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ESTIMATING THE RELATIONSHIP BETWEEN GRAIN CROP CONSUMPTION IN AUSTRALIA AND ENVIRONMENTAL SUSTAINABILITY

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ABSTRACT

The whole food system which involves agricultural production, food processing and packaging, distribution and retail as well as consumption requires inputs such as land, water, fertiliser, pesticides, herbicides and energy, which are responsible for environmental degradation. The main aim of this paper is to determine the size of the ecological footprint of grains consumption in Australia for evaluating the level of environmental sustainability. The ecological footprint methodology permits the monitoring of dominant threats to sustainability. One of the benefits of ecological footprint methodology is its capacity to distinguish between resources consumed and resources available and then reveal how ecologically sustainable those consumption patterns are. The study begins with an analysis of the ecological footprint of grain crops consumption, then analyses the biocapacity. The study concludes by making a comparison between ecological footprint and biocapacity and then assessing its sustainability of grain crops consumption. The paper uses both local and global yield data in terms of global hectare and local hectare respectively with inter-temporal time-series yield factors. This paper also uses production and consumption data on various grain crops. The refined method of determining the ecological footprint has provided a new assessment tool to gain insights into the environmental impacts of grain crops consumption. This method in this study had also highlighted the contribution of the EF as an indicator of environmental sustainability. Results indicate that the ecological footprint of grain consumption in Australia only exceeds biocapacity when the energy requirements of these crops are included in the evaluation. This study also reveals that that Australia's grain consumption is unsustainable at the national scale, and still below the world-average ecological appropriation level. The size of the revealed ecological footprint are responsible for the amount of the grain consumption, energy inputs, the size of the population, the degree of carbon dioxide equivalent (CO_2-e) gas emissions, and the amount of other farm inputs. This paper highlights the environmental significance of the ecological footprint of grain crops consumption in Australia. This paper also reinforces how intensely a sustainable future depends on the reshaping of the Australian grain industry. Finally, this paper discusses some of the implications of the method presented here for future footprint calculations and environmental sustainability. If Australia wants to shift to a smarter, more sustainable agricultural future; it must strive to shift to lower impact products and services, to increase the efficiency of the production through reducing energy inputs.

JEL Classifications: Q15, Q51, Q58
Keywords: Biocapacity, Ecological Footprint, Equivalence Factor, Population, Yield Factors.
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INTRODUCTION

In recent decades, the majority of the world's nations have experienced rapid economic growth on the one hand and unusual consumption patterns and loss of natural resources on the other. Therefore, the global ecological stock has increasingly worsened following the imbalance between ecological demand and supply. Ecological Footprint Analysis (EFA), since its inception in 1996, has been applied to measure the imbalance between ecological demand and supply, both at micro and macro levels (Wackernagel and Rees 1996).

This method has also been extensively accepted as a sustainability indicator for a given population (Borsa and Marchettini 2008; Lenzen and Murray 2003; Niccolucci et al. 2008; Wackernagel et al. 2004). It measures the amount of natural resources needed to satisfy the consumption requirements and waste assimilation needs of an individual, a city, a nation, a country or the entire human world in a given year (Wackernagel et al. 2002; Wood and Garnett 2009). The consumption requirements of these populations is then converted into the amount of productive area, expressed in terms of hectares per capita at world-average productivity (Wackernagel and Rees 1996). Thus, EFA has provided a policy guide and planning tool for sustainability by comparing ecological footprint to the available land, usually referred to as biocapacity (BC).

There have been many instances where the ecological footprint model has been applied to identify the level of environmental impact and to measure sustainability. For example, VicUrban (2007) found the local resident ecological footprint of Aurora and showed that the ecological footprint of Aurora's residents is 7.03 global hectares[1] (gha), which is much lower than that of the average Victorian. The Environmental Protection Authority (2008) assessed the state-level ecological footprint of Victorian consumption, which is unsustainable and its ecological footprint is more than three times higher than the world average. Lenzen and Murray (2003) revealed the country-level ecological footprint and mentioned that the per capita ecological footprint of Australians is considerably larger than results obtained in previous studies. Wood and Garnett (2009) assessed regional sustainability and showed that the higher-density urban populations have larger ecological footprints than rural and remote populations in the Northern Territory.

In recent years, some researchers have paid much attention to ecological footprint as the tool for calculating the agricultural land requirement for crops consumption (Dong et al. 2010; Khan et al. 2009; Kissinger, Fix and Rees 2007). Dong et al. (2010) found that food consumption patterns have a large effect on total land requirements, and they also showed that grain consumption has a strong correlation with the ecological footprint. Kissinger and Gottlieb (2012) found a positive relationship between the size of the grain ecological footprint and consumption in Greece. Food that is consumed above a person's requirements represents avoidable greenhouse gas (GHG) emissions and use of natural resources (Friel et al. 2013).

Nevertheless, most ecological footprint studies are not yet attentive to and do not account for the appropriate crop consumption for a defined population on which the footprint falls. In addition, these studies calculated ecological footprint using only global yield factors instead of local yields so that their findings would not be consistent with regional settings and regional policy decisions. The calculation of the ecological footprint of any product or crops, the most effective method is a hybrid of these two approaches

(Wackernagel et al. 2002); although it is not popular in crops consumption research in Australia.

This study therefore, aims to incorporate this progressive and dynamic body of literature to enhance its potential contribution as an indicator of grain crops consumption and its sustainability. The case study here is Australia's grain crops consumption from 1995 to 2010. The study begins with an analysis of the ecological footprint of grain crops consumption, then analyses the biocapacity. The study concludes by making a comparison between ecological footprint and biocapacity and then assessing its sustainability through some potential implications for policy making.

BACKGROUND

Australia has a total land area of 7.7 million km^2. However, less than 6 percent of this land area has soil conditions suitable for annual crops (Harvey and Perrett 2011). Approximately half of this suitable land area is planted annually for commercial grain crop production. Grains either refined or whole, are a basic staple food of most people, so they are treated as major tradable crops in the world. Australia is a relatively small producer of grains on a global scale, however, due to its low-level consumption, it accounts for a significant portion of global trade (PwC 2011).

Wheat is Australia's main grain crop and came to Australia with the European settlement in 1788 (GRDC 2010). Despite the economic benefits of wheat production, the environmental cost is considerably high in Australia. Emission statistics for wheat production varies among researchers. Bradbear and Sharon (2011) reported that the equivalent of 304 kg of carbon dioxide (CO_2) was emitted during the production and delivery to port of 1 tonne of wheat, whereas Muir (2013) mentioned this statistics is 205 kg per tonne and Biswas et al. (2010) reported 400 kg of CO_2 per tonne. So this study considered the average emission as 354 kg per tonne based on these statistics to convert tonnes into CO_2e. Whereas the rate of emissions in the atmosphere from 1 tonne of barley production also accounts for 244 kg of CO_2e emissions.

Pulses are annual crops that are used for human and animal food. Muir (2013) calculated 153 kg CO_2e emissions for 1 tonne of chickpeas. Leng (2012) calculated 1 tonne of cottonseed yields approximately 200 kg of oil, 500 kg of cottonseed meal and 300 kg of hulls, and altogether requires 20GJ of energy. On the other hand, Collison et al. (2012) calculated 1 tonne of rapeseed/canola produces 539 kg CO_2e emissions. Rice is both an important sequester of CO_2 from the atmosphere and a significant source of GHG emissions. Maraseni et al. (2009) found 1 kg of rice yield generates emissions of 0.18 kg CO_2e.

From the primary production process to end use, all of the grain crops have an impact on the environment. (Friel, Barosh & Lawrence 2013). Australia has the seventh-largest per capita ecological footprint of 6.68 global hectares (gha) (Radio 2012). It has moved one place from eighth since 2010. In terms of impact on the world's natural resources, Australia is now sitting behind Qatar, Kuwait and the United Arab Emirates. Agriculture accounts for 16 percent of Australia's GHG emissions. Of that, 17.4 percent comes from the land use changes through cropping, pastures and soil preparation (DCCEE 2010). While there is considerable evidence on the effects of agricultural consumption on the environment in the literature (Bradbear and Sharon 2011; Edmonds 2004; Friel et al.

2013), no studies have been carried out on grain crop consumption and its impact on the environment in Australia.

METHODS

Crops Land Footprint

Unlike conventional methods in which only global averages are used and then multiplied by an equivalence factor[2] (EQF), this study used both local and global averages to find the ecological footprint of the grain crops. In addition to the equivalence factor of the existing method, this study also used the inter-temporal yield factor (IYF)[3], currently employed in the National Footprint Accounts (Kitzes et al. 2008). While yield factors (YFs)[4] compare the productivity of a given land use type, IYFs account for changes in the world-average productivity over time (Brock et al. 2012). A refined ecological footprint method for the assessment of the cropland footprint is displayed below:

$$\mathrm{EF_{crop}} = \sum_{\mathrm{t}}^{\mathrm{n}} \left[\left\{ \left({}^{P}/_{Y} \right) + \left({}^{IM}/_{Y} \right) - \left({}^{EX}/_{Y} \right) \right\} \times \mathrm{IYF} \times \mathrm{EQF} \right] \quad (1)$$

Where $\mathrm{EF_{crop}}$ denotes the hypothetical land area required for a studied grain crop (n) in a certain year (t). P indicates production (local or domestic) of the grain in tonnes (t). IM and EX refer to the amount of import and export respectively. The variables Y represent average yield (local and global). IYF is an inter-temporal yield factor, whereas EQF refers to an equivalence or conversion factor. Yields were assessed in tonnes per hectare (t/ha) and year. The total ecological footprint of grain crops in Australia is represented in gha, while ecological footprint per capita is measured by dividing the total Australia's population.

Energy Land Footprint

There are two kinds of land associated with the production of grain – crops land and energy land. Energy land/forest is defined as the area to sequester (or remove) CO_2 produced in the mechanical operations associated with crop production, planting, harvesting, transporting and processing (Plymouth 2000). Therefore, the energy embodied during the lifecycle of the studied commodity was converted to CO_2 emissions and then translated into area demanded using the carbon sequestration factor and the ratio of carbon to CO_2 (Kissinger and Gottlieb 2010). So both the carbon sequestration factor and conversion factor are needed to calculate the ecological footprint of energy land for grain crops. The simplified equation for the assessment of the energy land footprint and the forest land required to support grain production is displayed below (Eq. 2):

$$\mathrm{EF_{energy}} = \sum_{\mathrm{t}}^{\mathrm{n}} \left[\{(P) + (IM) - (EX)\} \times \frac{CSF}{C\ to\ \mathrm{CO2\ ratio}} \times EQF \times IYF \right] \quad (2)$$

Where EF_{energy} denotes the hypothetical energy land area required for a studied grain crop (n) in a certain year (t). The variable CSF represents the carbon sequestration factor which needs to be divided by the carbon to carbon dioxide ratio to achieve the yield factor. A moderate amount of the literature revealed the amount of energy needed for the lifecycle of the studied commodity and converted the energy into CO_2e[5]. For example, Bradbear and Sharon (2011) showed 1 tonne of wheat creates 304 kg CO_2e in the atmosphere during the production process. Now we need the YF to convert this emission amount into carbon intake area.

GFN represents the annual carbon uptake of 1 hectare of world-average forest. It was calculated by the carbon sequestration rate (0.97) divided by the ratio of carbon to carbon dioxide (0.27). So the YF will be 0.97/0.27 or 3.59 i.e. 1 hectare of world-average forest can absorb 3.59 tonnes of CO_2e from the atmosphere annually.By multiplying the tonnes of CO_2 produced by the amount absorbed by each hectare, we find that it would take (304/1000)/3.59=1.09 hectares of forest to absorb 1 tonne of CO_2 produced during wheat production. However, this 1.09 hectares refers to the required forest area. To create an ecological footprint, the figure needs to be presented in gha using the conversion factor given by GFN. Using the conversion factor (hectare to the global hectare), we find that 1 hectare of forest is equal to 1.26 gha or world-average productivity.

To find the gha value of 1 tonne of wheat production, we need to multiply the hectares of forest needed (0.109) by the conversion factor of 1.26 gha. i.e. 1.09 × 1.26 = 1.37 gha. Finally, the inter-temporal yield factor is used to establish the final results. Now the value of IYF is 1. So the ecological footprint of wheat consumption in 2010 in Australia is 11522186 × 1.37 × 1 = 15785394 gha, and the per capita ecological footprint of wheat is 0.73 gha.

Cropland Biocapacity

Biocapacity reflects the ability of local available land resources. The biocapacity of grain crops for time series data is calculated as follows:

$$\mathrm{BC_{crop}} = \sum_{\mathrm{t}}^{\mathrm{n}} \{(A \times YF) \times IYF \times EQF\} \tag{3}$$

Where, for any grain crop n, in a given year t, A represents the bioproductive land area available at the country level, and YF, IYF and EQF are the country-specific yield factor, the world-average inter-temporal yield factor, and the equivalence factor for grain crops respectively. BC reveals whether existing natural capital is sufficient to support the current consumption and production pattern (Wackernagel et al. 2004). The EQF represents the productivity-based scaling factor that converts a specific land type (such as cropland or forest) into a universal unit of biologically productive area. Whereas the YF refers to the productivity coefficient for different land types in proportion to the world average. This productivity coefficient is specific to each country and each year.

This study then assesses the sustainability of the grain crops by subtracting ecological supply or biocapacity (BC), from ecological demand (EF), i.e. consumption of natural resources. When EF_c exceeds BC, ecological deficit occurs, and it represents the resources demand cannot be achieved locally. When EF_P exceeds BC, ecological overshoot occurs and it represents the rate of resources exploitation has exceeded its maximum carrying capacity and the local ecosystem is depleting.

DATA SOURCES

The calculation of grain crops' ecological footprint requires a large amount of information about land use, production, consumption, exports, imports, agricultural productivity, GHG emissions and socio-economic data. Australian grain crops-related data are sourced from the Global Footprint Network (2012), the Australian Bureau of Statistics (ABS 2013), the Australian Crop Report 2012 and 2014 of the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES 2014), and the Grain Research and Development Corporation (GRDC 2012). Per tonne grain production CO_2e emissions (kg CO_2e/tonne) data are collected through the weighting of several study findings.

RESULTS

Ecological Footprint of Grain Consumption

On average during the research period, Australia's grain consumption ecological footprint was 24.6×10^6 gha based on local yield and 31.8×10^6gha based on global yield. The results indicate the increasing trend of the ecological footprint from 1995 to 2010 from 13.0×10^6 to 38.3×10^6 gha based on local yield and from 17.9×10^7 to 49.9×10^7 gha based on global yield. Meanwhile, the per capita grain ecological footprint increased from 0.85 gha to 1.91 gha, which was almost double the average level of Australia in 2010 (GFN, 2010). The largest area of ecological footprint was used by wheat consumption as 10.0×10^6 gha (per capita 0.55 gha) out of 24.4×10^6 gha (per capita 1.34 gha) in 1995 in comparison to 17.6×10^6 gha (per capita 0.82 gha) out of 32.0×10^6 gha (per capita 1.44 gha) in 2010. Figure 1 presents a summary of Australia's ecological footprint for major grain crops such as wheat, barley, lupins, rapeseed, chickpeas and cottonseed. The overall size of the grain consumption footprint in 2010 (4.99×10^7gha) was larger than in 1995 (28.1×10^6gha), the footprint per capita increased slightly from 1.34 to 1.49 gha because of the larger number of consumers and amount of exports.

Grain ecological footprint also depicts the ecological appropriation per consumption item in percentage terms, which is shown in Table 1. The wheat consumption category of grain crops was the largest category with a percentage increase from 41.06 in 1995 to 55.09 in 2010, with some fluctuations from 1998 to 2004. The appropriation results indicate that barley consumption covers the second-highest productive land area, even though the consumption patterns changed greatly.

FIGURE 1: EF OF MAJOR GRAIN CONSUMPTION BASED ON LOCAL YIELD IN AUSTRALIA

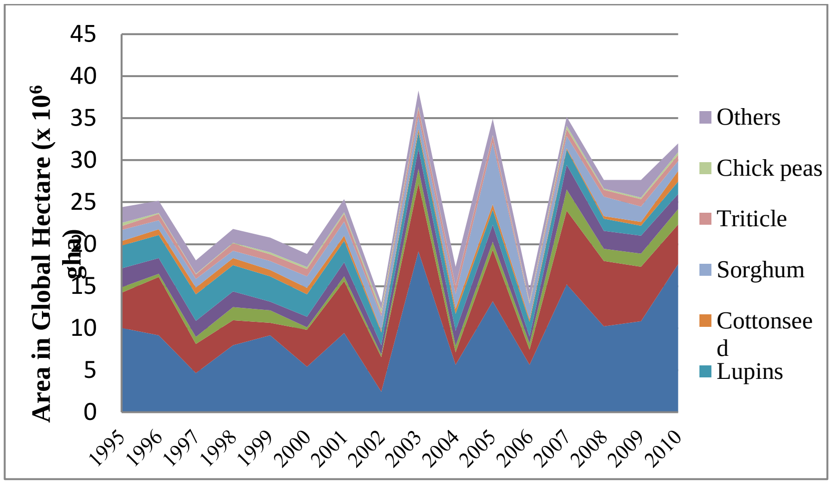


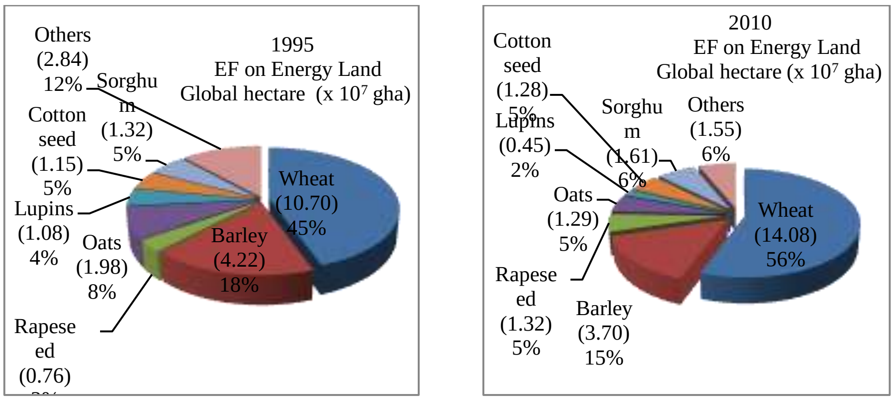
TABLE 1: ECOLOGICAL SPACE APPROPRIATION (PERCENT OF THE TOTAL ECOLOGICAL FOOTPRINT) FOR GRAIN CONSUMPTION USING LOCAL YIELD

Grain Types	1995	1998	2001	2004	2007	2010
Wheat	41.06	36.54	37.10	29.21	43.22	55.09
Barley	17.16	13.58	24.41	8.54	24.96	14.74
Lupins	11.18	14.31	10.15	11.71	5.15	4.65
Oats	9.12	8.49	6.58	10.36	8.33	5.65
Rapeseed	2.70	7.24	2.29	4.26	7.24	5.73
Cottonseed	2.14	3.97	2.41	3.57	0.44	3.87
Sorghum	5.39	4.02	6.55	9.80	4.14	3.69
Triticale	1.88	3.95	3.66	5.42	2.47	2.32
Chick peas	1.59	0.39	0.62	0.31	1.03	1.02
Others	7.77	7.52	6.23	16.83	3.01	3.24
Total	100.00	100.00	100.00	100.00	100.00	100.0

Energy Land Footprint

Grain crops covers both the cropland and energy land, because cropland is required to grow the quantity consumed, and the energy/forest land is required to remove the CO_2 emissions from the mechanical operations (Plymouth 2000). In calculating the energy land footprint of grain crops, first, this study converted CO_2e emissions into per tonne crops production. Second, we translated this CO_2e emissions into equivalent area demanded in terms of hectares. Third, this hectare measure was converted into gha using the conversion ratio and finally multiplied by the IYF.

FIGURE 2: THE OVERALL GRAIN ENERGY LAND FOOTPRINT DIVIDED INTO VARIOUS CATEGORIES OF GRAIN CONSUMPTION

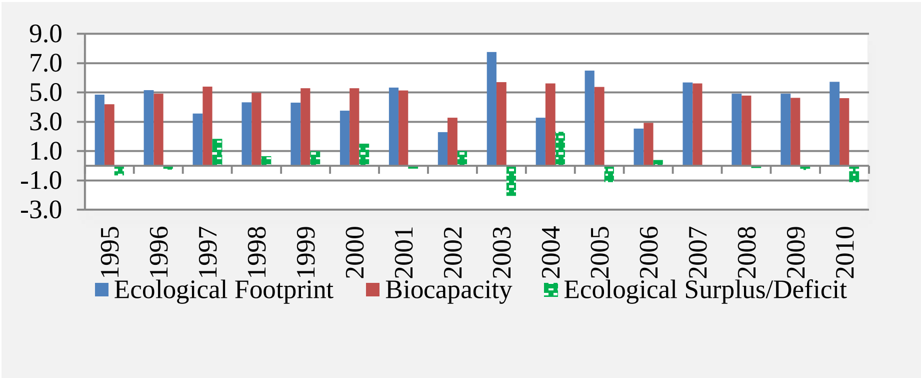


Wheat production accounts for the highest share of energy land footprint, increasing from 44.49 percent in 1995 to 55.71 percent in 2010. This was due to large wheat consumption, higher energy inputs used and CO_2e emissions in the atmosphere (361 kg CO_2e/tonne) in comparison to other grain crops. Barley production accounts for the second-highest energy land footprint based on the emission statistics given by Collison et al. (2012) as 244 kg CO_2e per tonne of barley production and consumption. The highest CO_2e emission, 539 kg/per tonne, by rapeseed production is revealed by Collison et al. (2012), but the ecological impact through energy land is less than the wheat and barley production because rapeseed has low production and consumption.

Biocapacity of Grain Crops

This study calculated the ecological footprint of grain crops using socio-economic statistics. Using actual grain harvested land use data, this study obtained ecological capacity/biocapacity (BC) of grain crops for 1995 to 2010. As a whole, the level of ecological capacity was higher than the ecological footprint of grain consumption both for local and global productivity. As one unit of grain production process requires both the equivalent productive crops land area and energy land area for GHG emissions, the combined ecological footprint of crops land and energy land mostly exceeds the biocapacity. For example, in Figure 3, from 1995 to 2010, most of the years' ecological footprint of grain consumption were higher than the biocapacity, except 1997, 1998, 1999, 2000 and 2002. The years in which the ecological footprint of consumption exceeded biocapacity means consumption of natural resources exceeded the regeneration of natural resources, resulting in an ecological deficit. Conversely, when biocapacity exceeds ecological footprint then ecological surplus occurs. More importantly, for all years from 1995 to 2010, the ecological footprint of grain production exceeded the biocapacity, meaning ecological overshoot occurred, and this represents the rate of natural resources exploitation has exceeded its maximum carrying capacity and the local ecosystem is depleting.

FIGURE 3: ECOLOGICAL FOOTPRINT, BC AND ECOLOGICAL SURPLUS/DEFICIT OF GRAIN CONSUMPTION IN AUSTRALIA FROM 1995 TO 2010 (GHA, X 10^7 GHA)



CONCLUSIONS, POLICY IMPLICATIONS, AND LIMITATIONS

Grains consumption/production is defined as unsustainable when the ecological footprint of consumption/production surpasses the ecological supply (Ying et al. 2009). This study found variation in the ecological footprint coming from grain consumption and production. The increase in the ecological deficit of grain crops in Australia is primarily a result of the increase in population, type of consumption, degree of CO_2e emissions, grain yields and energy inputs used (Collins and Fairchild 2007). The ecological footprint result of this study on grain crops is 1.27 gha, which surpassed the national ecological appropriation level of 1.07 gha. This figure also accounts for almost one-quarter of the overall ecological footprint of 6.5 gha for 2010 in Australia. The results suggests that the means of reducing the EF of crop include less energy inputs, a decrease in the consumption of fuels and chemicals, a decrease in emissions of CO_2 equivalent gases.

These results indicate that Australia's grain consumption is unsustainable at the national scale, and still below the world-average ecological appropriation level. The results also indicate that while the Australia presents the smallest land footprint per unit of production or consumption, its energy footprint is higher here as a result of higher fertilizer and energy inputs. The study only focused on the figure of whole grain crops instead of processed grain, like pasta, bread, cereals etc., to avoid double counting. Moreover, the intensity of human-induced changes to land (Lenzen and Murray 2003) are not considered in this study, which would also change the results to some extent. However, it also emphasized that this approach is far away from being perfect and that while each of the calculation procedures discussed here has its unique merits, each should be developed further. Most of the impact on the environment actually comes from human consumption of grains. If we really want to tackle the impacts on the environment, we must as a society begin to address the impacts of our consumption patterns. The emissions generated from providing the food we eat and the goods we purchase are together more than four times the emissions from our own personal use of electricity (ACF 2007). If Australia wants to shift to a smarter, more sustainable agricultural future, we must strive to shift to lower impact products and services, to increase the efficiency of the production through reducing energy inputs. One advantage of the method implied by the research presented in this paper is the potential to identify policy relevant directions for minimizing the grain crops footprint. One of the potential directions that is relevant to the policy-changing option of reducing the footprint is to change the commodity composition. Reducing the ecological footprint of the crop must focus on the efficiency with which inputs are used and converted to grain crops. If the yield can be at least maintained while inputs are reduced, this will reduce carbon emissions per hectare and save money on input costs and increase profitability per hectare or tonne. The outcome of this study would support decision makers and policymakers with information on how much biological productive area we have and how much we are using to achieve sustainability on grain crops. The case of grain crops in Australia is just one of many commodities upon which we all depend on. The method taken in this paper enhances the advantages and accuracy of the ecological footprint analysis.

ENDNOTES

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[1] The global hectare is normalised to the area-weighted average productivity of biologically productive land and water in a given year.

[2] The equivalence factor is calculated as the ratio of the average suitability index for a given land type divided by the average suitability index for all land types.

[3] IYFs are calculated for each year and land use type in order to track changes in the world-average bioproductivity over time of each land type.

[4] For major land use types that produce only a single primary product, yield factors (YFs) are calculated using the equation $YF_N^L = \frac{Y_N^L}{Y_W^L}$ where Y_N^L refers to yield for a given country and land type and Y_W^L denotes world-average yield for a given land type (GFN 2008).

[5] The estimation of CO_2e refers to the carbon dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_20) which are added up into the GHG emissions figure and usually expressed as kilograms of CO_2 equivalent (CO_2e) per tonne of product.

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