# Global trade scenarios: some lessons from regional case studies.


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**ABSTRACT**

Through the use of a mixed method approach, the Shipping in Changing Climates project, projects 4 contrasting future scenarios of trade with a high degree of resolution in terms of both commodity and regional coverage. Whilst presenting results in terms of global total (or commodity totals) is often necessary this will capture the net effect in regional trade, and obfuscate contrasting trends amongst key exporters. The projections of output by commodity and region are informed by climatic and socio-economic framing through use of contrasting i) representative concentration and ii) shared socio-economic pathways. These values are used in conjunction with derived elasticities to generate estimates of future trade or are outputs from energy modelling exercise using a dedicated energy model (TIAM UCL). For a group of key commodities such as iron ore, grain, coal and bio-energy the implications for production in key regions such as China, Africa and the Former USSR are extracted, serving to identifying the causal links between climate and socio-economic framing, scenario narrative and ultimately changes in exports. Some dramatic trends such as an increased biomass output in Africa or a reduction in Chinese iron production can be attributed to both direct and indirect responses to climate framing. The extraction of regional case studies serves to illustrate the implication for trade patterns on current (or potential) centres or 'hotspots' of production and adds insight into distinct processes which differentiate the scenarios with a common climate framing. .



*Keywords: Scenarios, Trade, Production, Climate Change*


## 1. INTRODUCTION

It is estimated that shipping currently services over 90% of the volume of global trade (Hummels (2007), OECD Trade and Agriculture Directorate (2008), Korinek and Sourdin (2010)). Within the last 5 decades the continued trends of globalisation has seen the extension of supply chains and increased trade in intermediate materials and shifts in centres of production of high value, manufactured goods which has become more specialised Caniato et al (2013) and UNCTAD (2013). During this period international trade (in tonnage) has grown faster than GDP, whilst the ratio of trade to output (measured in value terms) has increased three fold over the last five decades (Behar and Venables (2011), Hummels (2007)). This period coincided with a commensurate growth in the emissions attributable to the shipping sector which are currently comparable to the aviation sector (Smith et al. 2014). Within Smith et al. (2014) it is anticipated under a business as usual, that shipping's emissions will increase by 50%-250% between 2012 and 2050.

The evolution of shipping demand and emissions is thus inexorably linked to changes in world trade and influenced by diverse factors and their interlinkages (Walsh and Mander, 2017). Demand for shipping services has many drivers, for example levels of economic growth and the extent to which externally sourced material can compete with domestically produced commodities, which in turn reflects cost differentials and the effect of trade barriers. This brings huge complexity to estimating future demand for shipping, and associated emissions. The scale and urgency of the changes necessary in the shipping sector in, for example, adhering to a 1.5 °C temperature threshold (as explicitly framed in the Paris Agreement) or indeed adapting to the potential impacts of climate change, highlights that the future cannot be 'business as usual', and points towards the use of a scenario approach to explore these highly diverse and uncertain futures

## 2. SCENARIOS

Scenarios seek to answer hypothetical questions about the future in which plausible but contrasting states are compared. More practically, scenarios are can be seen as providing a connection between modelling and narrative exercises. Explorative and normative (Maier, Guillaume et al. 2016) scenarios make projections based on the extent to which established trends are (dis)continued, ideally serving as a heuristic tool (Berkhout, Hertin et al. 2002). Within that framework back-casting scenarios attempt to identify how longer term objectives might be met by identifying causal linkages between current and future conditions (Vergragt and Quist 2011). Recent climate scenarios have been informed by both respective socio-economic and climatic framing through the development of shared soghcio-economic pathways (SSPS) (O'Neill, Kriegler et al. 2014) and representative concentration pathways (RCPs) (Van Vuuren, Edmonds et al. 2011). The former reflects growth rates for population and GDP at the national level whereas the latter entails emission concentration constraints associated with different levels of radiative forcing and emissions.

### 2.1 AIMS and OBJECTIVES

To explore how climate mitigation, adaptation and impacts will impact the shipping sector Shipping in Changing Climates project is a multi-disciplinary, collaborative project that seeks to determine the scope for greater energy efficiency in maritime transport. One of its primary aims is the generation of global trade scenarios (2010-2050) at a high degree of resolution, in terms of both commodities and regional representation. This project takes a range of commodities into account including those that may be particularly impacted by climate mitigation, adaptation and impacts. This paper reports on contrasting scenarios of production at the regional scale, which in turn informed trade scenarios by acting as dependent variables for econometric analyses. More specifically, for a key number of bulk commodities and regions the historically observed elasticity between export supply and regional production across time is derived using ordinary least squares method, loosely following Constantinescu, Mattoo, Ruta (2015). Utilising i) the elasticity of export supply and ii) the future projection production based on a scenario, the fitted values of export quantity of a specific region, year commodity, scenario with the rest of the world are estimated. Whilst the resulting impact on trade associated with these scenarios is reported in Walsh et al. (2017) presented in this conference.

The main rationale for focusing on regional comparison is that at smaller scales (country or region) the impacts associated with climate change may be more pronounced or manifest more rapidly than at a global level, particularly as regional impacts may be obscured (or cancelled out) when results are presented at a higher (i.e. global) scale (van Vuuren, Isaac et al. 2011). Ideally this allows for a more holistic account of how climate change impacts and adaptation are likely to have diverse effects across commodities whilst accepting regional specific conditions. Furthermore examining regional specific conditions

### 2.2 SCENARIO FRAMING

4 scenarios are presented, reflecting two 2 °C and 4 °C futures. Two scenarios are informed by SSP1/RCP2.6 and SSP5/RCP8.5, entitled Greenroad (GR) and Highroad (HR) and there are two scenarios in which SSP2 is expressed across both 2 °C and 4 °C , entitled Middleroad2C (MR2C) and Middleroad4C (MR4C). Broadly speaking GR envisions a sustainable globalised future with limited challenges to climate adaptation and a low material intensity and rapid technology transfer. HR reflects a more globalised world in which fossil fuel continues to dominate but there is a higher climate adaptation capacity, developed and developing regions converge in terms of lifestyles with increased material intensity and regional specialisation of materials. Both middle road scenarios reflect a continuation of recent trends with some barriers to trade and continued inequality amongst regions, distinguished based on whether they satisfy a 2 °C and 4 °C budget. The main features of each scenario are summarised in Table 1.

### 3.1 METHODOLOGY

This section will cover 3 main aspects; the choice of commodity, the method applied and the choice of region/county.

### 3.2 COMMODITY CHOICE

Coal: Over the previous decade, coal contributed to approximately 10% of seaborne trade in terms of tonnage. The World Energy Council estimate that approximately 5.7 billion tonnes of coal equivalent are currently produced annually, representing 29% of Total Primary Energy Supply (TPES) in 2014 (IEA 2016). Coal production in 2014 is regionally concentrated with two main regions; USA and China contributing to over half global production in 2014. This commodity is included as it reflects decarbonisation efforts (such as fuel switching) within the energy and industrial (steel and cement) sectors.

**Table 1: Summary of Scenario descriptors.**

| Sub-elements | | | | |
|---|---|---|---|---|
| Scenario | GR | MR2C | MR4C | HR |
| RCP | 2.6 | 2.6 | 8.5 | 8.5 |
| SSP | 1 | 2 | 2 | 5 |
| Economic Growth | High, convergent but diverse | Moderate and uneven | Moderate and uneven | High, convergence between nations |
| Energy System | Renewable Focus | Mixed with some renewable penetration | Mixed with some renewable penetration | Fossil |
| Material Intensity | Low | Moderate to High | Moderate to High | High |
| Energy Intensity | Low | Varied amongst Economies | Varied amongst Economies | High |
| Population Growth | High **(Quant data)** | Medium **(Quant data)** | Medium **(Quant data)** | Peak and Decline **(Quant data)** |
| CCS Availability | High | Moderate | Low-Moderate | Low |
| Bio-Energy Availability | High | Moderate-some environmental degradation | | Low to moderate-significant competition for land |
| Trade Barriers | Low | Moderate, some barriers to fossil/bio trade | | Low |

Iron ore: As mentioned, steel remains one of the most carbon intensive materials, with the sector acknowledging that decarbonisation entails overcoming significant technical challenges (Bellevrat and Menanteau 2009; Wortler, Schuler et al. 2010; Morfeldt, Nijs et al. 2015). By its very nature, the demand for Iron ore will be very dependent on steel demand by technology route, reflecting the competing drivers of both economic growth/material demand and decarbonisation. More specifically the replacement of traditional blast furnace with electric arc furnaces (using recycled steel) will displace the use of both (coking) coal as well as iron ore. As with steel, iron ore demonstrates the concentration of production in key regions, in this case Australia, China and Brazil contributing to over 70% of global production in 2050 [1] with China also are representing the largest ore importer (WorldSteel 1980-2016).

Grain: whilst the commodities mentioned above are arguably more responsive to climate mitigation efforts, the demand and trade of grain will undoubtedly be affected by climate change impacts. In this instance grain is taken to refer to an aggregated group including wheat, rice, barley, oats, maize, etc. This category reflects a group of staple products including basic foodstuffs and (increasingly) the demand for animal feed. Therefore demands for grain will respond not just due to population increase but also to changing consumption patterns through for example increased meat consumption. Recently (2014) global grain production is concentrated in a few geographical areas, with China, the US, India and Russia contributing to half of global production. With Japan, Saudi Arabia, Egypt and China contributing to 20% of imports whilst the US, France, Argentina and Brazil contribute to 40% of total exports (FAO 2016).

Biomass: this category is arguably the most complicated as there exists numerous definitions of what constitutes biomass. For example a definition of biomass may include informal or commercial harvesting of

[1] When adjusted to mimic global average iron content, production estimates of Chinese ore (which is generally low quality) decreases significantly.

wood fuel. The IEA estimate the production of primary solid bio-fuels (measured in net TJ) has increased by 77% between 1980 and 2010, with growth in Asia, African and European Markets. Within this study, biomass includes both crop and solid (lingo-cellulosic) based material. The main rationale for the inclusion of biomass in this study is the apparent reliance on BECCS implied in many 2 °C emission scenarios. Given the geographic constraints on production, comparing output of biomass can assist in identifying regions which may become economically more important in the future, as well as (in the case of BECCS) a comparison against potential $CO_2$ sink sites.

Please note that in order to avoid double counting, the projections of grain output are presented as relating primarily for agricultural production including animal feed. Furthermore, the elasticities between production and trade are derived historically, before biomass expansion in many regions therefore it is conceivable that a significant growth of grain for bio-energy purposes in a given region may overestimate the resultant changes in trade. These points are important as the TIAM category "Biomass" does not distinguish between **specific** feedstock routes, which in some cases (such as maize for bio-energy production) may overlap with commodities captured in grain projections. Therefore it should be noted that the constraints which inform the grain projections do not necessarily apply universally to biomass production.

### 3.3 CHOICE OF METHODS

The Shipping in Shanging Climates project adopts a mixed methodology approach in which trade (and the output estimates upon which they are derived). Production scenarios for energy commodities are constructed using the TIAM-UCL global energy system model. TIAM-UCL is a linear programming cost optimisation model which minimises energy system costs (at a discount rate) and maximises social welfare. In this instance variables (such as temperature framing, SSP, Population, bio-fuel availability etc.) are inputted in generation of scenarios. These variables are summarised in Table 1. For more detail on how the model generates projections of trade and production of energy commodities please refer to Walsh et al. (2017) for more information on the scenario process. For energy commodities, coal and biomass trade projections are taken as outputs from the TIAM-UCL energy scenario model in which variables (such as temperature framing, SSP, population, bio-fuel availability etc.) are inputted in the generation of scenarios. These variables are summarised in Table 2. A detailed description of input assumptions, approaches and data sources for TIAM-UCL can be found in Anandarajah (2011), Anandarajah, et al. (2013). In-depth descriptions of TIAM-UCL processes and uses are available in Price and Keppo (2017) and Raucci (2017).

In each scenario produced using TIAM, the energy consumed (in terms of different energy carriers, such as electricity and coal) within the steel sector is identified, giving an indication of the type of technology predominately used. In order to estimate the steel production associated with each region, the energy intensity of steel production is first calculated by deriving process energy estimates from Morfeldt, Nijs et al. (2015) for different process routes and technology. This is estimated by following the process from ore inputs to steel production, examining the inputs (including energy) and outputs from each sequential production stage. This provides an estimate on the process energy requirements (Pj/Mt) associated with steel production. Once steel production by process route is estimated for each region, the ore intensity estimate derived in the same manner as energy intensity. This provides an estimate of the ore required to produce steel in each region. For each region, annual ore production is projected based on historical growth rates, modified as part of the scenario process ensuring ore demands are met and national ore reserves are not depleted (Yellishetty, Ranjith et al. 2010).

For grain production is projected based on projections to yield and harvested area using 2010 as the base year (FAO, 2016) and is informed by population changes but also assumptions on the demand for animal products. The latter is bounded by estimates of arable area (FAO, 2016) or expandable land. The former takes potential climate change impacts into account as percentage changes to currents yields based on different temperature framing and time scales. Where possible regional specific assessment, such as (Roudier, Sultan et al. 2011) are used. In the absence of regional specific data more generic information is used, such as (Lobell and Gourdji 2012; Rosenzweig, Elliott et al. 2014). In particular Lobell and Gourdji (2012) provide a range for the foreseeable % decrease in crop per increase degree Celsius increase in temperature. This is used in conjunction with model mean projections in regional temperature increase (in terms of different RCPS) taken from the AR5 scenario data base (IPCC 2014). Where appropriate effects of adaptation are explicitly from the literature. In the absence of specific data on the efficacy of adaptation measures, the potential impact of adaptation measures are estimated by comparing the potential increase in yields (if historical trends continue, until parity is reached with maximum achievable alternatives) with the % decrease in yields estimated using climate sensitivity estimates from Lobell and Gourdji (2012). In this case the impact on yields will depend on the extent to which potential yield growth are exceeded by the projected impact due to temperature increase.

### 3.4 CHOICE OF CASE STUDY REGIONS

Africa: incudes all countries contained within the African continent, including Egypt. This region has been identified as one of the regions which has the highest capacity to expand cultivated area (Fischer 2011) as well as (in some countries) increase yields (Pretty, Toulmin et al. 2011). This may be important for the potential expansion of biomass. Furthermore, it has been suggested that countries in West Africa have significant ore deposits that could be capitalised in the future (Markwitz, Hein et al. 2016).

China: The recent scale of Chinese production and rate of growth across several commodities means that projections of global production and trade are highly sensitive to assumptions on how Chinese resource demands will change over time. This has been particularly evident in recent years for commodities such as grain, steel and iron ore, where trends in Chinese demand have influenced global trade and production. If recent growth rates for specific commodities such as steel are maintained or indeed replicated, Chinese output would dominate global production. Therefore scenario results can be sensitive to assumptions on the point at which demand or supply for different commodities will peak or indeed decline.

Former Soviet Union (FSU): This region has significant deposits of iron ore as well as remaining a significant producer of steel. In more recent years (2016) Russia has emerged as an important exporter of grain. Arguably of greater relevance is the potential for agricultural land expansion as regions become cultivable due to increasing temperatures (Kiselev, Romashkin et al. 2013).

USA: In contrast to other case study regions, the USA represents a more developed region and is chosen to reflect a region which has reached industrial maturity and intensive agricultural production. The US remains an important producer and exporter of grain but (due in part to its role as an important maize producer, a crop considered to be particularly sensitive to changes in temperature) has the potential to be significantly impacted by climate change. Furthermore at a country level, the US remains (along with China) one of four largest coal producers since 2005 (IEA 2016).

### 4.1 RESULTS AND DISCUSSION

The main results for grain production are presented in Figure 1 below. It should be noted that with one exception (USA HR), none of the regions project a decrease in output by 2050. However both the need to limit nitrogenous fertiliser and the impacts of climate change mean that all scenarios will have inherent limiting factors to yield growth. African grain production projections range from treble to equivalent the baseline value, both 4C scenarios. Partially in response to increases in population and demand for meat, the high road scenario projects an increase in yields in areas (following a narrative of high adaptation) that are traditionally less productive than comparable areas (such as neighbouring countries). This is offset by reduction in yields in more productive areas where limits to adaptation may have been reached or cannot be maintained. However the expansion of land is more impactful as many countries (such as the Democratic Republic of the Congo and Angola) have significant un/under-utilised non forested areas, accepting that not all of this will be cultivable Jayne et al. (2014). In contrast, the scenarios with less adaptive capacity demonstrate a reduction in output after 2030 as yields reductions of (10-20% relative to 2010 as a function of temperature increase following Lobell and Gourdji, 2012). In China the middle road scenarios arguably reflect continued growth comparable to recent trends, prompted by increasing domestic meat consumption as opposed to population. These scenarios project growth in output primarily due to land expansion as opposed to yield increases, (baseline grain yields, mostly comprised of rice are comparatively high) Again the biggest deviation is evident between HR and GR scenarios as the HR reflects a reversal of recent trends in reducing agricultural intensity Jiang et al (2013) as well as land expansion and intensification, again prompted by increases in both animal feed demands and food demands, however after 2030 climate change impacts become more manifest, frustrating further yields increases. The projections for the Former Soviet Union present an interesting case. As the econometric method informed by these projections, applies changes to trade in the baseline year of 2010, changes in production are based on changes to yields and productive areas in 2010. However, Russia suffered a significant drought in 2010 and therefore the projections might be seen as being conservative relative to what is achievable, conversely a more ambitious projections (based on different baseline year) of production risks overestimated export capacity, relative to 2010. That being said, all scenarios project increase in output as yields increase (Russian yields are currently less than those in a similar agro-environmental zone, Canada) but more crucially, the capacity to expand into new areas that become cultivatable due to climate change (Lioubimtseva et al. 2015). By 2050 in the HR scenario for example it is projected that the harvested area increases by 30% by 2050. None of the scenarios project significant increase in the population of the former USSR. In the case of US grain none of the scenarios project significant increases in output, this is due to the predominance of maize in Agricultural production, which is both historically dependent on continued fertiliser input, but also sensitive to temperature increases (Bassu, 2014). This is exacerbated as intensive agricultural practice in the US limits the capacity for land expansion, although the land expansion in HR scenario is offset by a reduction in yields following Rosenzweig et al. 2014 (based on level of temperature increase). In the case of

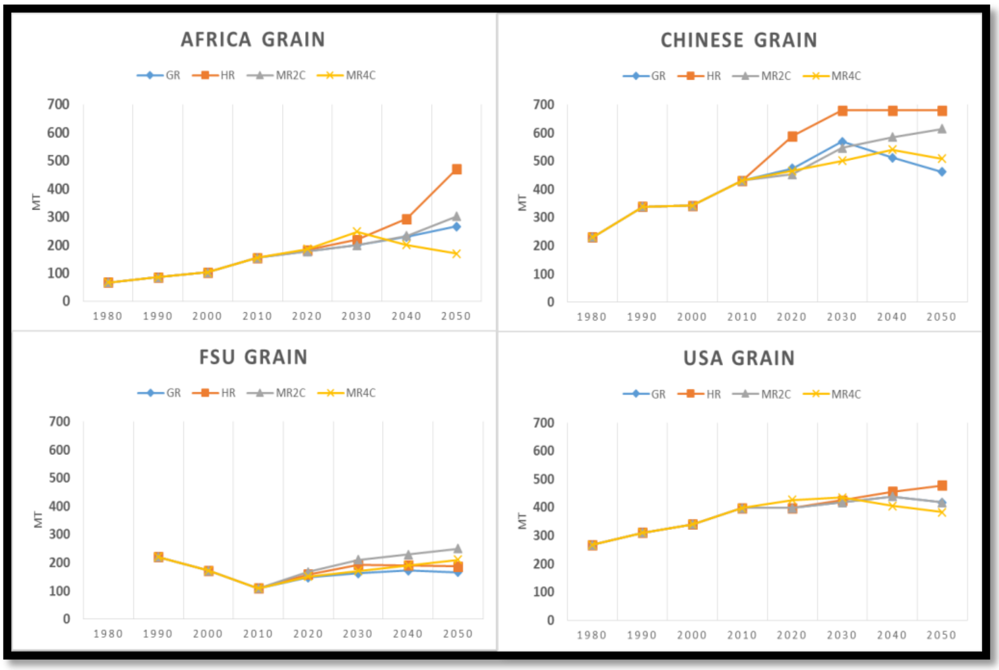


Figure 1: Grain production by region and scenario.

The projections of iron ore reflect a greater degree of diversity between regions than grain (Figure 2). This is partially due to the greater concentration of productive mining capacity and the fact that iron ore is used in a more restricted number of sectors than grain which has food, feed and industrial uses. At present Africa is a very limited producer of iron ore.

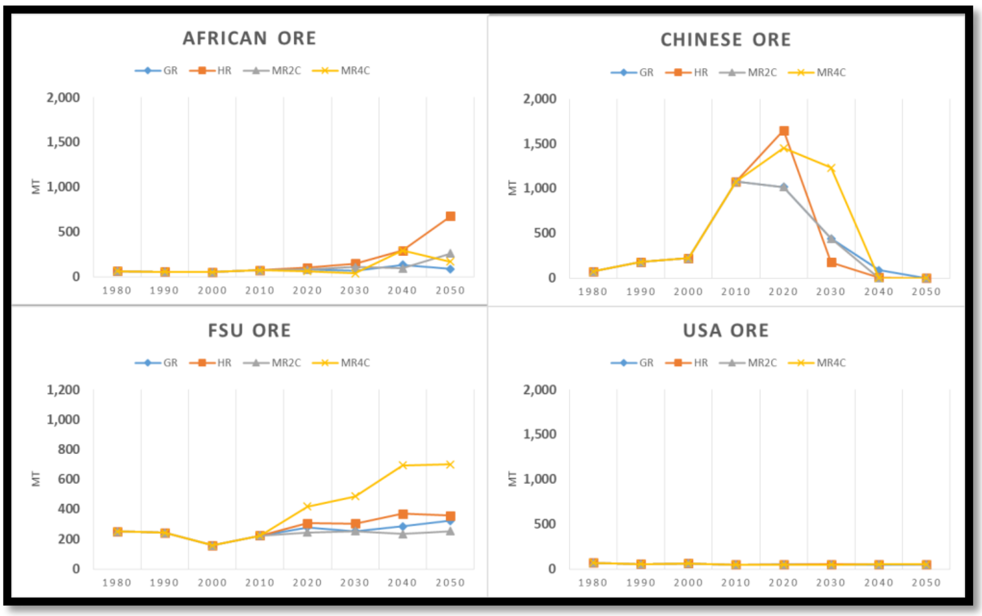


Figure 2: Ore production by region and scenario.

Therefore in the GR scenario (with its increased use of scrap recycling instead of virgin steel production) there is limited impetus to increase production. In contrast the HR scenario, with its narrative of globalisation, envisions increased virgin steel demands and the hitherto unexploited reserves in western Africa (such as

Sierra Leone) become profitable to exploit. China demonstrates the greatest departure from the baseline as Chinese ore production as Chinese ore is of low quality as becomes depleted as domestic steel production continues. The Former Soviet Union presents a similar narrative as Africa. Russia in particular possesses one of the largest reserves of ore which are also of high quality (USGS, 2016). However the geographic scale of Russia (and the Ukraine) whereby ore deposits are concentrated away from exporting ports, frustrates a similar scale of export expansion. As in the case of African ore, a global increase in ore demand (in this case under the MR4C scenario) provides sufficient impetus to invest in additional export infrastructure, sufficient to increase export capacity. By contrast US ore has remained stagnant since the 1980s (including during periods of expanding steel demand both globally and in the US). Furthermore US ore reserves, whilst in the top ten globally are less (as % of global totals) than many international alternatives and present a lower iron content (USGS, 2014). Therefore as an example of market stagnation, none of the scenarios envision a change in US ore output but production is insufficient to deplete reserves by 2050.

In contrast to the previous commodities, all regions present similar manifestations of the different scenarios (Figure 3). All regions present convergence in terms of biomass production across the 2 °C scenarios both in terms of growth and the absolute levels of output projected by 2050. In the GR scenario all scenarios envision significant growth in output following the exponential growth of BECCs.

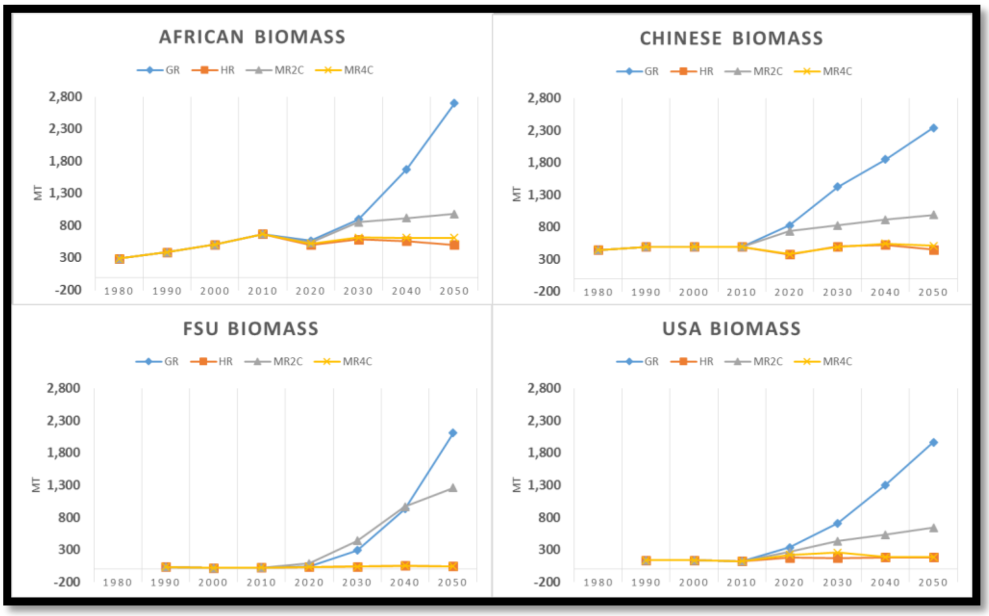


Figure 3: Biomass production by region and scenario.

This requires significant land expansion into regions currently underutilised (such as envisioned for grain in Africa under the HR scenario) and therefore plays a role in checking the growth in grain output. In absolute terms, none of the regions in MR2C show equivalent levels of bio-energy output as GR. In this scenario BECCS is still very important (equivalent to natural gas in 2010) but not as prodigious as in the GR scenario (in MR2C nuclear power becomes the largest component in the energy mix by 2050). Again in this scenario, the highest level of growth is seen in the FSU which has (as mentioned previously) a significant land area but more crucially possesses a vast stock of woody biomass. Neither of the high emission scenarios envision significant increases in biomass production, easing the pressure on land use for other agricultural purposes.

The contrasting projections of coal production show similarities with bioenergy in terms of correspondence in how the scenarios manifest across regions, in this case the US and China (Figure 4). As with biomass, the scenario framing plays a fundamental role with a clear distinction between 2 and 4 °C scenarios (heavily influenced by coals role in electricity generation), particularly in the two largest coal producers; the USA and China. However, important distinctions remain, in all 2 °C scenarios (excepting China) coal production is negligible by 2050 whereas Chinese production declines to 2000 levels, this is partially attributable to the continued presence of integrated steel production in China, which requires coal inputs as well as possessing the largest reserves of coal. Africa is not considered to possess considerable coal reserves whereby production grows at a slower rate under a high emission scenario in contrast to the other regions.

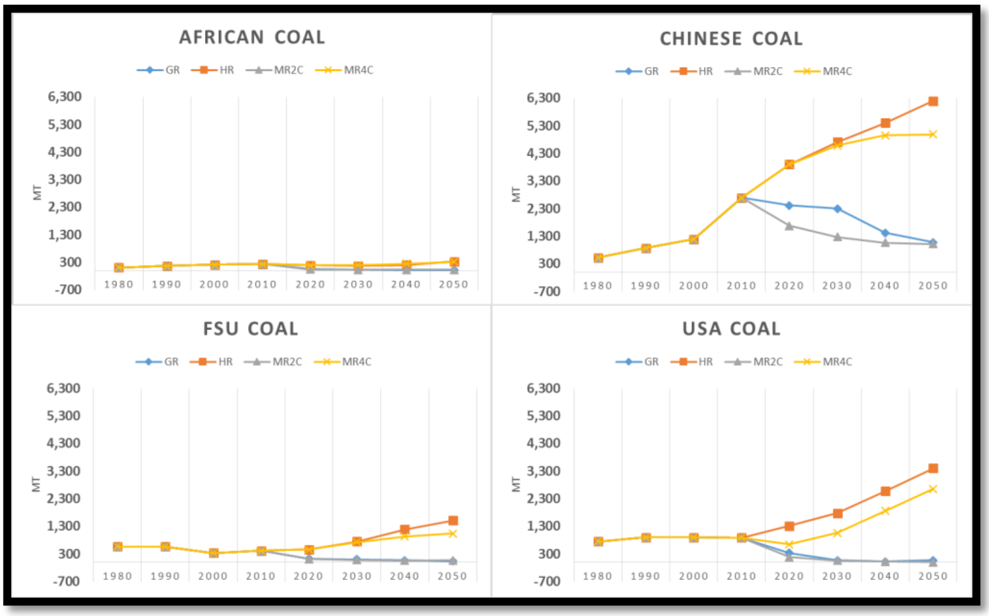


Figure 4: Biomass production by region and scenario.

## 5. CONCLUSIONS

This paper presents an overview of production estimates for a number of bulk commodities that have a direct and indirect climate focus and being part of a scenario process are hypothetical. This paper presents a range of projections for developed and industrialising economies demonstrating that in most cases a climatic framing can make a pronounced difference in the output of key commodities or (depending on context) arrive at similar end points due to different pressure (such as a reduction in yields due to either climate impacts or a reduced fertiliser application). Particularly in relation to land use the scenarios encompass a great degree of uncertainty. In Africa for example crops yields in many countries are significantly lower than in other producing regions, whilst also anticipated to be affected by climate change. Therefore the likely impact of climate change will depend on the extent to which adaptation and or 'sustainable intensification' can outpace the impact of climate change. Similarly, many of the scenarios project increases in harvested areas in areas where land expansion is at least feasible. This contrasts with some existing FAO projections which suggest most of the future grain demands will be met by changes in yields (Alexandratos and Bruinsma, 2012). However this is heavily influenced by the scale of projected impacts which in most case (with some regional exceptions such as sub Saharan Africa) are not projected in this instance to be catastrophic (also evidenced by biomass increases). A more dramatic manifestation of climate change impacts would place greater pressure to expand agricultural area. One of the key findings is that (at least in the case of dry goods) decarbonisation doesn't necessarily equate to dematerialisation as for example biomass increases as coal decreases. However there are important cross sectoral linkages as decarbonisation is seen to reduce both ore and coal demand. Similarly, not all regions will be impacted to the same degree, in each commodity and scenario overlap, there are instances of stagnation (such as US ore). The scenarios demonstrate the importance of being cognisant of both regional and commodity specific characteristics. So whilst most regions may maintain bio-energy production, for example, the stocks of iron ore and coal are fixed. The extent to which production centres shift will be heavily influenced by decarbonisation but the net effect will is more complicated so by 2050, a switch from coal to biomass may well favour Africa over China and the US, Chinese ore is likely to be depleted or no longer mined regardless. In summary the case studies presented here, whilst contributing to a larger study reminds us that scenarios can assist in not only presenting high level trends but highlighting the regional trends that can be lost out if results are purely expressed at a global level.

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