One Man's Meat…. 2050? Ruminations on future meat demand in the context of global warming.

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Abstract

This paper considers a range of issues relating to the contribution of meat consumption and livestock production to global warming given the need highlighted by the Committee on Climate Change (CCC) to reduce global GHG emissions by over 50% by 2050. The IPCC Climate Change 2014 report recognised that demand oriented measures may also contribute to GHG mitigation. The paper reviews a number of studies which examine demand-led mitigation potentials, concluding that such estimates ignore the market effects of changes in meat consumption habits or demand oriented policies. A simple partial equilibrium model of the beef, poultry, pig and ovine meats is developed for the major regions of the world to explore the impact of a range of scenarios which may reduce meat consumption and GHG emissions. These include emissions taxation, long term trend in reduction of red meat consumption in developed economy regions, and supply side improvements in livestock emissions intensities. The paper discusses problems associated with many published demand elasticities suitable for incorporation into a market model, problems of selection from a widely varying published estimates and their appropriateness for longer run projections. The dearth of published supply elasticity estimates is also highlighted. The modelling concludes that economic and population growth to 2050 without any mitigation measures will lead to a 21% increase in meat consumption and a 63% increase in GHG emissions by 2050. However, the mitigation projections from the scenarios explored only generate a 14% reduction in cumulative emissions from the baseline 2050 projections, insufficient to met the CCC target.

Keywords: meat demand; climate change; emissions intensities; elasticities; taxation.

1. Introduction

The impetus for this paper began with the concerns expressed almost 10 years ago in a major FAO-LEAD [1] report '***Livestock's long shadow'*** (Steinfeld, 2006) which reviewed the contribution of livestock in the emerging environmental issues of increasing water scarcity, land degradation, land use change and biodiversity, and on atmosphere and climate. It concluded that the *'livestock sector emerges as one of the top two or three most significant contributors to the most serious environmental problems, at every scale from local to glob*al'. Such an uncompromising assessment then focused on the policy agendas to ameliorate the impact of livestock production. By the very nature of the study, the emphasis was on production-oriented solutions. Economic policy approaches were highlighted that could improve resource use efficiency in production by reducing subsidies and distorting production incentives, by pricing natural resources used in livestock production to reflect their full economic and environmental costs and/or taxing them accordingly. But equal emphasis was given to outlining land management and husbandry considerations that would be necessary to curb greenhouse gas (GHG) emissions. The IVth IPCC Climate Change report (Metz et al, 2007) also seized on the policy adaptation strategies in the FAO–LEAD report in general terms, but was more specific regarding mitigation. The preponderance of research publications into livestock and their contribution to global warming subsequent to these two reports have focussed on mitigation strategies, particularly those in the scientific literature, addressing the

[1] The Livestock, Environment and Development Initiative, supported by the World Bank, the EU and some of its member states overseas development agencies, and IFAD

issues both of appropriate measurement and of reduction in emissions intensities[2] from livestock products, particularly from ruminant livestock (Opio et al, 2013; Gerber et al , 2013a, 2013b; McLeod et al, 2013;)

The consumption of meat has been criticised particularly in relation to the resource demands its production makes compared with equivalent nutrition that can be provided through crop products (Cassidy, 2013; Rask, 2011; Eshel,2014). The primary thrust of many such studies has been in addressing the resource demands of differing foods in relation to food security and finite and diminishing resource availability rather than on their emissions profiles. More recently, there has been emerging recognition of the potential for demand related measures in reducing GHG emissions from meat and milk production. This is complemented by the increasing weight of medical and dietary advice and research into the benefits of reducing over-consumption of meats, especially red and processed meats that have been associated with a range of chronic disease and other health related problems, a further consequence of which would be to diminish the GHG emissions involved in their production (Aston, 2012; Briggs, 2013). The IPCC AR5 also recognised the potential for positive health co-benefits of reducing meat and milk demand in countries with high levels of animal protein consumption (IPCC, 2014c).

However, notwithstanding the weight of scientific opinion regarding the social costs of meat consumption and benefits of reducing it, the expected levels of future global population economic growth are likely to push world meat consumption in a contrary direction. This paper sets out to address the potential longer term impact such developments may have on the demand for meat, and its effects on global GHG emissions. First, it outlines recent developments in global meat consumption and emissions from the livestock and meat sectors in the context of the global carbon challenge. It then considers a range of demand-related measures which could contribute to emissions reductions. A simple partial equilibrium model is developed to examine a range of scenarios which could contribute to reducing livestock sector emissions, particularly for ruminants, and also how the effectiveness of such measures might compare with supply-side mitigation of emissions intensities. The analysis is disaggregated at regional (continental) and sub-regional level[3] and particular emphasis placed on scenarios relating to the demand for ruminant meats.

2. Recent developments in meat consumption

Figure 1 shows that by 2013, global meat consumption was provisionally estimated by OECD at 303 million tonnes, a rise of a little over 100 million tonnes since 1995, and an annual average growth rate of 2.3% (OECD, 2015). Underlying this were some differing trends amongst the individual meats, with consumption of poultry meat the driver of world meat consumption growth, increasing at over 3.6% annually and pig meat at over 2%. Ruminant meat consumption rose more slowly, with beef only at a little over 1% p.a. By 2013, consumption of non ruminant pig and poultry meats, the relatively cheaper meats, was almost 223 million tonnes, nearly three-quarters of global meat consumption

Tables 1, 2a and 2b examine the regional characteristics of global meat consumption in 2013 based on OECD provisional data. Global per capita consumption of meat was 34kg/head, but almost 90 kg in both N America and Oceania[4]. Per capita meat consumption in Europe and S

[2] Measured as the weight in kg of GHGs emitted at their CO2 equivalents per kg of product.
[3] Note OECD data does not easily disaggregate to the sub-regional level, but is more current than that from FAO. The latter is more amenable for detailed regional-sub regional analysis and is used for the subsequent modelling in this paper. Another difference worth noting is that OECD ovine consumption is only sheep meat, whilst that of FAO also includes goat meat.
[4] Developed Oceania –i.e. Australia and New Zealand.

America ranged around 60 kg/head, whilst that in Africa was less than 12 kg/head, and in Asia almost 26kg. Per capita consumption in Africa is dominated by red-meats, whilst in Asia pig meat predominates and together with poultry make up over 82% of the per capita meat intake. In Latin America and Caribbean (LAC) poultry meat is most important followed by beef . Per capita consumption in Europe is dominated by pig and poultry meats, whereas in N America and Oceania, species per capita consumption profiles are quite similar, with poultry dominant, but beef and pig meat both having significant shares of total meat consumption. Consumption of ovine (sheep meat) is low, except in Oceania, and around or below 2kg/head elsewhere.

The Americas accounted for over 44% of global beef consumption (Table 2a), Asia almost 60% of pig meat consumption and Europe over 23%. Africa and Asia together consumed more than 80% of the world's sheep meat. Table 2b shows changes in the species shares of regional meat consumption this century. It reveals that the share of beef in global meat consumption and in every region has declined since 2000 falling below 20% of global meat consumption by 2013. Pig meat shares of regional and global consumption have remained broadly constant whilst poultry meat's share rose strongly in every region, and from 32.9 to 38.9% of global meat consumption. Sheep meat's share of global meat consumption fell marginally to 5%, though still remains significant in Africa.

Figure 2 shows the relative importance of population and economic growth[5] underlying these recent developments in global and regional meat consumption patterns between 2000 and 2011. World meat consumption increased by 2% p.a., but population growth contributed more than half of this amount. The dominance of population growth's contribution to that of total meat consumption since the turn of the century is common to all regions except Asia and S America, where the impact of the 2008 global economic recession was more muted, and economic growth much stronger in China, India, and Brazil than elsewhere in the world.

3. The global carbon budget, livestock emissions and the emissions challenge through demand management

The IPCC Fifth Assessment Report (AR5), noted that annual anthropogenic GHG emissions have increased by 10 Gt CO_2-eq[6] between 2000 and 2010[7]. Energy supply accounted for 47% of the increase, industry 30%, transport 11% and buildings 3%. GHG emissions have grown in all sectors except in agriculture, forestry and other land use (AFOLU), which have remained stable, and have declined as a percentage of total emissions (IPCC, 2014a, 2014e). Figure 3 shows that the AFOLU sector accounted for 24% of the estimated 49 ± 4.5 Gt CO_2-eq of direct emissions in 2010. The AR5 concluded:

'Without additional efforts to reduce GHG emissions beyond those in place today, emissions growth is expected to persist, driven by growth in population and economic activities. Baseline scenarios, those without additional mitigation, result in global mean surface temperature increases to 2100 from 3.7°C to 4.8°C compared to pre-industrial levels.'

The message from the Committee on Climate Change (CCC) is that anthropogenic GHG emissions must be reduced by at least 50% by 2050 (relative to 2010) in order to limit the

[5] As revealed by per capita consumption growth
[6] Gt CO_2-eq gigatonnes (billion tonnes) of carbon dioxide equivalent, in which the main AFOLU GHGs have CO_2-equivalent weights of CO_2 (1), methane, CH_4,(25), and Nitrous oxide,N_2O,(298).
[7] the base year for AR5 projections

global temperature rise to 2°C above pre-industrial levels based on possible IPPC AR4 scenarios of GHG emissions pathways[8] and associated global temperature changes. Already, it is estimated that the cumulative emissions of CO_2 alone if continued on their current trajectory will have exceeded their carbon budget ceiling to ensure global temperature rises remain below 2°C above pre-industrial levels by 2040 (Le Quéré, 2015).

Table 3 shows the key sources of anthropogenic emissions in meat production and the average emissions intensities for each livestock species based on life cycle analysis of a range of production systems (Gerber, 2013a; Opio, 2013). The dominance of methane emissions from enteric and manure management elements in ruminant production is evident, whilst carbon dioxide and methane are the principle emissions in non-ruminant meat production associated with straight and compound feeds. Land use change (LUC) emissions are subject to uncertainties of measurement and concept. Allocations are however made for LUC from forest to pasture expansion and from savannah (Cerrado) to soya production, particularly in the context of S America. Average emissions intensities for beef cattle are twice those of sheep and goats, and almost eight fold greater than for pigs and poultry. There is however considerable variation in emissions intensities within each livestock species, depending on region, production system, climatic type and enterprise productivity. Figure 4 illustrates this variability in beef production, and the significantly lower levels of intensities in the developed economy regions, where mixed dairy beef systems are the most emissions intensity efficient, given the spreading of breeding animal overhead between milk and meat outputs. Table 4 provides a summary of livestock emissions in the context of global anthropogenic emissions. Methane from livestock comprise over half of livestock emissions, and 44% of all anthropogenic methane emissions. They also contribute over half of total anthropogenic nitrous oxide emissions. Whilst the global warming potential (GWP) of such gasses is high, their persistence in terms of their longer term 100 year global warming potential (GWP100) is less than for carbon dioxide, to which livestock production only contributes 5% of the global total. Figure 5 presents estimates of total livestock GHG emissions and those of its constituent meat and dairy products in which global livestock emissions in the 2005-2010 period averaged 6.2 Gt CO_2-eq. Livestock for meat systems accounted for about 4.4 Gt CO_2-eq of which cattle for beef contributed 2.8 Gt CO_2-eq, and milk, 1.8 Gt CO_2-eq.

Under the premise that agriculture must contribute its share of emissions reductions, the likely levels of future meat consumption and their associated GHG emissions in meeting this condition set the scale of the adaptation and mitigation challenges for the global livestock industry, and for the policy makers and shapers of public opinion and attitudes in terms of potential action or regulation to promote behaviour change (of consumers and producers). These challenges are not insubstantial as Table 6 reveals. Livestock and meat production contributed over 58% of GHG emissions in the AFOLU sector. If the livestock and meat industry is to bear its pro-rata share of AFOLU sector cuts, its annual GHG emissions would need to fall from 6.9 to 3.4 Gt CO_2-eq by 2050, which would equate to a ceiling on cumulative emissions of 206 Gt CO_2-eq.

As indicated in the Introduction, much of the emphasis hitherto has been on identifying supply-side measures to mitigate and reduce GHG emissions from livestock production, and also on the underlying research that climate, environment and agricultural scientists identify as being essential to meet that challenge. Attention has regularly been drawn to the heavy influence developed economies have on meat consumption thereby driving production emissions elsewhere in the global meat economy through imports. Their agricultural policies are also now firmly oriented towards delivering environmental objectives, amongst which the reduction

[8] Referred in IPCC reports as the representative concentration pathways (RCPs) of a wide range of simulations of climate change scenarios.

in their domestic agriculture GHG emissions features increasingly prominently However it is also worth noting that production related emissions from developed economies in N America, Europe and Oceania are only a little over 25% of global livestock emissions[9]. This raises a critical question as to whether the focus and major part of future research and technology developments into mitigating livestock emissions intensities which are most likely to be conducted in the developed economy regions[10] will be appropriate and transferable to those developing regions where demand and emissions growth will be higher and where there will be the greatest global pay-off in reducing the intensity of their livestock emissions.

The Foresight Report, presaging the IPPC report on Climate Change 2014, concluded demand for the most resource-intensive types of food must be contained and waste in all areas of the food system must be minimised (Foresight, 2011). IPCC subsequently identified the need to switch consumption from products with higher GHG emissions in the process chain to those with lower GHG emissions, whilst recognizing that food demand change is and will remain a sensitive issue given that in many regions their populations still suffer from hunger and a lack of food security (IPCC 2014c, 2014d). They concluded that:

'w*hile demand side measures are under-researched, changes in diet, reductions in losses in the food supply chain and other measures could have a significant impact on GHG emissions from food production equivalent to 0.76 -8.55 Gt Co2–eq /year'* (IPCC 2014c),

although the detailed report was more equivocal in declaring these as technical mitigation potentials only.

Such estimates of emissions potential are predicated on the basis that any assumed reduction in consumption through diet change or in food waste is realisable, without addressing the policies and market mechanisms within which they will necessarily have to be delivered and may constrain the outcome. They are highly mechanistic estimates, albeit that they may be embedded as scenarios within sophisticated physical-climate change models with environment, land and resource use systems as integral components. Studies by Lee-Gammage (2014), Bazjeli et.al.(2014), Westhoek et.al. (2014), and IPCC op. cit. all estimated demand-induced mitigation potentials. Bazjeli examined the effect of a 50% reduction in waste and a shift to a range of "healthy diets" characterised by specific reductions in meat consumption. Westhoek explored the consequences of replacing 20-50% of EU animal derived foods with plant –based foods. IPCC cite the study by Stehfest et al (2009) that makes specific assumptions about waste reduction and declines in the level of meat consumption, including zero consumption of animal products. Smith et al (2013) go further to argue that '*consumption-based measures offer a greater potential for GHG mitigation than do supply-side measures'.* This is of course a proposition which is worth pursuing further.

Nor do these studies distinguish between total food waste and avoidable waste, the latter being most relevant and a smaller proportion of total waste (Smith et al , 2013). In the UK, WRAP estimated that over 14% of food purchased was either avoidable or potentially avoidable waste, but that rates of meat and dairy product household waste were considerably lower than for fresh vegetables and salads and bakery products[11]. Furthermore, there had been little change over the 5 preceding years in reducing avoidable meat waste, suggesting that there is little further opportunity to easily reduce household meat waste or to do so is problematic (WRAP, 2013). If such patterns are repeated elsewhere in developed economies, then clearly the waste

[9] Though significantly higher on a per capita basis of its consumption CO_2 equivalent.
[10] And where production systems are often quite different from those in developing economy regions of the world.
[11] See also Monier et al. (2010)

mitigation potential will largely need to be met in developing regions. However, a report into global and EU food waste by Priefer (2013) indicated that 50% of food produced in the world is wasted. It highlighted that household food waste in developed countries was greater than that in developing countries, and so the potential for waste reduction in households is greatest in developed economy countries[12]. Conversely waste in the production, storage, processing and distribution supply chains of many developed countries upstream of the final consumer has been reduced considerably in recent years, but not in developing countries, where integrated supply chains or cold chains are not commonplace. Policies or measures directed at encouraging waste reduction will reduce effective demand for food products, as less product will need to be purchased at any given price. Some market price adjustment is thus likely, and the fall in consumption inevitably smaller than the reduction in waste, given that a lower price will have a some positive effect on non-wasteful consumption. Hence estimating mitigation potentials for waste reduction are at best speculative, and such mitigation potentials aspirational targets without having regard to the feasibility of their delivery and the market processes in which consumption adjustments take place. .

4. Modelling future meat demand and GHG emissions

There have been a number of published studies using partial equilibrium or computable general equilibrium models to project future food demand and availability. Some have bio-economic, land and water resources components but their primary focus has been to explore the impact of economic development and climate change on the natural resource base and productivity of agriculture, and their consequences for food security to 2050. They do not set out, however to measure emissions[13] nor to examine policy or other measures aimed directly or indirectly at restricting meat consumption, or mitigating the carbon emissions intensity of food products. Such studies include an IFAD report by Nelson (2010), and a number of global models reviewed in Valin (2014) and von Lampe (2014). There thus appeared to be a gap in modelling the long run emissions consequences of future meat demand and the potential emissions impact of mitigation and adaptation measures directed at reducing meat consumption.

A simple partial equilibrium regional model of the global meat market was developed to explore these questions. The Baseline model includes beef, pig, poultry and ovine meats and comprises the continents/regions of Africa[14] and its constituent sub regions North, Central, East, West and Southern Africa; Asia and its sub regions of Central, East, South, South-East and Western Asia; Central, South America, and the Caribbean; Northern America; Europe and Oceania. Production and consumption projections are then linked to their average sub regional species emission intensities to obtain total GHG emissions for each meat, region and sub region.

Let per capita regional demand Qdc_{ij} for product i $(i=1\ldots m)$ and region j $(j=1..k..n)$be given by the equation

$$Qdc_{ij} = \alpha_{ij}\, GDPc_j^{\beta 1ij}\, Pij^{\beta 2ij} \qquad (1)$$

[12] Priefer cites an FAO study which estimated that the per capita food waste by consumers in Europe and North America is 95115 kg/year, while this figure in Sub-Sahara Africa and South/Southeast Asia is only 6-11 kg/year.
[13] In principle, their supply and consumption projections could readily be converted into emissions.
[14] The model solution is based on the sub regional demand and supply functions and emissions intensities for Africa and Asia, the regional (i.e. continental) totals being the sum of their sub regions.

where P_{ij} is the average of the export and import price for product *i* in region *j*, $GDPc_j$ is real per capita income, and $\beta 1ij$ and $\beta 2ij$ are the income and own price elasticities of demand respectively.

Total regional product consumption is obtained from (1) and the regional population Pop_{ij}

$$Qd_{ij} = Qdc_{ij} \cdot Pop_j \tag{2}$$

The regional domestic supply function Qs_{ij} is given in (3)

$$Qs_{ij} = \gamma_{ij} \, P_{ij}^{\upsilon ij} \tag{3}$$

Where υij is the own price elasticity of supply. Global consumption QD_i^w and supplies QS_i^w are obtained from (4):-

$$QD_i^{\,w} = \Sigma_j \cdot Qd_{ij} \quad \text{and} \quad QS_i^{\,w} = \Sigma_j \cdot Qs_{ij} \tag{4}$$

The world price P_i^w is defined as the weighted average price of consumption and production in each region.:-

$$P_i^{\,w} = \Sigma_j \cdot P_{ij} \cdot \left(Qd_{ij} + Qs_{ij}\right) \cdot \left(QD_i^{\,w} + QS_i^{\,w}\right)^{-1} \tag{5}$$

The model is solved as a constrained non linear optimisation problem in which the most efficient market price is sought subject to global market clearing i.e. zero global net trade.

$$\text{Min } P_i^w \quad s.t. \; QD_i^w - QS_i^w = 0$$

Emissions intensities for each product and region, are denoted by ep_{ij} and total regional product emissions for product *i* by EP_{ij} . Global product emissions, $EP_i^w = \Sigma_j EP_{ij}$, are defined in (6) as

$$EP_i^{\,w} = \Sigma_j \cdot ep_{ij} \cdot Qs_{ij} \tag{6}$$

Because the model is a net trade model in which individual regions may have either excess demand or supply, a specific trade matrix is not identifiable, and consumption emissions in any region EC_{ij} are derived from the sum of its domestic production emissions plus those emissions on its net imports (excess demand). The latter are defined as the product of net imports of region j and the weighted average emission intensity of the K = 1….k excess supply regions, denoted as ES_{iK}. Thus for importing regions j=k+1…n

$$EC_{ij} = EP_{ij} + (Qd_{ij} - Qs_{ij}) \, ES_{iK} \qquad k<n \tag{7}$$

and global consumption emissions EC_i^w *by*

$$EC_i^{\,w} = \Sigma_j \cdot EC_{ij} \tag{8}$$

The model is conditioned by sub regional income and own price elasticities of demand, and own–price supply elasticities together with 2010 base values of per capita consumption, population, real per capita incomes and trade weighted, PPP adjusted average import/export prices of each meat, total consumption (ie total supplies/offtake) and sub regional production. Given assumptions outlined below regarding future economic and population growth, the model is solved for the base period of 2010, and then for 2050[15]. The absence in most published studies of statistically significant or substantive values for cross price elasticities both of demand and supply necessitate each meat product is solved as an autonomous market. Equilibrium regional consumption and production are then converted according to species and sub regional CO2-eq emissions intensity coefficients to regional consumption and production emissions. Producer and consumer price changes are identical –no explicit price transmission process, nor trade policy barriers or domestic agricultural policies impede to perfect price transmission from world to domestic markets. The model also implicitly assumes that there will be sufficient land, water, labour and capital resources to meet the requirements for any supply expansion in response to market price changes.

5. Model data, assumptions and elasticities

Base year per capita consumption, total supplies (human consumption plus other uses[16]), production, export and import unit values as price proxies were obtained from FAOSTAT, and GDP per capita at PPP was from UNCTAD (2015). The key assumptions in the model relate to future economic and population growth as drivers of demand. Assumptions for per capita economic growth to 2050 were derived from a recent report by PwC (Hawksworth, 2015) and shown in Table A2. These are less optimistic than in an earlier study by Nelson et.al. (2010), and lower than the 2004-2013 GDP per capita average growth rates. There is support for such a view. Dellink highlighted the consequences of climate change on economic growth, reducing the aggregate rate of growth by between 0.7 to 2. 5% by 2060 (Dellink, 2014)[17]. Indeed, for the past 4 years there have been consistent downward revisions in longer term growth forecasts as each year progresses (Fulcrum and Consensus Economics, 2015). Global annual per capita growth rates are projected as around 2.6%, with growth in most regions and sub regions below 3% and only Southern Asia, South East Asia and Southern Africa above 3%. Population growth projections are based on UN (2015) under the medium fertility rate scenario affecting future growth, and shown in Table A3. The global population is projected to increase by 2.6 billion between 2010 and 2050, reaching 9.6 billion people in 2050, though alternative low and high fertility rate scenarios place the possible range as between 8.3 to 10.9 billion. Crucially, the projections show 52% of the population increase to be in Africa, especially Eastern and Western Africa, and 37% in Asia, notably in Southern and South East Asia.

If modelling is to do more than mechanically extrapolate the impact of population growth on future meat consumption and emissions, then per capita meat and total demand and supply growth need to be incorporated in a model that will permit regional and global price adjustments through domestic and global market adjustments. This either explicitly or implicitly will require estimates of income and own price elasticities of demand and preferably cross price elasticities, or models with equations from which such elasticities can be derived.

[15] It is also able to generate results for intermediate periods 2020, 2030 and 2040.
[16] Such as for seed, and normally a small proportion of total usage.
[17] It is also worth noting that both IPCC AR4, reiterated in IPCC AR5 (IPCC, 2014b), observed that climate change will also result in higher real prices for food past 2050, though commented on the lack of new studies exploring price changes. It is not clear whether these earlier assessments of real price increases also incorporate demand led factors.

Many of the recently published studies of meat demand since 2000 however, tend to reveal inter-species cross price elasticities that are neither significant statistically nor in magnitude. Supply elasticities or modelling of supply response in other ways will also be necessary if we are to allow meat prices to moderate the future income induced demand growth. This may seem basic but the selection of the size of such elasticities has been crucial in the differences in long term projections that a number of well known global food security models have made, even under consistent common assumptions of economic and population growth (von Lampe, 2014; Valin, 2014).

Many of the more recently published studies on meat demand have been based on food expenditure based AIDS-variant models. However, expenditure elasticities are not necessarily the same as income elasticities unless the income elasticity of food expenditure is unity. Generally this is unlikely to be so given that food expenditure tends to decline as a proportion of income (Rask, 2011). Furthermore, income elasticities of expenditure are rarely corrected for quality effects in purchase so that the estimates are biased upwards if interpreted as quantity elasticities, particularly at higher income levels[18].

Nevertheless, there is no shortage of income and price elasticity of demand estimates in the recent literature although the range of estimated values even for specific countries or regions can vary enormously. (Table A.1). Hence, in global modelling, there is a dilemma of selection. It is perhaps surprising to find that many of the income and price elasticity estimates for products such as beef are relatively high even in developed economy countries. Elasticity estimates for some regions, particularly in Africa are particularly sparse and data quality poor from which to derive them. This is a challenge to modellers given that these regions a priori might be expected to have relatively higher price and income elasticities of demand for the various meats.

In the long run, Engel adjustment for the impact of rising real per capita incomes on price and income elasticities is necessary, although for developing economy countries, even a projected doubling of long term real per capita incomes by 2050 may not take them far down the elasticity-income curve, producing only small consequential reductions in their elasticity values. The author's estimates suggest that by 2050, even a doubling of the average base period levels of African or Asian real per capita incomes might only reduce the magnitudes of their income and (absolute) own price elasticities for meat and milk by 0.1 to 0.2.

A series of studies of food demand for 146 countries based on International Comparison Programme data include meat and dairy in the food product groups, (Seale, 2003, Regmi, 2010 and Muhammad, 2013) but do not distinguish between different types of meat. They do enable regional averages to be constructed and indicate the values around which elasticities for individual meats will generally range . However, they are less helpful for the analysis of the GHG impact of meat consumption, given the widely differing emissions intensities of beef, sheep and goats, pigs and poultry. Income elasticities in many of the global economic food models are conservative with values in the 0.3-0.4 range for ruminants and non ruminants alike, and rarely above 0.5 depending on country/region. Their meat price demand elasticities tend to cluster around -0.25 (FAPRI, 2015). Small income elasticities will tend to diminish the impact of economic growth as a driver of future demand for meat relative to population growth whilst small price inelasticity will amplify the effect of exogenous changes or supply shifts but diminish the consumption response to price (or tax) changes. Settling on plausible values of

[18] An exception is the study by Pomboza (2007)

long run demand and supply elasticities is therefore essential if such models are to realistically reflect the long term evolution of meat consumption[19].

Recent literature on supply response elasticities is very sparse, and elasticities can either only be derived by inference from the supply and price changes projected by global models or more directly from the supply side equations in the models (if released into the public domain). In the longer run, integrating future technology and management–induced productivity gains, land area substitution opportunities between enterprises, climate change impact on feed availability and costs, and land use change which can significantly affect emissions intensities, particularly for intensive pig and poultry enterprises heavily dependent on soya production from S America, add complexity to estimating supply elasticities.

Table 6 presents the global demand and supply elasticities for the different meats implicit in the Baseline model[20]. An all meat average is also computed to compare with those from the study of Muhammad (op. cit.). Baseline model income and price elasticities for meat are close to those of the international study, although those for milk lower than the dairy elasticity estimates from the international study. This difference may relate to the Baseline model data being liquid milk consumption, whereas the dairy elasticities will contain processed milk products. Overall the Baseline aggregate supply and demand elasticities seem to be plausible.

6. Baseline Model Projections and Scenario Analysis

Baseline model and scenario projections are provided in full in Tables A.4 and A.5. Global total meat consumption per head rises from 41.5 kg to 50.2 kg, an increase of 21%. Projected consumption of liquid milk rises by 16%. Poultry consumption is projected to rise by 36%, ovine meat consumption by over 50% (but still very low), pig meat by about 11% but beef by only 6%. The model's projections are compared with those from a number of other recent studies in Table 7 (Alexandratis, 2012; Willenbockel, 2014). The Baseline global meat consumption projection of 476 Mn tonnes represents an annual growth rate of 1.3%, identical to that in the FAO projections, although the latter are from a slightly earlier base period. Consumption growth rate projections for the individual meats in both the Baseline and FAO models do not differ markedly, and the total consumption of ruminant meats in both studies are of similar levels. The primary difference between the two sets of projections is that the Baseline model projects higher non-ruminant consumption. The projected ruminant meat total consumption of 124 Mn tonnes and 352 Mn tonnes for non ruminant meat fall within, but toward the lower part of the projected ranges of the Willenbockel study. Figure 6 presents the Baseline model projections of regional per capita consumption. Consumption per head increases in all regions except N America and Europe, remaining stable in the latter .

Table 7 and Table A.5. summarise changes in the Baseline model projections of GHG consumption emissions between 2010 and 2050. The largest annual and cumulative emissions increases are in the beef sector, which could contribute over 43% of global livestock emissions, albeit a reduction by over 2 percentage points from 2010 base period emissions. Ovine meat emissions more than double with the emissions share increasing by about 2 percentage points. Poultry meat emissions rise by nearly 90% and the share of emissions increases by almost 1.5 percentage points. Pig meat emissions increase by 48% and its share falls by 1 percentage point. Global livestock emissions could rise by 63% over the next 40 years. Cumulative global

[19] Tiffin (2010) does estimate long run price and expenditure elasticities for the UK
[20] The 2010 base values of income and own prices for the meats in all regions were independently varied by 1%, ceteris paribus, and the consequent changes in consumption and supply derived.

livestock emissions are projected to be 304 Gt CO_2-eq by 2050 over 100 Gt CO_2-eq more than the "minimum desirable" reduction indicated by the CCC(op. cit.).

A number of scenarios which a priori have the potential to reduce the growth in meat consumption emissions projected in the Baseline model results of Table A.5 are next explored, especially with respect to red meat. They are as follows:-

- ***I A trend decline in red meat per capita consumption***

A recent Chatham House report highlighted that whilst public awareness of anthropogenic climate change is high, there remains a significant awareness gap of the role of meat consumption in global warming. Closing this gap is a precondition to encouraging consumers to reduce their meat consumption voluntarily as climate change does not currently feature in their consumption decisions (Bailey, 2015). Its online survey in the BRICS countries, Germany, Poland, UK, Russia and the US revealed respondents in Brazil, China and India more likely to give greater consideration to climate change in their purchases of meat and dairy products, and more willing to modify their consumption behaviour accordingly. Whilst the scenario does not incorporate a trend reduction in meat consumption in emerging and developing economy regions, it does examine an autonomous annual trend decline in red meat consumption per head in the developed economy regions of around 0.007% p.a., equivalent to a 25% long term reduction in demand ceteris paribus. This is predicated on the assumption that sustained and long term health and dietary information and advice from governments and their agencies to reduce consumption of red and processed meat consumption and about the contribution of meat production to global warming, will eventually bear modest fruit.

- ***II Taxes on ruminant meat consumption***[21]
    - *IIa A tax of $80/tonne per tonne of ruminant meat consumption emissions in developed economies from 2010 to 2050*
    - *IIb A universal global CO_2-eq tax of $80/tonne of carbon/tonne of ruminant meat emissions.*

A number of studies have recently emerged exploring the potential effectiveness of carbon taxes on food consumption, diet, health and emissions , especially red meats. However, these have been specific country studies in Denmark, the UK and France (Edjabou, 2013; Briggs, 2013; Caillavet, 2014). Briggs et al estimated a potential reduction across the UK of 3% of total GHG emissions from a carbon tax equivalent to about $US42/tonne imposed on the emissions values of most foodstuffs in the UK diet based on own and cross price elasticities estimated from the UK Living Costs and Food Survey. Caillavet et al (2014) explored 2 scenarios within their AIDs expenditure model of a (non emissions related) food tax of 20% on products with animal contents and a 20% tax on food categories regarded as injurious to health and the environment. The social costs of carbon emissions have variously been estimated at between US$20 to 80 per tonne (Foresight, 2011). However a recent study by Luckow et.al (2014) projected the market price for CO_2 at around $US60 per short ton in 2040, which when extrapolated from their published data would be equivalent to $93 per tonne by 2050. Table 9 illustrates the equivalent carbon and product price tax rates in $US 2010. It can be seen that even a $50/tonne CO_2-eq would have equated to a tax on the beef price of over 56% and over 28% of the trade price of sheep meat. There would inevitably be political ramifications if such high carbon taxes were to be applied. Nevertheless, this paper assumes

[21] Tax in the model is imposed as a tax wedge in which the optimal solution will allocate the incidence of the tax on the pre-tax equilibrium price between consumption and production.

taxes of $US80 per tonne of CO_2 in order to gauge if a relatively high tax rate has the potential for making a significant impact on ruminant meat consumption.

- ***III Global livestock productivity gains reducing emissions intensities.***

This scenario examines the possibility of developed regions reducing all livestock emissions by 25% by 2050. It assumes that developing regions can reduce their emissions intensities for beef, ovine meat and milk by one-third of the current gap between their emissions and those of developed regions, and by two thirds of the gap for pigs and poultry.

- ***IV a combined approach of I+IIb +III***

The final scenario recognises the most probable need for a supply and demand driven approach to reducing emissions.

It is probably most informative to consider as a group the emissions consequences of each scenario relative to the Baseline 2050 projections. These are shown for red meat in Figure 8 as the tax and consumption trend scenarios were only relevant to those products. Relative to Baseline 2050, Scenario I would reduce beef consumption by 3 Mt and by 1 Mt for ovine meats. Imposing a tax on red meats in the developed economies alone in Scenario IIa would only reduce global consumption by 1 Mt, primarily because most consumption growth is in the developing regions. On the other hand, a heavy tax on meat consumption universally applied in Scenario IIb would reduce consumption of beef and ovine meats by 6Mt. The impact of a combination of productivity gains together with Scenario IIb and downward trending consumption in Scenario I suggest a fall in red meat consumption of 13Mt. Even a combined strategy of demand and supply oriented approaches as postulated here might only reduce total ruminant meat consumption by around 11% relative to the Baseline 2050 levels of meat consumption.

It is interesting to note that within the model, there are limits to the efficacy of carbon taxes on meat, irrespective of the political dimension of taxing foods. Table 9 illustrates that the effectiveness of an $US80 carbon tax applied constantly from 2010 to 2050 would diminish from 4.6 Mt CO_2-eq/$ tax in 2010 to 3.1 Mt CO_2-eq /tax by 2050. Clearly this reflects the countervailing effects of economic growth driving per capita consumption upwards over time. Figure 7 illustrates the corollary that a sharp increase in tax rate until 2050 approaching 100% of the pre-tax equilibrium product price would be required to reduce beef consumption from the Baseline 2050 level of 93 Mt to 78 Mt. Figure 9 presents the scenario impacts emissions of each livestock species. Beef emissions under IV would fall by 1.4 Gt CO_2-eq, pig meat by 0.17 Gt CO_2-eq , ovine meat and poultry meat by 0.1 Gt CO_2-eq. The cumulative emissions impact of the scenarios are shown in Figure 10, under which the combined strategy would reduce cumulative emissions for all livestock products to 274 Gt CO_2-eq, still in well excess of the target level of 206 Gt CO_2-eq suggested as necessary by CCC.

7. Discussion and conclusions

Encouraging consumers to change their behaviour and eating habits leading to reductions in meat consumption will be a significant challenge for policymakers and opinion formers alike with perhaps sustained and greater emphasis on health awareness as a key driver where over-consumption and obesity is prevalent. But, it may be problematic to achieve this where livestock, their meat and milk are an integral part of a society and its culture, essential for draft power and food, a store of wealth, and define the identity of many peoples. Although there is some recent evidence, that even in a number of emerging economy countries, consumers may be willing to consider the environmental impact of meat consumption and may be prepared (they say) to reduce their per capita red meat consumption, strangely, however, this was not echoed so strongly by respondents in developed economy countries. The difficulty for governments in proactively persuading consumers to eat less meat is that they risk the ire and opposition from those engaged in the meat industry supply chain as it will inevitably lead to adverse economic consequences for domestic meat industries. A similar argument applies to taxation of (red meats).

The big wins from food waste reduction are likely to require significant investment in infrastructure, particularly in those developing economy regions where storage and logistics throughout their supply chains are often at best rudimentary and post harvest food waste/losses critical to their food security. In the developed economy regions, reducing levels of avoidable household food waste still remains a challenge, although much has been done elsewhere within the supply chains. It will however reduce marginal production, storage and distribution costs and is therefore intrinsically a supply curve shifter which ceteris paribus, would tend to lower prices. Similarly, reduction of avoidable waste by consumers will lower effective demand for product. This will tend to depress its price and hence the fall in consumption will be less than the potential measured by the assumed reduction in waste. Furthermore, evidence from the UK tends to show that waste is more prevalent for fresh produce (fruit and vegetables), and less so for meat and dairy products. If this pattern is repeated throughout developed economies, the gains from reducing avoidable waste in their meat consumption are likely to be limited.

The paper has considered the potential for reducing meat consumption through taxation, and the model examined an explicit scenario for this. For commercial livestock products, levying tax at the point of slaughter would probably be the most practical way to implement a tax on indigenous product, whilst carbon-related import taxes might reduce consumption in regions of excess demand. Taxation is equally applicable to consumption or production of meat, and a consumption tax will still impact on both consumers and producers, the incidence of the tax depending on both the supply and demand elasticities. Given that food consumption taxes may be politically and ethically difficult to justify in poor and less developed countries, the practical issues of acceptability are not without problems, not only by consumers, but by producers too.

The price equivalent rates of carbon taxation on ruminant meat within the range of estimates of the social costs of carbon relative to red meat prices would appear to be substantial compared with those usually applied on foods and consumer goods and services. There is therefore a question as to whether they would be politically acceptable at such levels when even a real mid range social cost of carbon tax of $50 per tonne may be equivalent to a tax of over 50% of the base period 2010 price for beef, and still over one-third of the price in 2030. Whilst lower levels of carbon taxation may give a signal to consumers, as a direct demand deterrent it may be less effective, and the Baseline model suggests that a universal carbon tax on beef in 2050 would need to rise to very high levels to remove even a modest fraction of the growth of global beef consumption by then. The restriction of carbon taxation of red meat consumption to developed economy countries (perceived as progressive) will be less effective in reducing global emissions than universally applied carbon taxes on beef and ovine meats.

There are a number of questions relating to the practicality of imposing a carbon tax on meat. Deciding the appropriate rate of consumption tax is not straightforward even given the price of carbon. Would importing countries tax imports at the emissions intensity rate of the supplying country or at an average global emissions intensity level, when the latter would necessarily discriminate against carbon–efficient exporting countries. Would exported product receive an import tax carbon credit offset for any domestic carbon taxes already paid in the exporting country? Is it likely meat exporting countries would be willing to impose a carbon export tax instead, given the importance of foreign exchange earnings to their economies, particularly in S America? How do we determine the appropriate import tax rate for a non-differentiated traded product when it may come from a more emissions efficient dairy beef system than from a grassland system? Would we also need to tax indigenous production at the system emissions intensity rates, or at some average? Should all types of meat (not just red meats) be taxed at their appropriate rates of emissions intensity? And why just tax meat as production of all foodstuffs have emissions intensities.? Finally, whilst taxing meat consumption and/or production on its carbon emissions may generate health benefits it is likely to be a less than optimal tax from a nutritional perspective to achieve specific dietary objectives, and may also have some unintended adverse consequences.

Land use change elements of whole supply chain emissions for beef in particular, where calculations have been historically based on loss of forest to pasture, may overstate future emissions intensities. Rates of deforestation and pasture expansion have declined in the last decade, and ruminant production intensification has increased, especially in Brazil. The historical-based emissions intensity estimates related to LUC in recent studies of red meat production also exclude the carbon sequestration offset of increased grassland area, so may be overestimates of their future emission intensities. If the increased demand for meat is to be satisfied through an even greater expansion of non-ruminant meat consumption, the land use change emissions intensity component for soya production could well continue to rise steadily above current estimates.

The scenarios explored suggest the demand-side measures for the meats, combined with the assumed lower emissions intensity scenario are still likely to leave the sector short of the emissions reductions necessary by 2050 to make its proportionate contribution to global emissions reduction. Lowering emissions intensity in the regions where meat demand growth will be greatest has to be a key part of an overall strategy to reduce red meat emissions, to which demand related measures can make a contribution. If in the coming decades differences in emissions intensities for ruminant meats are not narrowed significantly between regions with low private costs of production but high emissions intensities, and those with higher cost but lower emissions intensities, then future policies such as carbon taxation which internalise the social costs of emissions may alter their relative competitiveness and international trading patterns could consequently change. From a global perspective, it may make sense in future to export meat from lower emissions intensity regions to those where there is excess demand and higher emissions intensities if the price of carbon is high. The model in this paper suggests (production and transaction cost differences aside), that the developed economy regions and S America might in future be the ones meeting the growth in demand located in Africa and Asia. This may run counter to the direction of environmental policy objectives in the developed world of reducing their own livestock production emissions, but emissions are global, not local.

Many of the complex bio-physical models of climate change which incorporate agricultural systems omit the economic dimensions of market responses to mitigation measures both in production and consumption. The latter will surely reduce the mitigation potentials currently being identified by such models. It therefore remains a challenge to the profession to ensure that economic analysis is not simply bolted on as after-thought but form an integral part of the bio-physical and economic systems that should be modelled together. Hence there is still much to be done in evaluating the impact of economic drivers on meat consumption and hence on climate change, and of the reciprocal economic impact of climate change on long run meat production, given the dynamic relationship between the two. It is of course the interaction of demand with supply which will also determine the scale of the ruminant emissions mitigation challenge, not solely that through population growth. More especially, the evaluation of a range of appropriate measures to manage meat demand growth can make an effective contribution to quantifying its impact on global GHG emissions which a simple model such as that developed in this paper can readily facilitate. However, it would seem unlikely that demand reduction measures will in themselves provide the solution for reducing 2050 meat emissions from global meat consumption below current levels unless there is a sea change in global consumer diets. But where we may be in 2050 will also reside in the magnitude of the long run meat demand and supply elasticities. Is there a yet a consensus of what their true values could be?

Tables and Figures

Table 1 Global per capita meat consumption by species in 2013 (kg/head)

Region	Beef	Pig	Poultry	Ovine	Total
Africa	4.4	1.0	4.2	2.2	11.8
Asia	2.7	12.8	8.4	1.7	25.7
LAC	17.0	9.6	30.8	0.6	57.9
N America	24.9	20.6	43.1	0.4	89.0
Europe	10.7	27.2	21.4	1.7	61.1
Oceania	23.4	19.8	37.8	8.9	89.9
World	**6.5**	**12.6**	**13.2**	**1.7**	**34.0**

Source OECD 2015

Table 2a Regional shares of global meat consumption by species 2013 (%)

Region	Beef	Pig	Poultry	Ovine
Africa	10.6	1.2	4.8	20.3
Asia	25.6	59.9	38.3	62.2
LAC	23.9	6.8	21.1	3.0
N America	20.2	8.4	17.0	1.3
Europe	18.2	23.2	17.7	11.0
Oceania	1.5	0.6	1.2	2.2

Source OECD 2015

Table 2b Species shares of regional meat consumption 2000 and 2013 (%)

	Beef		**Pig**		**Poultry**		**Ovine**	
	2000	**2013**	**2000**	**2013**	**2000**	**2013**	**2000**	**2013**
Africa	39.4	37.8	7.8	8.2	29.7	35.3	23.1	18.7
Asia	12.1	10.7	52.5	49.8	27.9	32.8	7.5	6.7
LAC	38.1	29.3	16.7	16.6	43.8	53.1	1.5	1.0
N America	31.5	28.0	24.2	23.1	43.7	48.4	0.6	0.5
Europe	21.0	17.6	48.1	44.6	26.9	35.0	4.0	2.8
Oceania	29.6	26.0	17.2	22.1	32.7	42.0	20.5	9.9
World	22.8	19.2	38.8	37.0	32.9	38.9	5.5	5.0

Source OECD 2015

Table 3 Sources of anthropogenic emissions in meat production and average emissions intensities

	Beef Cattle	Ovine	Pig	Poultry
	% of total emissions			
Enteric, CH_4	42.6	54.9	3.1	
Manure Management CH_4	1.4	2	19.2	1.6
Manure Management N_2O	3.6	2	8.2	4.8
Applied/deposited manure N_2O	18.1	17.6	7.9	22.6
Fertilizer/crops residues N_2O	7.4	8.8	9.1	9.1
Feed CO_2 /CH_4 (Rice)	10	11.1	30.6	24.8
LUC soybean CO_2	0.7		12.7	**21.1**
LUC Pasture expansion CO_2	14.8			
Energy CO_2	0.9	1.8	3.5	7.6
Post farm CO_2	0.5	1.7	5.7	6.9
Average emissions intensity kg	46.2	23.8	6.1	5.4

Source Gerber 2013a, Opio 2013, MacLeod 2013

Table 4 Livestock emissions and total anthropogenic emissions 2005-10

	All sources	As % all Sources	From Livestock	As a % of Livestock	Livestock as % all anthropogenic
CH_4	7.8	16.0%	3.4	50.2%	44.0%
CO_2	37.2	76.0%	1.9	27.1%	5.0%
N_2O	2.9	6.0%	1.6	22.7%	53.0%
All	49.0	100%	6.9		14.0%
Error	± 4.5				

Source: Gerber 2013b, IPCC 2014e

Table 5 Reductions needed in GHG emissions to meet RCP 2.6 climate change scenario

Gt CO2 -eq	2010	2050	Cum. emissions 2010-50
Total emissions	49.0	24.0	1460
AFOLU total	11.8	5.9	353
Livestock	6.9	3.4	206
Livestock share of AFOLU	58.6%		
Livestock share of total	14.1%		

Sources: IPCC 2014e; Committee on Climate Change

Table 6 Implicit global demand and supply elasticities in the Baseline model

	Demand		Supply
	Income	**Own Price**	**Own price**
Beef	0.488	-0.417	0.359
Poultry	0.689	-0.517	0.623
Pigs	0.486	-0.340	0.734
Ovine	0.659	-0.432	0.719
All Meat	***0.640***	***-0.470***	***0.622***
Milk	0.414	-0.297	0.798
Consumption weighted averages derived from Muhammad et.al. (2013) 146 country			
All Meat	***0.636***	***-0.466***	
Dairy	0.646	-0.474	

Table 7 Baseline and other model projections of meat consumption to 2050

	Baseline model			FAO [a]		Willenbockel [b]
	Mn tonnes				Mn tonnes	Mn tonnes
	2010	**2050**	**% p.a. incr**	**% p.a. incr**		
Beef	64.6	93.3	0.9	1.2	105.3	
Poultry	98.7	185.1	1.6	1.5	178.8	
Pig	109.9	166.6	1.0	0.8	141.4	
Ovine	14.2	30.8	1.9	1.8	24.4	
TOTAL	**287.4**	**475.8**	**1.3**	**1.3**	**450.0**	
Ruminants	78.8	124.2			129.7	110-175
Non ruminants	208.5	351.7			320.2	320-500

[a] **A**lexandratis (2012). Author's calculation of 2050 consumption from 2005-07 base data and growth rates cited

[b] Willenbockel (2014) cited in **a** comparison of results of 9 CGE and PE models examining food security in 2050

Table 8 Baseline model projections of emissions 2010 and 2050

	Annual Consumption Emissions			**Cumul**
	2010	**2050**	**Change**	**2010-50**
	MT CO2 eq		**%**	**Gt CO2 eq**
Beef	**2759**	**4236**	**54**	**132**
Poultry	**515**	**976**	**89**	**29**
Pig	**651**	**961**	**48**	**31**
Ovine	**338**	**762**	**125**	**21**
Milk	**1773**	**2893**	**63**	**91**
Total	**6035**	**9828**	**63**	**304**

Table 9 Equivalent carbon price and product price tax rates on ruminant meat

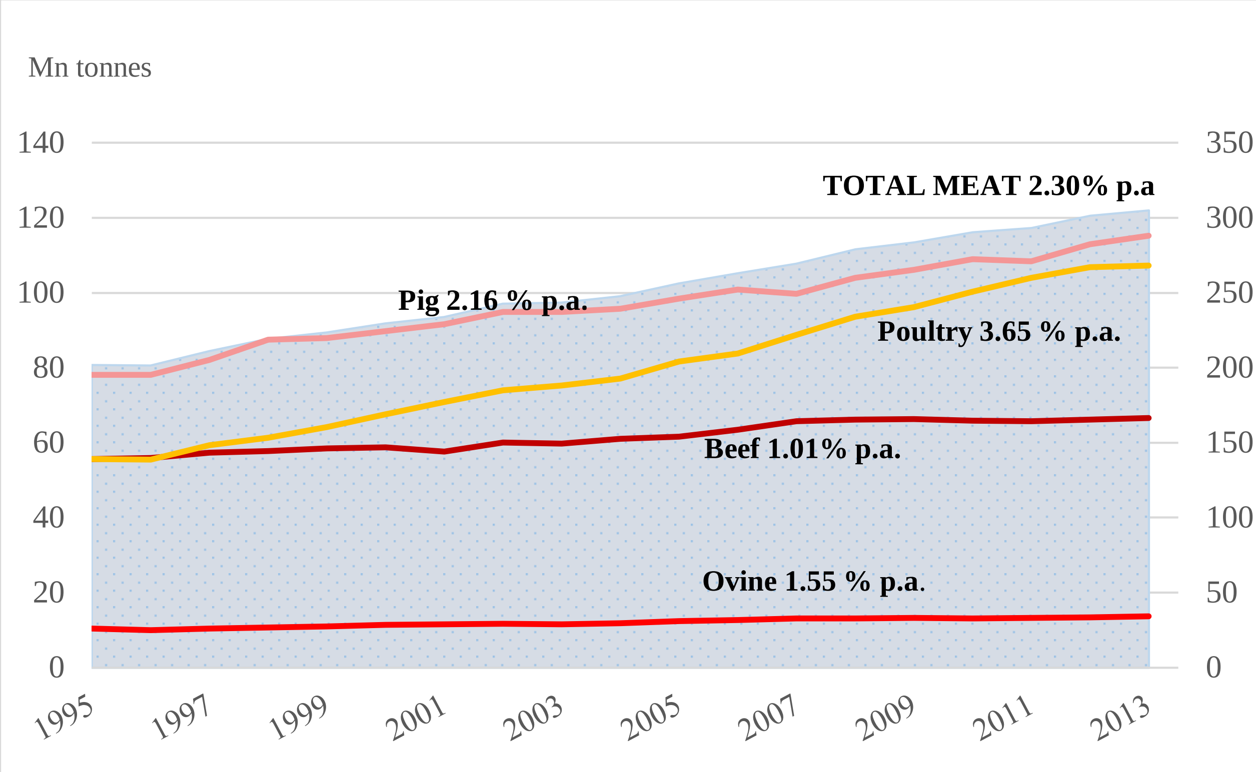
$US / tonne CO2-eq	$US/tonne beef	$US /tonne sheep meat	% of 2010 beef trade price	% of 2010 sheep trade price
20	**924**	**476**	**22.5**	**11.3**
50	**2,310**	**1,190**	**56.3**	**28.3**
80	**3,696**	**1,904**	**90.1**	**45.3**
100	**4,620**	**2,380**	**112.1**	**56.7**
Average trade price 2010	**4,100**	**4,200**		

Table 10 Efficacy of carbon tax on beef

	Consumption Mt	Emissions Mt CO_2-eq	Consumption Mt	Emissions Mt CO_2-eq	Emissions reduction Mt CO_2-eq/$ tax
	Baseline No Tax		**Tax $80/tonne CO2-eq**		
2020	**71.9**	**3414**	**62.0**	**3045**	**4.6**
2030	**78.7**	**3516**	**69.7**	**3171**	**4.3**
2040	**84.5**	**4251**	**78.0**	**3922**	**4.1**
2050	**93.4**	**4238**	**87.9**	**3989**	**3.1**

Figures

Figure 1 Recent trends in meat consumption 1995-2013



Source OECD 2015

Figure 2 Drivers of meat consumption growth 2000-2011

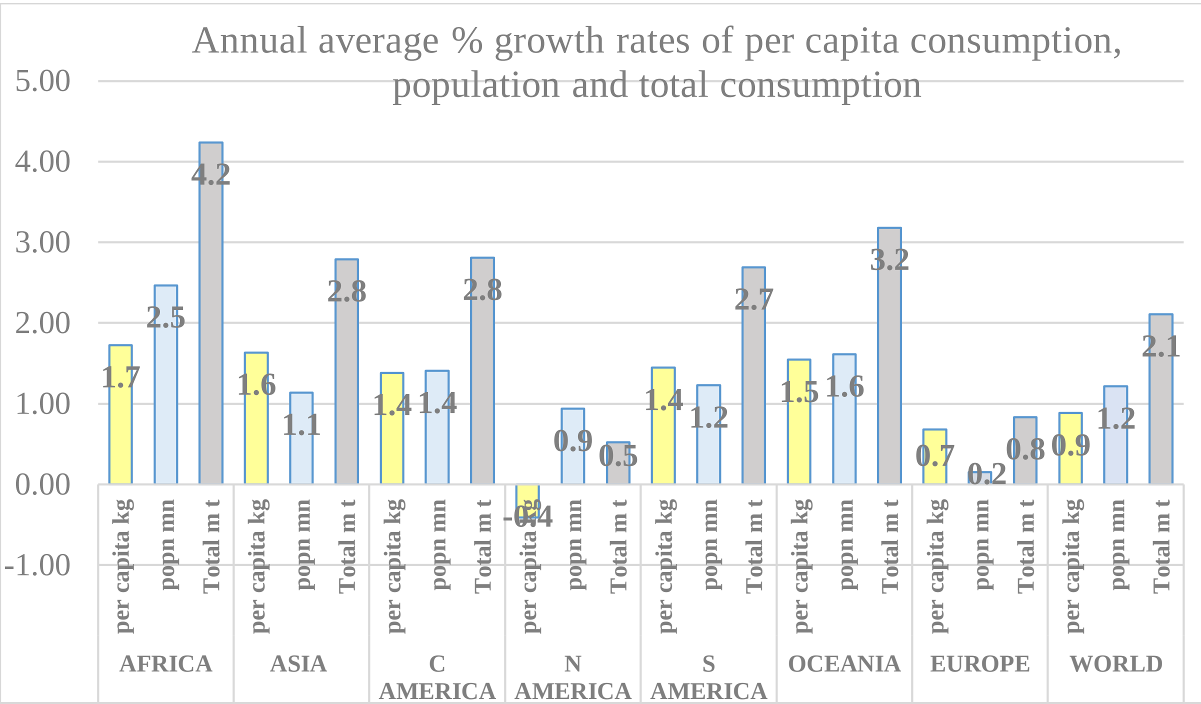
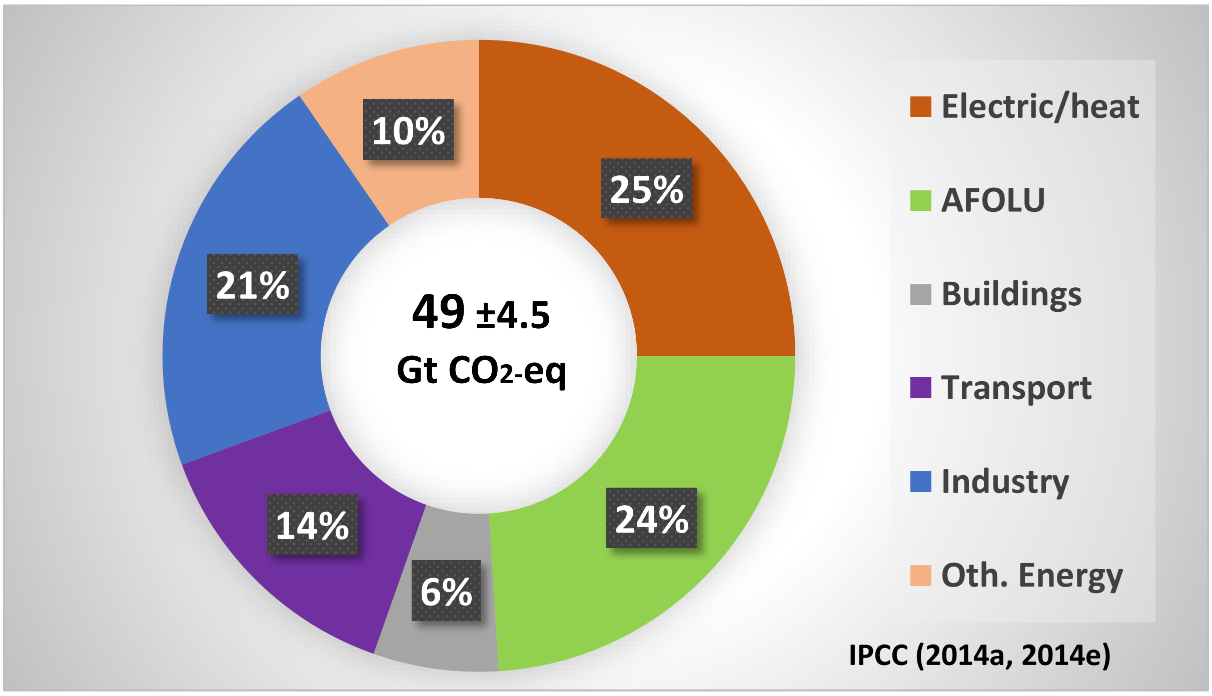
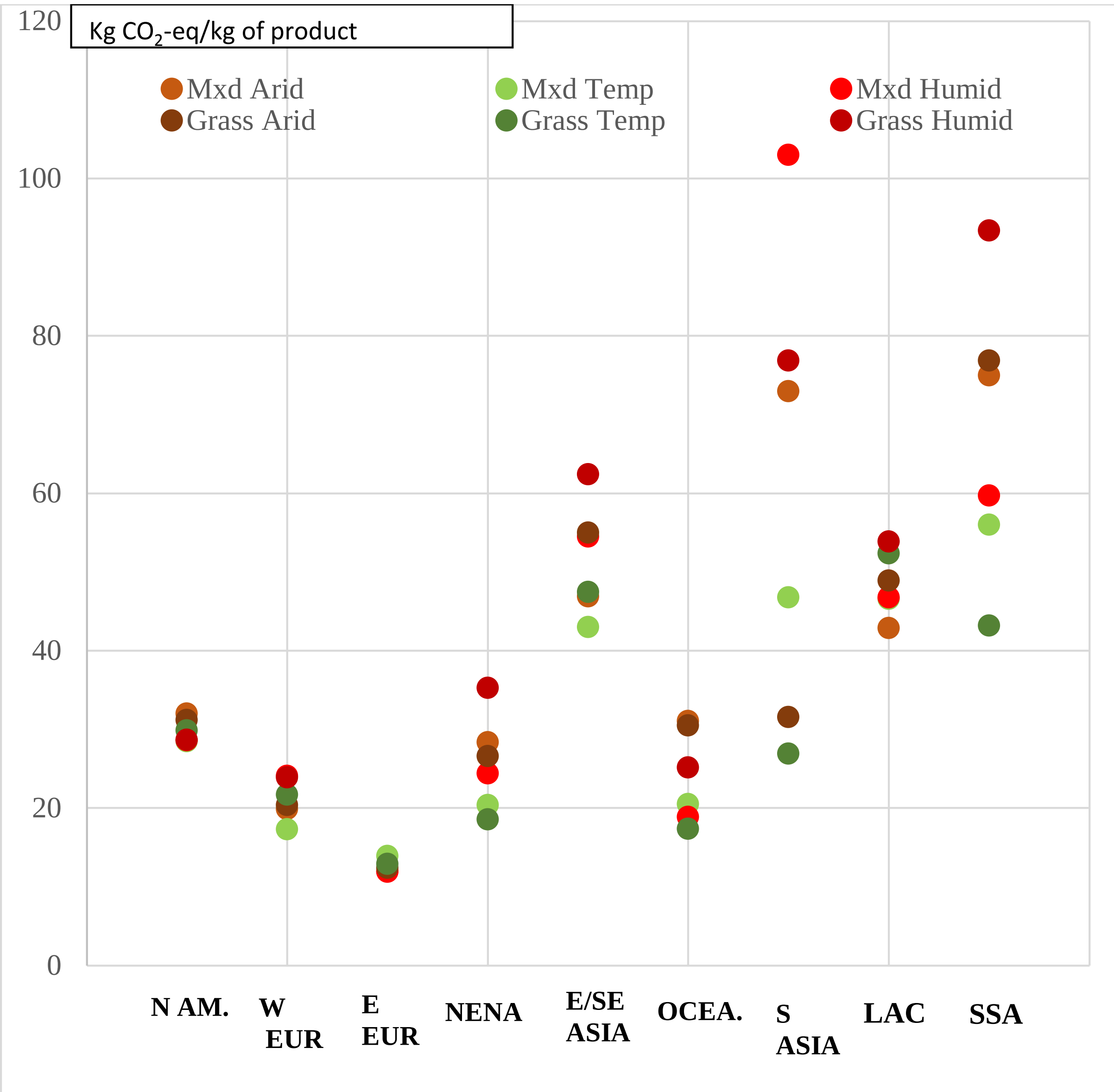


Figure 3 Direct anthropogenic emissions by economic sectors in 2010



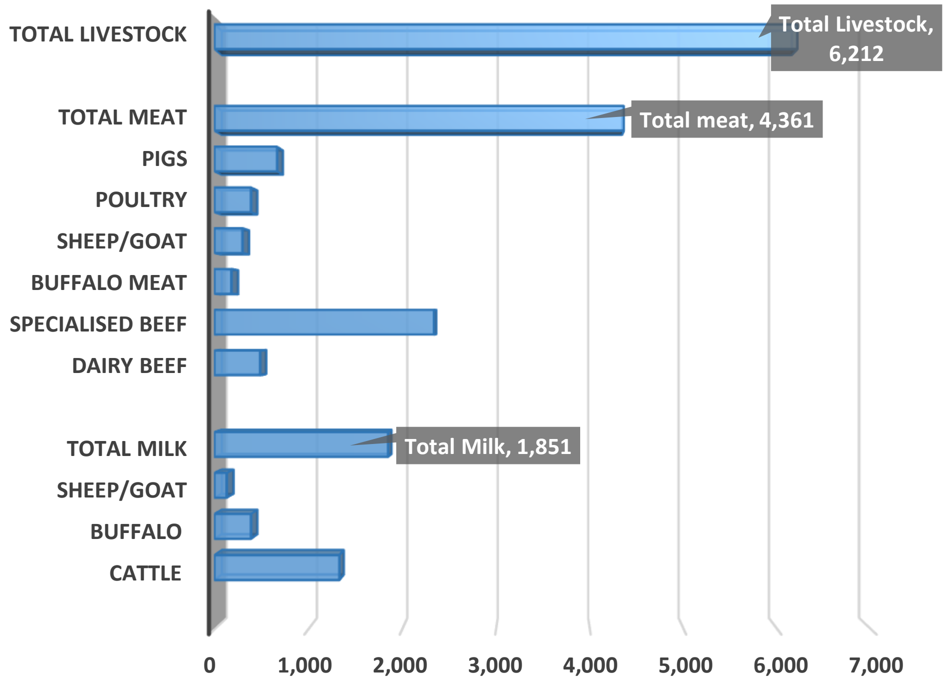
Source IPCC 2014d

Figure 4 Regional, system and climatic variations in mean emissions intensities of cattle



Source: derived from Opio 2013

Figure 5 Livestock emissions by species and product Mt CO_2-eq



Source Gerber 2013b

Figure 6 Regional per capita meat consumption in 2010 and 2050 Baseline projection (kg)

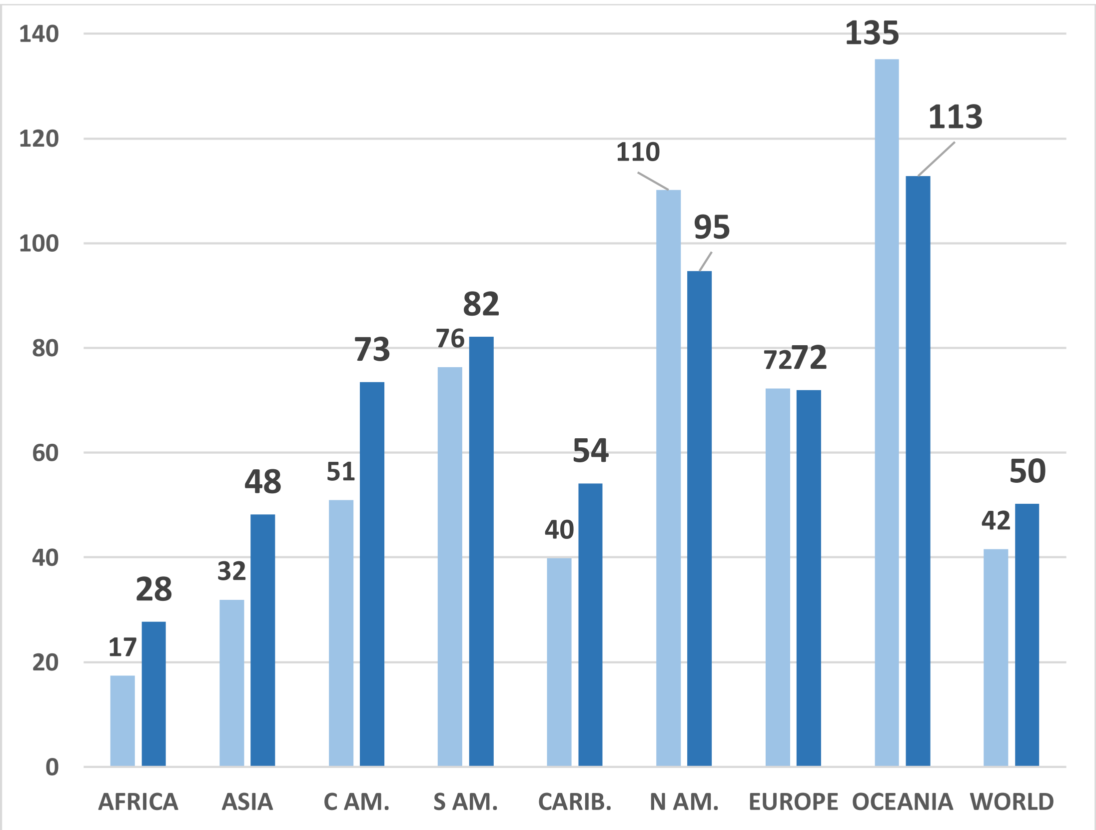


Figure 7 The effect of a carbon tax on beef consumption

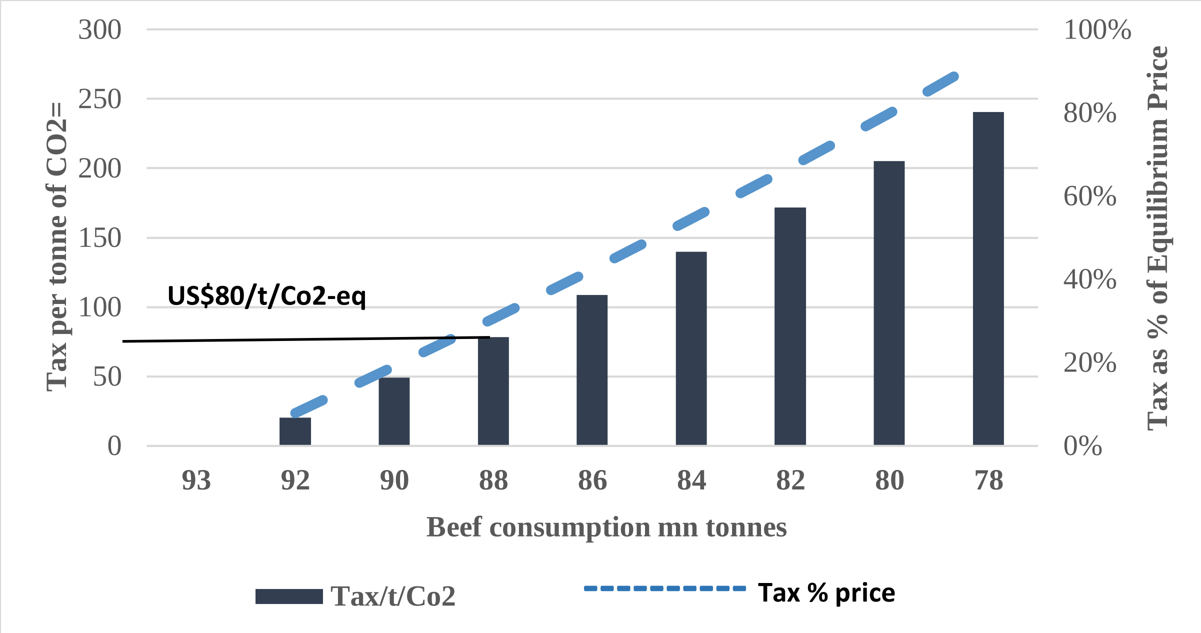


Figure 8 Comparison of red meat consumption under the scenarios (Mt)

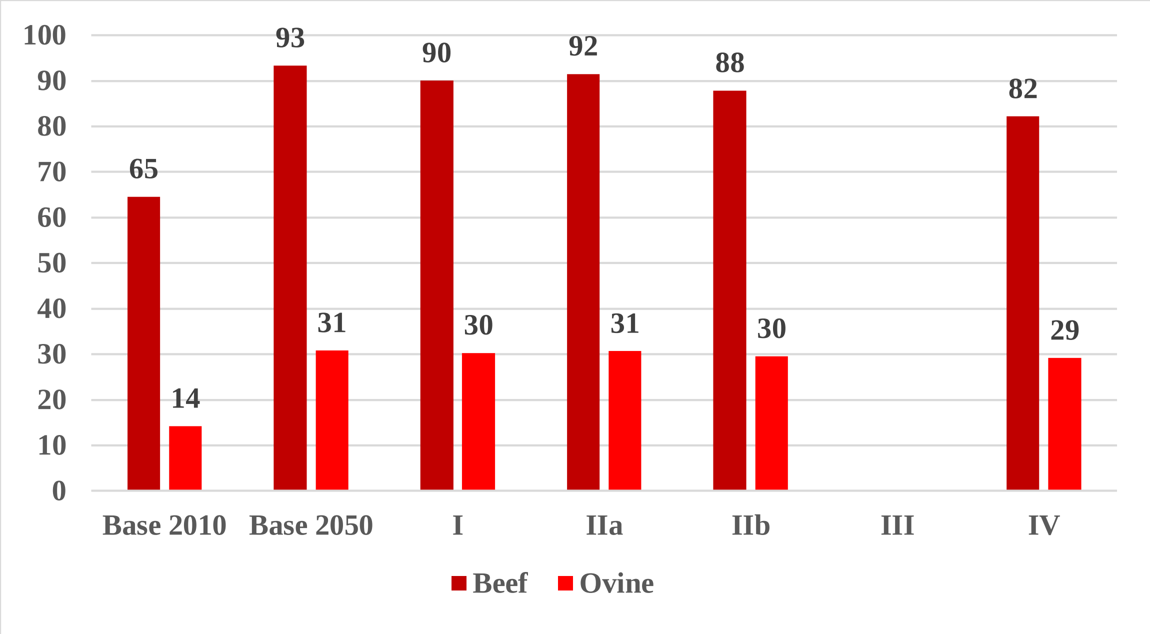


Figure 9 Impact of scenarios on emissions (Mt CO_2-eq)

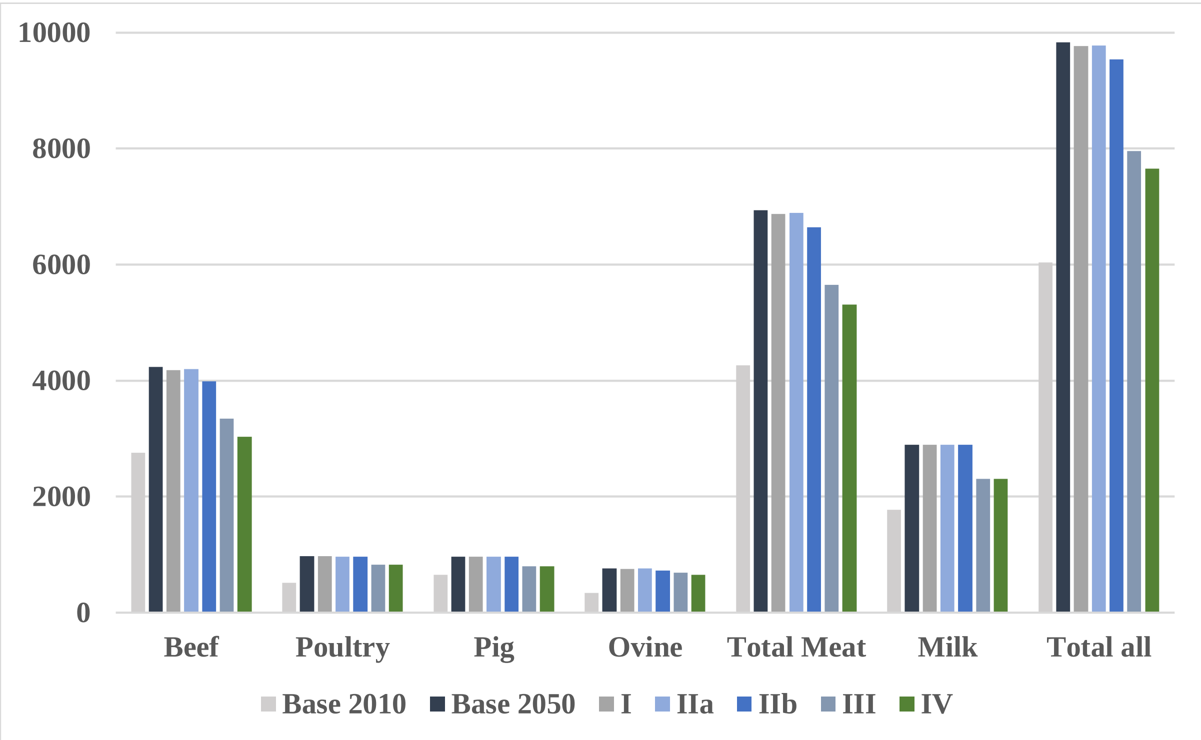


Figure 10 Scenario cumulative emissions relative to Baseline 2050 projection (Gt CO_2 eq)

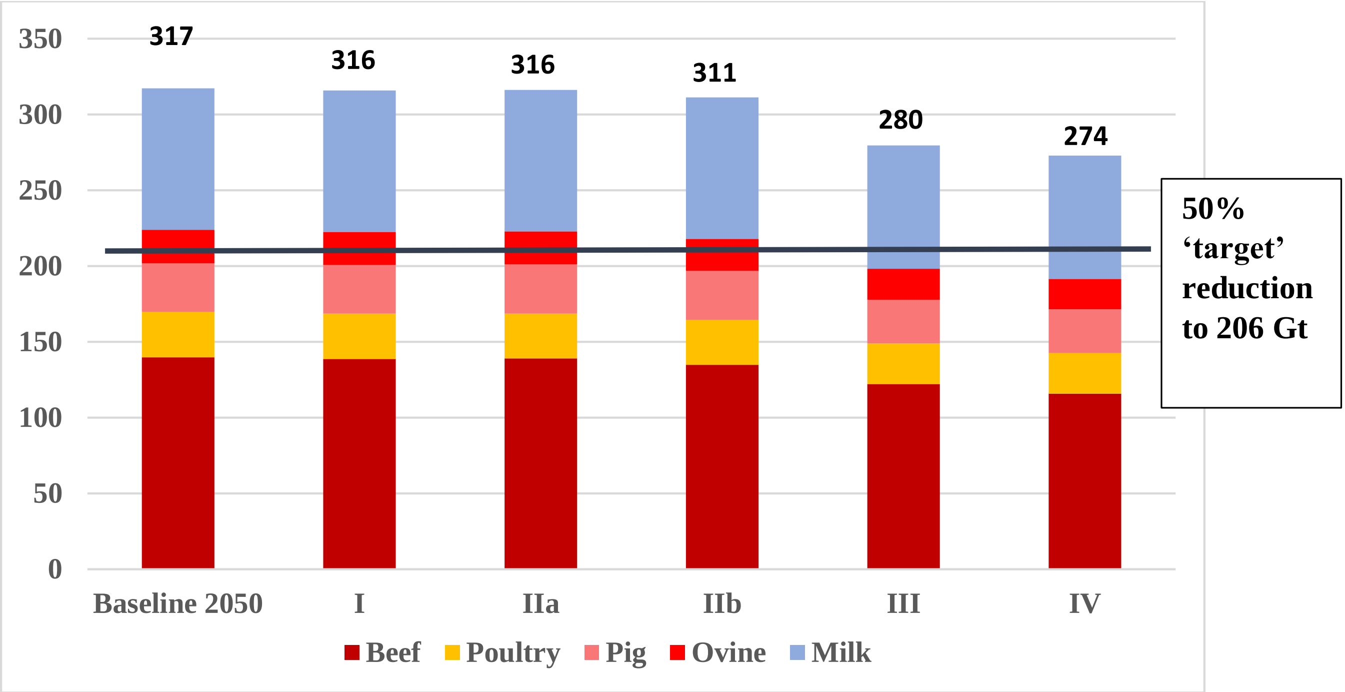


Table A.1 Recent estimates of meat and dairy income and own price elasticities of demand by country and region (mostly post 2000)

		All Meat		Beef		Ovine		Pig		Poultry		Dairy		
Source	Cont./Region	Inc	Price	Inc	Price	Inc	Price	Inc	Price	Inc	Price	Inc	Price	Country
	AFRICA													
Author				0.58	-0.58	0.59	-0.08	1.11		0.94	-0.20	0.48	-0.15	
Muhammad et al (2013). Author's aggregation		0.76	-0.56									0.79	-0.58	Aggreg Region
	C Africa													
Author						0.71		0.73	-0.61	1.77				
Muhammad et al (2013). Author's aggregation		0.80	-0.58									0.81	-0.60	Aggreg Region
	E Africa													
Muhammad et al (2013). Author's aggregation		0.79	-0.58									0.81	-0.60	Aggreg Region
USDA (2015)										1.20				Kenya
Chantylew (1997)				1.53	-1.62	1.49	-1.21	0.18	-0.20	0.22	-0.58			Kenya
Author						0.59	-0.08					0.74		
	N Africa													
Author				1.10	-0.14	1.54				1.37		0.87	-0.29	
Muhammad et al (2013). Author's aggregation		0.73	-0.54									0.75	-0.55	Aggreg Region
FAPRI (2015)				0.30	-0.20					1.00	-0.20	0.40	-0.20	Egypt
USDA (2015)										1.50				Egypt
	S Africa													
Taljaard PR et al (2006)				1.24	-0.75	1.18	-0.47	0.95	-0.37	0.53	-0.35			
FAPRI (2015)				0.40	-0.25					0.42	-0.20			S Africa
Author				1.29	-0.17							1.07		

		All Meat		Beef		Ovine		Pig		Poultry		Dairy		
Source	Cont./Region	Inc	Price	Inc	Price	Inc	Price	Inc	Price	Inc	Price	Inc	Price	Country
Muhammad et al (2013). Author's aggregation		0.69	-0.51									0.72	-0.53	Aggreg Region
	W Africa													
Author								0.44				0.68	-0.12	
Muhammad et al (2013). Author's aggregation		0.79	-0.58									0.83	-0.61	Aggreg Region
USDA (2015)										1.20				Nigeria
	ASIA													
Author				0.45	-0.52	0.41	-0.16	0.61	-0.11	1.30		1.03	-0.07	
USDA (2015)				0.37		-0.10		0.48		1.03				
Muhammad et al (2013). Author's aggregation		0.73	-0.54									0.77	-0.56	Aggreg Region
	C Asia													
Muhammad et al (2013). Author's aggregation		0.69	-0.50									0.71	-0.52	Aggreg Region
Author				0.50		0.65				1.92				Region
	E Asia													
FAPRI (2015)				0.46	-0.36			0.20	-0.27	0.36	-0.34	0.35	-0.80	Aggregate
				0.80	-0.30			2.00	-0.90	1.20	-0.80			Japan
Bai et al (2012)				1.33	-1.19	1.33	-1.19	0.86	-0.80	1.44	-0.31			China
Bai et al (2008)												0.48	-0.44	China
Dong D., & Gould (2001) Cited in Abler(2010b)												1.19	-0.41	China
Gale and Huang (2007)												0.67		China
Gould and Villareal (2006)												1.00	-0.39	China
Dong D., Gould (2004)				1.14	-0.97			1.28	-0.57	1.13	-0.87			China

		All Meat		Beef		Ovine		Pig		Poultry		Dairy		
Source	Cont./Region	Inc	Price	Inc	Price	Inc	Price	Inc	Price	Inc	Price	Inc	Price	Country
Ma et al (2004)				1.09	-0.12	1.15	-0.03			1.40	-0.80			China
Chizuraet al (2000)				0.50		0.67								China
					-0.96									China
Abler (2010a)				0.20	-0.40	0.20	-0.40	0.20	-0.50	0.30	-0.50			China
Abler (2010a)				0.30	-0.70	0.20	-0.70	0.40	-0.80	0.70	-0.80			S Korea
S Henneberry and Hwuang S (2007)				1.6.	-1.25			0.40	-0.50	0.40	-0.70			S Korea
Author				0.81	-0.44			0.79	-0.14	0.48	-0.13	2.28	-0.56	
Muhammad et al (2013). Author's aggregation		0.74	-0.54									0.74	-0.54	Aggreg Region
FAPRI				0.17	-0.18					0.50	-0.20	0.05	-0.04	India
USDA (2003)										1.50				India
Chatterjee et al 2007												0.96		India
Mittal (2006) Cited in Abler (2010b)												1.19	-0.78	India
Author				0.82						0.92		0.43		Region
Muhammad et al (2013). Author's aggregation		0.74	-0.54									0.79	-0.58	Aggreg Region
	SE Asia													
FAPRI ELASTICITY DATABASE				0.39	-0.22			0.40	-0.12	0.46	-0.30	0.74	-0.68	Aggregate
Hansen J (2012)								0.15	-0.51	1.00	-0.65			Indonesia
ibid								0.85	-0.40	0.90	-0.65			Philippines
ibid								0.42	-0.90	0.48	-0.35			Thailand
ibid								1.47	-0.90	1.47	-0.90			Vietnam
ibid								0.30	-0.60	0.20	-0.50			Malaysia
USDA (2015)										0.87				Malaysia
ibid										1.00				Philippines
Fabiosa and Jensen (2003)												0.71	-0.64	Indonesia

		All Meat		Beef		Ovine		Pig		Poultry		Dairy		
Source	Continent / Region	Inc	Price	Inc	Price	Inc	Price	Inc	Price	Inc	Price	Inc	Price	Region / Country
Author				0.84	ws	0.84		1.67	-0.30	0.69	-0.10	0.92	-0.61	Region
USDA (2015)										0.50				Thailand
Muhammad et al (2013). Author's aggregation		0.75	-0.55									0.76	-0.56	Aggreg Region
	W Asia													
USDA (2003)										1.20				Turkey
Author				0.87		0.43	-0.20			2.66		0.21	-0.29	
Muhammad et al (2013). Author's aggregation		0.68	-0.50									0.71	-0.52	Aggreg Region
	C.AMERICA													
FAPRI ELASTICIY DATABASE				0.20	-0.20			0.50	-0.15	0.45	-0.22	0.15	-0.21	Mexico
Author				0.70	-0.28			1.18	-0.19	1.79	-0.18	1.34	-0.21	
Muhammad et al (2013). Author's aggregation		0.64	-0.47									0.66	-0.48	Aggreg Region
Abler (2010a)				0.80	-0.70			0.70	-0.60	0.70	-0.70			Mexico
	S. AMERICA													
Coelho amd de Aguiar (2007)				1.35	-1.02			1.21	-1.67	1.10	-0.91	1.05	-0.81	Brazil
FAPRI ELASTICIY DATABASE				0.15	-0.16			0.46	-0.20	0.42	-0.19	0.27	-0.48	Aggreg
Menenzes et al (2008) Cited in Abler (2010b)												0.72	-0.98	Brazil
Pinto-Payeras (2009) Cited in Abler (2010b)				0.57		0.47		0.84	-0.87	0.38				
Seale J-Jr.,et al. (2003)		0.66	-0.53									0.72	-0.58	Brazil
Lema D et al (2007)				0.21	-0.36					0.15	-0.09	0.13	-0.09	Argentina
ibid				0.25	-0.44					0.11	-0.75	0.21	-0.13	Paraguay
ibid				0.14	-0.50					0.12	-2.76	0.15	-0.12	Bolivia
Author				0.48	-0.11			1.55	-0.36	0.71	-0.15	1.37	-0.18	Region

		All Meat		Beef		Ovine		Pig		Poultry		Dairy		
Source	**Continent / Region**	**Inc**	**Price**	**Inc**	**Price**	**Inc**	**Price**	**Inc**	**Price**	**Inc**	**Price**	**Inc**	**Price**	**Region / Country**
Muhammad et al (2013). Author's aggregation		0.70	-0.51									0.72	-0.53	Aggreg
	CARIBBEAN													
Author												1.34	-0.21	
	N AMERICA													
Author				0.61	-0.02				-0.33	1.18	-0.08		-0.12	
FAPRI (2015)				0.32	-0.75			0.36	-0.67	0.48	-0.76			USA
Muhammad et al (2013). Author's aggregation		0.35	-0.26								-0.37	0.37	-0.27	Aggreg Region/USA
USDA (2015)						-0.58	-1.87	0.66	-0.73	0.01		0.12	-0.04	USA
Pomboza (2007)				0.75	-0.46	0.82	-0.81	0.75	-0.68	0.75	-0.82	1.08	-0.88	

Source	Continent / Region	All Meat Inc	All Meat Price	Beef Inc	Beef Price	Sheep / goat Inc	Sheep / goat Price	Pig Inc	Pig Price	Poultry Inc	Poultry Price	Dairy Inc	Dairy Price	Region / Country
Seale J-Jr.,et al. (2003)	EUROPE	0.27	-0.37									0.35	-0.28	Germany
ibid		0.60	-0.59									0.66	-0.53	Poland
ibid		0.34	-0.28									0.36	-0.29	Italy
ibid)		0.35	-0.28									0.38	-0.30	UK
ibid		0.26	-0.21									0.28	-0.22	Denmark
Tiffin R et al ((2011)												0.85	-1.00	UK long run
ibid				1.12	-0.59	0.89		0.82	-0.78	1.13		1.02	-0.05	UK short run
Gracia, a. and L M Albisu (1998)		1.14	-0.58	1.26	-1.00	1.35	-0.82	1.21	-0.76	0.91	-1.26			Spain
Thiele (2008)		1.19	-1.02	1.46	-0.53			1.50	-0.83	1.23	-0.69	0.89	-1.00	Germany
Seale J-Jr.,et al. (2003)				0.43	-0.35							0.38	-0.31	France
Caillavet et al (2014)		0.96	-1.34	0.96	-1.11									France
FAPRI(2015)				0.26	-0.21			0.24	-0.22	0.40	-0.32	0.07	-0.12	aggregate
Author				0.76	-0.42		-0.30	0.24	-0.12	1.63	-0.22	0.32		Region
Muhammad et al (2013). Author's aggregation		0.78	-0.40									0.57	-0.41	Aggreg Region
	OCEANIA													
FAPRI				0.21	-0.22			0.47	-0.32	0.40	-0.29	0.07	-0.15	
Abler (2010 a)				0.10	-0.90	0.30	-1.40	0.30	-1.20	0.20	-0.50			N Zealand
Author				0.64	-0.47		-0.23	0.51	-0.23	1.36	-0.08	0.70		
Cashin (1991)				1.65	-0.82	0.53	-0.99	0.23	-1.20	0.06	-0.23			Australia
Muhammad et al (2013). Author's aggregation		0.49	-0.36									0.51	-0.37	Aggreg Region

Note Author's aggregation of Muhammad is a consumption weighted average of the relevant elasticity for those countries within a region.

Author's own estimates from time –series estimates of logarithmic demand function of per capita consumption regressed on real per capita gdp and average trade prices at PPP.

Table A.2 Annual real GDP growth rates and model assumptions

	Average 2004-2013 [a]	IFPRI 2010 [b]	Baseline model [c]
AFRICA			
C Africa	4.56	3.9	2.5
E Africa	3.25	4.2	3.0
N Africa	2.33	2.6	3.1
S Africa	2.25	3.0	3.7
W Africa	3.32	3.6	2.9
ASIA			
E Asia	7.38	4.7	2.8
S Asia	4.99	5.0	4.1
SE Asia	4.08	4.5	3.7
W Asia	3.04	2.8	2.4
C AMERICA	1.43	3.0	3.0
S AMERICA	3.42	3.2	2.6
CARIBB.	3.03	3.0	2.8
N. AMERICA	0.85	2.2	1.8
EUROPE	0.74	2.8	1.9
OCEANIA	1.24	1.8	1.7

[a] UNCTAD (2015); [b] Nelson et al (2010); [c] Hawksworth (2015).

Table A.3 Regional distribution of population change 2010-2050

	2050 Projection Mn	Growth rate 2010-50 (%p.a.)	Change 2010-50 (Mn d)	Share of global change (%)
AFRICA	**2,393**	**2.11**	**1 362**	**51.7**
C Africa	869	2.32	191	7.3
E Africa	316	2.33	527	20.0
N Africa	319	1.17	119	4.5
S Africa	75	0.59	16	0.6
W Africa	815	2.46	509	19.3
ASIA	**5,164**	**0.54**	**999**	**37.9**
C Asia	86	0.83	24	0.9
E Asia	1,605	0.02	12	0.4
S Asia	2,312	0.80	631	23.9
SE Asia	788	0.69	190	7.2
W Asia	373	1.19	141	5.4
C AMERICA	**229**	**0.89**	**68**	**2.6**
S AMERICA	**505**	**0.62**	**111**	**4.2**
N AMERICA	**446**	**0.63**	**100**	**3.8**
EUROPE	**709**	**-0.11**	**-31**	**-1.2**
OCEANIA	**57**	**1.10**	**20**	**0.8**
WORLD	**9,551**	**0.81**	**2 635**	**100.0**

Source: UN 2015 Medium Fertility Projections; Author's calculations

Table A. 4 Summary of Baseline model and scenario projections for consumption and emissions

	BASELINE		SCENARIOS				
Per capita consumption (kg)	**2010**	**2050**	**I**	**IIa**	**IIb**	**III**	**IV**
Beef	9.3	9.9	9.5	9.7	9.3		8.7
Poultry	14.3	19.5	19.5	19.5	19.5		19.5
Pig	15.9	17.6	17.6	17.6	17.6		17.6
Ovine	2.1	3.3	3.2	3.2	3.1		3.1
Total Meat	***41.5***	***50.2***	***49.8***	***50.0***	***49.5***		***48.8***
Milk	94.8	109.9	109.9	109.9	109.9		109.9
Total Consumption mt	**2010**	**2050**	**I**	**IIa**	**IIb**	**III**	**IV**
Beef	64.6	93.3	90.0	91.5	87.9		82.2
Poultry	98.7	185.1	185.1	185.1	185.1		184.6
Pig	109.9	166.6	166.6	166.6	166.6		166.6
Ovine	14.2	30.8	30.3	30.7	29.5		29.2
Total Meat	***287.4***	***475.8***	***472.0***	***473.9***	***469.1***		***462.5***
Milk	655.3	1041.5	1041.5	1041.5	1041.5		1041.50
Shares of Meat Consumption %	**2010**	**2050**	**I**	**IIa**	**IIb**	**III**	**IV**
Beef	22.5	19.6	19.1	19.3	18.7		17.8
Poultry	34.3	38.9	39.2	39.1	39.4		39.9
Pig	38.2	35.0	35.3	35.2	35.5		36.0
Ovine	5.0	6.5	6.4	6.5	6.3		6.3
Annual emissions Mt CO_2 eq	**2010**	**2050**	**I**	**IIa**	**IIb**	**III**	**IV**
Beef	2759	4236	4184	4,203	3989	3342	3033
Poultry	515	976	976	964	964	824	824
Pig	651	961	961	961	961	796	796
Ovine	338	762	752	759	729	692	655
Total Meat	***4263***	***6934***	***6872***	***6887***	***6644***	***5653***	***5308***
Milk	1773	2893	2893	2893	2893	2302	2302
Total all	**6035**	**9828**	**9765**	**9780**	**9537**	**7956**	**7651**
Shares of Emissions %	**2010**	**2050**	**I**	**IIa**	**IIb**	**III**	**IV**
Beef	45.7	43.1	42.8	43.0	41.8	42.0	39.6
Poultry	8.5	9.9	10.0	9.9	10.1	10.4	10.8
Pig	10.8	9.8	9.8	9.8	10.1	10.0	10.4
Ovine	5.6	7.7	7.7	7.8	7.6	8.7	8.6
Total Meat	**70.6**	**70.6**	**70.4**	**70.4**	**69.7**	**71.1**	**69.4**
Milk	29.4	29.4	29.6	29.6	30.3	28.9	30.1

Table A.5 Projected changes in regional shares of global meat consumption (%)

Region / subregion	2010	2050
AFRICA	**12.1**	**21.9**
C Africa	1.0	1.6
E Africa	3.9	6.8
N Africa	3.3	6.1
S Africa	1.7	2.0
W Africa	2.1	5.4
ASIA	**42.5**	**44.9**
C Asia	1.8	1.6
E Asia	17.9	14.7
S Asia	15.3	17.6
SE Asia	4.0	5.8
W Asia	3.5	5.3
LAC	**19.2**	**16.8**
C America	3.6	4.1
S America	15.1	12.1
Caribbean	0.5	0.5
N AMERICA	**10.5**	**7.6**
EUROPE	**14.5**	**7.9**
OCEANIA	**1.2**	**0.9**
Developed Economies	**27.2**	**16.4**

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