promote its continued development, both in the UK and potential supplier countries, especially as this is a non-commoditised market. Current level of conservation area protection criterion as followed in the WM scenario is also maintained in the GS and RE scenario, and only internationally recognised conservation areas (e.g. Ramsar sites, Sites of Specific Scientific interests, Natura 2000 etc.) are protected. In the WM scenario, biomass is continued to be sourced from regions where extraction is not regulated at the same level as EU, therefore, endangering food supply of communities where the use of biomass is essential for subsistence (e.g. building materials, medicines etc.), and also adversely affecting protected or vulnerable biodiversity. Meanwhile in the LS scenario, the UK Government recognise that, whilst much of the UK sourced biomass is sustainable in that it is produced under national agricultural or forestry certified schemes, at the global level deforestation and illegal logging continue, and the extent and coverage of sustainability assurance is limited. Past EU RED policy had been blamed vigorously for 'land-grabbing', causing rapid direct and indirect land-use change (plantation replaces high biodiversity areas or food crops), degradation of soil, and abusing rights of local communities or displacing many vulnerable ones in developing countries from where feedstocks are being imported to EU (as claimed by ActionAid 2011; Oxfam 2011). This has already resulted in more robust sustainability criteria which pave way for more sustainable local and international biomass resource management. Mandatory sustainability criteria are established at the LS scenario that extends GHG saving criteria imposed on 1G biofuels and bioliquids feedstocks to 2G sources (i.e. residues and other virgin biomass not in conflict with food security). It also includes direct and indirect land use change (LUC and iLUC), preservation of carbon stocks and highly biodiverse areas, social barriers etc. along with additional criteria for sustainable land-use management, particularly level of soil nutrient & long term carbon balances, influence of organic and inorganic fertiliser and their influence on crop, soil and water sustainability (e.g. nitrate leaching, eutrophication & acidification etc.). This brings wider application of sustainable growth media,

particularly use of biochar from sustainable local feedstock sources. Since 2013, DECC has started to enforce more rigid cross-compliance in bioenergy incentives i.e. issuance of ROC is tied with the sustainability criteria of biomass used. Such acts have stopped heavy reliance on imported biomass in the LS scenario but sustainable trade continues within Europe in the RE scenario. Where dedicated energy crops replace previous land uses like arable, grassland or forestland, the carbon debt (i.e. carbon 'pay-back' time) or carbon credit (i.e. carbon sequestration potential) are being considered. More examples of local sustainable supply chain management and biomass production are emerging through public-private partnerships (e.g. similar to China Green Carbon Foundation in Yunnan, China or Veracel Celulose, Bahia State, Brazil) to target international market in the GS scenario. Similarly in the LS scenario well-managed and appropriately located plantations form part of healthy, diverse and multi-functional forest landscapes (e.g. via implementation of the woodland Carbon Code by the UK Forestry Commission), compatible with biodiversity conservation, local social needs i.e. stronger rural multifunctionality (Wilson, 2008; 2009). More research into better understanding of detailed information about different components along the supply chain are being better dealt with, thereby reducing uncertainty regarding dynamics of carbon stock (above and below ground) against the land-use concerned, ecosystem services (e.g. biodiversity, water quality), geographical location and physical characteristics of land (soil), complex interaction between land and crop concerned etc. These information are constantly being fed into robust standardised Life Cycle Assessment (LCA) tools which facilitate development and use of better certification schemes (e.g. variants of the past FSC4, UKWAS5, PEFC6) and national policies (agro-ecological zoning and ecosystem services) in use for sustainable biomass production and consumption issues. Rigorous implementation of such criteria see all imported forms of biomass as prohibited. Implementation of sustainability criteria in GS is also dominated by the Global Carbon budget as developed by Global Commons Institute based on Contraction and Convergence (C&C)⁷

Technology learning pathways

Technical change is a gradual process and evolves through different stages (i.e. R&D, demonstration, commercialization, market accumulation, Diffusion). In the microeconomic context, learning curves emerged as an empirical method for analysis of the effect of learning on technical change. They measure technical change as cost improvement of a product or technology as a result of learning, and is often termed as "learning by doing" (Jamasb and Köhler, 2007). The learning effect is measured in terms of reduction in the unit cost (or price) of a product as a function of experience gained from an increase in its cumulative capacity or output. In other words, given sufficient investment in deployment, *learning-by-doing* will drive down unit costs over time towards commercialisation (Winkel et al, 2008). But innovation processes in real world are much more

⁴ Forest Stewardship Council

⁵ Woodland Assurance Scheme by the Forestry Commission, UK

⁶ Programme for the Endorsement of Forest Certification by the Canadian Standard Association

⁷ C&C is a framework for the negotiation, planning and implementation of a global carbon budget on CO₂ emissions. The budget is split up into annual allocations. There is a year-on-year contraction (or reduction) in the size of the annual allocation. C&C allows for this rate of contraction (or reduction) to be adjusted periodically as understanding of the climate science improves. C&C allocates emission entitlements to every country. Starting with current emissions levels, it proposes a scheduled convergence to equal per-capita entitlements globally by an agreed date (ZCB, 2010).

complex, an attempt to portrait them with a single learning rate in two dimensions can hide important differences (e.g. correlation between market growth and cost reduction has been unclear, and should not be assumed a priori given past experiences with many energy technologies (ibid.). Although significant *learning by doing* is involved, development of empirical learning curve for biochar production systems is difficult given the array of feedstocks it can use, production scale and non-existence of a dominant design/ configuration, multiple outputs (gas, oil and char), location-specific variations in capital and variable costs, and varying performance of technologies.

The Learning pathways matrix (by Winskel et al., 2008) can provide a better picture to cater these bottlenecks and thereby have been adopted here. The four axis comprises technical progression dimension (radical step-changes to incremental progression) and social dimension (concentrated or distributed institutional way of knowledge transfer).

As can be seen in the figure, the WM scenario still stays in the lower left quadrant given less impetus for technological progression in bioenergy and biochar production technologies. Besides, less dynamic learning mechanism exists given the niche small scale market and the technology at the hand of a few dominant market players (e.g. Carbon Gold's Grow Char). The GS and RE scenario see, on the other hand, more concentrated use of knowledge transfer due to global and regional 'technology push' and 'market pull' mechanisms in play for sustainable bioenergy deployment . These spillover effects will be felt by biochar R&D&D in these scenarios with some radical progression in technology (in terms of both *learning by research* and *learning by doing*), especially in the GS scenario which see some radical progression due to effective local dissemination of global knowledge . The GS scenario has, therefore, seen good progress in all biochar production technologies while radical progress has been made in the RE one for fast pyrolysis and gasification technologies given the need for more bioenergy than in any other scenarios. Advanced biomass integrated fast pyrolysis and gasification combined-cycle power plants (that produces more energy than char) are already in commercial stage of deployment in the RE scenario along with revolutionary breakthroughs in terms of mass-scale biological conversions and bioenergy from algae. Along with cases in the GS scenario, the LS one will witness more incremental progression in slow pyrolysis due to greater need of biochar as sustainable growth media /soil amendment and its demonstrated ability to sequester carbon. This is partly due to the success of large number of small-scale prototypes that already shared their learning experiences (*learning by using and interacting*) in global and regional communities (e.g. national, regional and global initiatives by IBI, demonstrated trials and knowledge sharing by successful EU biochar projects like Interreg Biochar project, EU Cost Biochar project etc.), resulting in higher successes in up-scaling and cost reductions. Such technologies in the LS and GS scenario have been largely able to attract and mobilise greater economic, organisational and political resources. As the LS and RE scenario rely more on local scale renewable energy, there will be more microgrids⁸ and distributed generation⁹ benefiting from

⁸ A microgrid is a small-scale power supply network (with or without heat) designed to provide power for a small area such as a rural community from a collection of decentralised energy technologies, and connected at a single point to the larger utility grid (Chowdhury et al., 2009).

variety of feedstocks locally available (e.g. aboricultural arisings, straws). Pyrolysis Biochar System (PBS) fit really well into such settings, providing bioenergy and at the same time supplying biochar as sustainable growth media/ soil amendments. Thus the LS scenario locates itself in the bottom right quadrant for being highly coordinated, concentrated and well-integrated system with dominant best-practices design that provides optimal result (i.e. low-risk, low cost, higher yield , higher carbon abatement and soil improvement).

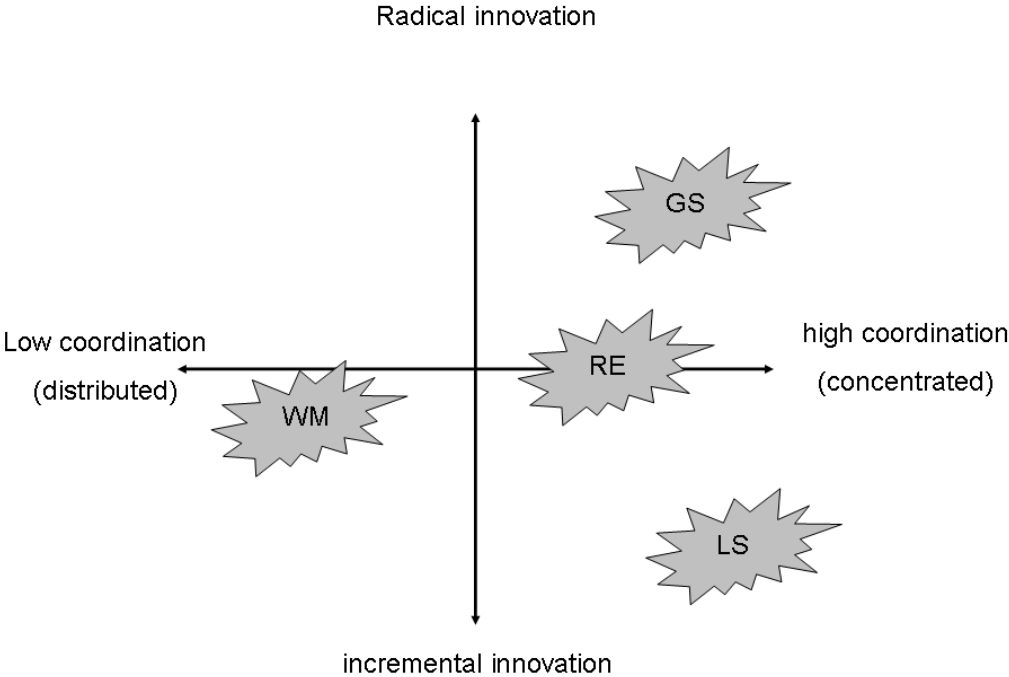


Figure 3: Technology learning pathways for biochar deployment

Land use types (broadbrush):

Key land-uses and changes in 2030 for the four scenarios revolve around multifunctionality transition theory (between degree of productivism and non-productivism) as promoted by Wilson, 2008 and 2009. The WM scenario promote highly globalised regions, therefore, have weak multifunctionality resulting in intensive productivist-driven agro-industrial farms promoting income maximisation, long food and fibre supply chains and low diversification of land-use. In the WM scenario, UK along with rest of the Europe continues to have larger land footprint than bigger countries from the developing world (e.g. average Europeans consumption is eq. to c 1.3 ha of land while China and India consumes less than 0.4 ha per person). In the GS scenario, Carbon taxes and credits are assumed to drive

⁹ Distributed generation can refer to power produced from both renewable and non-renewable sources while making sure the energy source and the consumer stay close together so that lesser energy is lost in transmission and distribution lines (ibid.).

drastic changes in agricultural land-use and promote multifunctionality more around the world, and also farmers reorienting their business accordingly market price signals. But it also promotes a levelled ground i.e. moderate multifunctionality where environmental sustainability stays as key but longer supply chain of biomass residues are encouraged to make their maximum use. The RE scenario experiences higher multifunctionality than the WM one, while the LS scenario also adopts stronger multifunctionality given disjointed nature with global market. To reduce reliance on fossil fuels, around 1 million ha of temporary grassland and marginal lands are converted to plant perennial crops, especially Miscanthus and Short-rotation Coppice (SRC) in the RE scenario. These energy crops along with other species are also promoted in the GS and LS scenario due to established evidence that these crops can provide micro-habitat diversity by optimising geometry of plantings, and also require lower amounts of agrochemicals and reduce physical disturbances. The LS scenario promotes the strongest agricultural and rural functionality characterised by strong socio, moral and environmental capital, resulting in low farming intensity and productivity, stronger local embeddedness between agricultural and rural actors. Thus in a lesser extent in the GS scenario but largely in the LS scenario concept of 'sustainable communities' is promoted i.e. communities that promote compact mixed land-use development, reduces pressure on energy use and infrastructure requirements while being sensitive to the environment, and overall a better quality of life and a stronger sense of community. In the LS scenario, product switching has been the basic approach where agricultural product mix already has moved away from high-emitting sectors (e.g grazing livestock) towards multifunctional land uses (e.g. agroforestry) that grow nutritionally-equivalent crop products with far less emissions. There is now a general consensus that organic farming is preferable, especially with respect to biodiversity, and best practices (that are less land and carbon intense) are being communicated widely amongst communities within the regions. Products from grazing livestock have become 'niche' markets due to their prices, and attract or rejuvenate urban agriculture at backyard or the City farm movements in abandoned lands. Along with many other sustainable growing media, multifunctional PBS (Ahmed et al, 2012 p. 490) fit well in this scenario and flourish as it can turn agriculture residues into biochar and bioenergy, improve soil structure, minimises chemical inputs, reducing emissions of nitrous oxide, nitrate leaching and other chemicals that adversely affect climate and other environmental factors. There are also novel ways to combine non-grazing livestock with woodlands and or perennial crops in this scenario.

Market logic (feedstock prices):

Unlike the trend in previous decades (i.e. bulk purchases by large end users typically done under bilateral contracts with the supplier), in the WM and GS scenario, international trade dominate the bulk biomass purchase market and thus prices seen in the UK are set by the international market. As a result, international demand influence the availability and price of biomass used in the UK. In the LS scenario, the UK Government influence choices in the individual, business and government sectors by internalising cost of carbon, either through trading or taxing, so that the true costs of emissions are accounted for. Such act and initiatives not only put significant impetus to active behaviour change but also influence individual purchase decisions by altering the relative cost of different options, as lower carbon choices also become the cheaper choices. Sustainability criteria, importability of biomass, demand influenced by different competing technologies at different scales also play a key role in ruling the market price especially in the RE scenario. Unlike the GS and WM scenario where

international market dominates and determine prices, specification, need and purchasing strategies of other end-use sectors (heat, electricity at small, medium and large scales) largely influence market prices of biomass in the RE scenario. Subsequently, there is no one biomass price, but a range of prices within the market place. In this scenario, small scale users experience higher prices than large scale users due to purchasing biomass on the spot market in relatively small quantities. On the contrary, larger-scale users have more access to long –term contracts, bulk purchase and the ability to use less processed feedstocks or more flexible feedstock specifications.

Oil and gas prices:

In the WM scenario, prices of oil have risen to a level which consequently has made enhanced oil recovery (including unconventional oil sources like heavy oil from Venezuela and Canadian Tar sands) economic by using advanced extraction technology, even though reliance on such oil means substantial release of more greenhouse gases. Oil-based infrastructure also continues in the RE scenario where UK rely on supply from Russia. In the GS and LS scenario, rapid decline occur in EROEI ratio (the Energy Return On Energy Invested) for the oil and gas sector, and paradigm shift has finally took place with more reliance on renewable energy, and substantial investment has been made to move away from oil based infrastructure by imposing higher carbon tax.

Carbon prices (£/tCO₂):

Given less demand and emphasis on low carbon economy, the WM scenario see carbon price struggling to go past £70 per tonne. On the other hand, the RE scenario observe a little higher carbon price than the WM one. But the GS scenario have a binding worldwide treaty in place that effectively regulate the flow of agricultural (and other) goods, and internalise the “carbon costs” which means an effective “carbon price” is in place, far in excess of business-as-usual projections made in 2010. Due to delayed actions from the international frontier, climate change impacts are now hard felt (i.e. much higher sea temperature and sea level rise as arctic ices continuously vanishes during summer months, bringing unprecedented level of cyclones, tornadoes and flash floods to most of the world’s coastal regions). More stringent actions to curb carbon emission mean drastic increase of carbon price is considered as a prerequisite for a sustainable world. Subsequently, carbon price hits £500 mark for the first time which drives both production and consumption of food (e.g. retail price of beef is £7 more expensive per kg) (as envisaged in ZCB, 2010, Hedenus, 2009).

4.5 Scenario outcomes

4.5.1 Feedstock types:

Feedstocks were selected based on a previous assessment for biochar deployment scenario for Scotland by Ahmed et al. 2012 which was based on Shackley and Sohi, 2010, Shackley et. al., 2011, Copeland and Turley 2008; Mortimer et al. 2009; Thornley et al. 2009; Wrap 2009; Wood-fuel Task Force 2008. A distinction was made between virgin and non-virgin feedstocks, where virgin feedstocks have not been chemically or biologically treated (but may have been physically altered). The virgin feedstocks considered were agricultural residues (i.e. straw from wheat, barley and oilseed rape), sawmill residues, forestry residue chips, small round wood and short rotation coppice. The

non-virgin feedstocks considered were waste wood, sewage sludge, garden and green waste, food waste, distilleries grain waste (Ahmed et al., 2012). Although many feedstocks are considered within the four scenario markers, not all of them belong to each scenario. For example, under the WM scenario, only virgin feedstocks that are affordable and can provide lower cost compared to fossil fuels are considered. Similar assumptions are considered for the GS scenario but for regional scale scenarios, inclusion of non-virgin feedstocks are considered. Details on the assumptions are further elaborated in a spreadsheet which can be made available upon request.

4.5.2 Feedstock amounts:

Initially potential availability of feedstock from domestic sources in 2030 are assessed based on other scenarios or non-scenario based estimates (Slade et al, 2011, Ahmed et al, 2012, Simon et al, 2011, CCC, 2011, ZCB, 2010, AEA, 2011, Thornley et al., 2009) that are consistent with the scenario logic and storylines adopted for this study. Consequently resource pyramid approach is used to derive availability for each scenario (as applied in Ahmed et al, 2012 and Shackley et al., 2011 while the concept were adopted from Cannell 2003, Bradshaw et al.2007). In this case, consistent internal judgements in line with the narratives are made to portray feasible constrained assessments from 'realistically available resources' based on future availability, demand for biochar and other competing uses.

Domestic availability: In the WM scenario, given lower technological learning rate for biomass conversion technologies and higher cost-effective utilisation of biomass compared to other scenarios, only the economic potential is considered. Given low demand for biochar application, only 10% of the available domestic resources from agricultural, forestry and sawmill residues are considered. These assumptions also hold for the GS with BECCS scenario. For the RE scenario, this is increased to 25% given more proliferation of biochar technologies (e.g. fast pyrolysis, gasification) that can produce more energy than char. this is raised to 50% and 75% in the GS and LS scenario respectively due to the paradigm shift from more consumption of fossil fuel to sustainable use of resources that are environment friendly. In the GS without BECCS scenario, there is rapid intensification due to restrictions on food import, and under these scenarios reduction of land footprint is aimed highly which means there will be 60% increase in crop production, resulting in more residues which includes straws and seed hulls. In this version of GS scenario, availability of land for energy crops follow similar deduction from Lovett et al., 2009 i.e. 350,000 ha of lower grade land is used which do not have any impact on UK food security. In the RE scenario, land required for food production would be unavailable to bioenergy crops, regardless of price. However, as food crop yields are predicted to increase this potentially release more land for bioenergy in the future. It means under this scenario one million ha is used growing energy crops and 1G biofuel crops (in line with lower end estimates by AEA 2011). But in the LS scenario, more land from permanent and temporary grassland are released for energy crops due to reduced grazing which means 3million ha of land can be used for SRC and Miscanthus plantation while some more land are exploited for SRF along with appropriately-sited afforestation, following the principles outlined by Read et al. (2009).

Table 1: Domestic and international feedstock availability for the four scenarios

Feedstock type	WM	GS	RE	LS
Agricultural residues	470,195	3,147,632	1,175,487	4,721,448
Forestry residues	80,000	909,091	200,000	1,363,636
Aboricultural arisings	0	2,525,253	85,250	3,787,879
Sawmill residues	8,600	589,226	224,467	883,838
Short Rotation Forestry (SRF)	0	378,788	0	568,182
Energy crops	0	1,006,250	958,333	10,681,818
Sewage sludge	0	754,500	615,000	584,112
Waste wood	0	2,779,625	1,691,919	5,075,758
Imported agricultural residues	0	15,557,855	0	0
Imported woody biomass	0	20,202,020	0	0
Pellets from Europe		0	250,000	0
Grand total	558,795	47,850,239	5,200,457	27,666,672

International availability through imports: Although in the WM scenario, UK have ample access to global biomass stocks (i.e. realistically available resource comprises of 5 million odt of agricultural residues and c. 405 million odt of woody biomass given higher investment in resource extraction and assuming 10% of the global stock in 2030 is available to the UK after meeting BAU sustainability criteria at 2012 level) , these are primarily intended for power generation (i.e. co-firing and biomass dedicated plants), and therefore none are considered available for biochar production. For the GS with BECCS scenario, similar assumptions also hold. Here, access to the multitude of different biomass resources has grown to its full potential, with diverse sources of sustainable biomass available globally (particularly perennial energy crops) . Technically mature pre-treatment technologies in compacting biomass at low cost to facilitate transportation (e.g. densifying woodchips) become readily available to ease one of the major logistical barriers for global biomass trade. International funding institutions e.g. the International Monetary Fund (IMF), World Bank (WB) and the African Development Bank (AfDB), private sector groups, and both domestic and international public

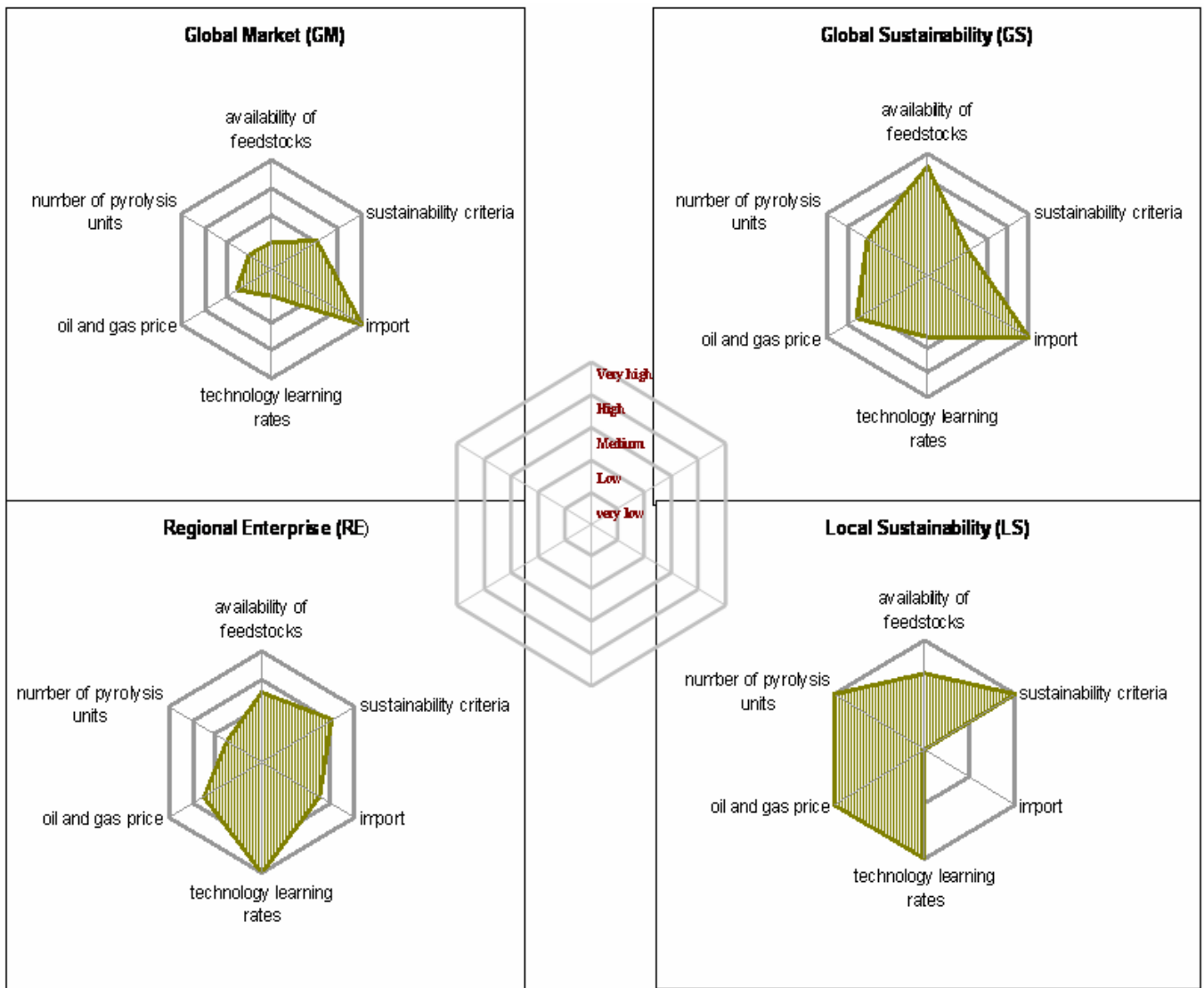


Figure 4: Spider diagram outlining key scenario assumptions and outcomes

policies have made new investments in logistics, infrastructure, monitoring and traceability in most exporting developing countries to reinforce robust sustainability criteria but also to make sure higher supply of unused biomass keep the global biomass supply chain healthy. Besides, significant investment has been made to upgrade UK's port and rail infrastructure to reduce cost in supply chains to avail surplus global sustainable biomass. Both the domestic and international markets have become mature with a buoyant spot market. The UK has access to 31 million odt of agricultural residues and similar amount of woody biomass (40 million odt), almost ten times less than is available realistically at the WM scenario because of the global binding C&C agreement and rigid enforcement of sustainability criteria that is now safeguarding tropical rainforests. According to Juninger 2012, Europe is currently the leading importer of biomass. For example, out of the total 16 million tonnes traded forestry residues for energy in the form of wood pellets, Europe consumed 80% while UK consumed 6% of the global total or 1 Million tonnes (CCC, 2011; Poyry, 2011). In the RE scenario, UK maintain its access to this amount despite its embargo on non-EU imports, thanks to increased supply from Sweden, Germany, Norway, Slovenia, Ukraine and other Balkan regions. In the LS scenario, UK only consumes what it produces.

Based on the assessments made on international and local availability, the WM scenario have the lowest biomass resources to produce biochar (around half a million odt), followed by around 5, 27.6 and 47.8 million odt for the RE, LS and GS scenarios respectively (table 1).

4.5.3 Number, scale and type of PU units:

As can be seen in table 2, scale and number of biochar production units in the GM and GS (with BECCS) is similar - small and medium scale but much lower in numbers compared to other scenarios, given intense competition for biomass for other uses, less demand for biochar etc. If BECCS do not materialise as predicted, the GS without BECCS scenario see the maximum proliferation of PU units. The RE scenario observes greater access and demand for biomass compared to the GM scenario but technologies are geared to fast and intermediate pyrolysis, gasification etc. as production of bioenergy is prioritised over higher yield of biochar, and increasingly being retrofitted to technologies using non-virgin feedstocks (e.g. use of digestate from AD plants). The LS scenario experiences higher access to biomass compared to the RE one due to larger success and availability of logistics to collect thinly spread domestic virgin resources but also due to wider use of non-virgin resources from biochar production. While the later type is more likely to be used in medium scale slow pyrolysis units, the former sources are used for small scale units within the farm and rural communities.

Table 2: distribution of pyrolysis units across scenarios

scenario	total biomass (int+domestic)	Number of pyrolysis units				
		Small (S)	medium (M)	large (L)	ratio between scales (S:M:L)	
GM	558,795	93	12	1	33:33:33	
GS(with BECCS)	505,050	80	10	1	33:33:33	
GS(without BECCS)	47,850,239	561	1,682	65	15:60:25	
RE	5,200,457	390	195	7	15:60:25	
LS	27,666,672	8,300	692	0	80:20:0	

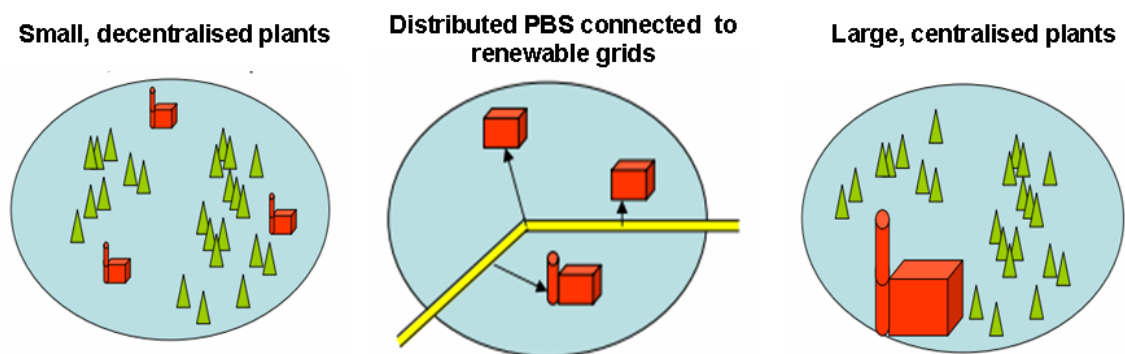


Figure 5: Nature of Pyrolysis units (adopted from Möller, 2005; Möller & Nielsen, 2007)

5 Conclusions

The scenario development procedure applied in this study was designed to provide qualitative assessment of drivers that can be used for further assessment of biochar deployment potential in not too distant future for the UK but can be extended to the context of other European countries. The IPCC SRES / UKCIP socio-economic scenario framework was applied to develop the scenario logic, storylines and assumptions to make consistent quantitative judgment over demand and availability of biomass for biochar production. In 2030, the WM scenario depicts a world dominated by globalisation and liberalisation with a small niche market for biochar dictated by key market players (e.g. carbon Gold). The GS scenario witness successful international cross-border cooperation kick-started by a series of extreme events (e.g. rapid sea level rise and abrupt changes in temperature than foreseen) resulting in maximum availability of biomass for biochar production. The LE scenario, as a demonstration of stronger EU coordination (aka Fortress Europe), experiences regional pursuit of economic self-interest where biochar production technologies producing more oil or gas dominate. On the other hand, the LS scenario (aka Small is Beautiful) observes transition to local environmental sustainability accompanied by local regional bottom-up cooperation resulting in rapid behavioral change, manifold local adaptation measures including rapid use of sustainable growth media (e.g. biochar). Most of the variables included here are either of qualitative nature. A few that are quantitative but highly sensitive (e.g. prices) can foresee fairly wide range of emerging patterns up to 2030 and therefore not quantified. Thus carefully articulated qualitative interpretation have been made for these variables based on extensive literature review before proceeding to a plausible and reasonably consistent quantification of biomass availability and scale of biochar deployment.

Even though this provides a good starting point as biochar deployment scenario, there are several rooms for future research and improvements. For instance, these scenarios can lead to making spatially explicit regional case studies that can capture how changes in land use can be driven by the scenarios adopted here and how different scenario can guide different carbon abatement potentials or different C-stocks by incorporating different quantitative system models (e.g. Cantarello et al., 2011). Besides, more variables can be included and portrayed that are consistent with the scenario

logic, narratives and assumptions adopted. Detailing variables like amount of power and heat generation from PBS and their demand, demand and use for other by-products from PBS (i.e. bio-liquids, syngas), carbon emission factors (in terms of heat and agricultural offsets), carbon intensity for dominant transportation systems, prices for heat, electricity and transport, feed-in tariffs would be useful for extending this exercise to construct scenario based LCA and techno-economic modelling of biochar deployment. We do admit that the future will not resemble any of the scenarios described here - rather probably contain bits and pieces of every scenario. Nevertheless, the foremost purpose here is to offer the possible context; to choose viable, self-consistent possibilities of multi-scale biochar deployment that can emerge by the interplay of key drivers, and to try to cover the highly uncertain and complex future space that fit the context studied here. It also aim to provide some thinking space through alternatives when setting the course for strategic policy decisions and the debate about the future of land use, technologies, biomass, food, energy, fibre, agriculture, rural communities and the natural environment. No scenario analysis can be devoid of uncertainties and neither is this one. Given further allocation of resources, improvements can also be made by engaging national, regional and local stakeholders at all steps of the scenario-building process.

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