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# Environmental Footprint Comparison amongst Dairy, Grain and Meat Products in California

Michael R.W. Walmsley*[a], Xia Liu[b], Petar S. Varbanov[b], Jiří J. Klemeš[b]

[a]Energy Research Centre, School of Engineering, University of Waikato, Hamilton, New Zealand
[b]Centre for Process Integration and Intensification – CPI[2], Faculty of IT, University of Pannonia, Veszprém, Hungary
m.walmsley@waikato.ac.nz

A more holistic environmental footprint assessment methodology is applied to the production of four different types of food products from the California Central Valley agricultural area. Resource and energy supply chains from farm to consumer are evaluated for two animal based food products (milk powder and ground beef) and two grain based products (fried rice and wheat bread). Intensive farming and irrigation practices are assumed to apply to the food production systems. The work supports previous studies that grain based food products meet human nutritional needs far more efficiently than animal based ones like meat and dairy. As fossil fuel energy resources, arable land and clean water for irrigation become less available due to resource depletion and competition from other activities, significant environmental footprint reduction is possible with a shift to a more grain based low environmental footprint diet.

## 1. Introduction

The challenge of feeding the world's population in a more sustainable way with limited land, water, energy, and environmental resources requires a more holistic footprint assessment methodology. Green House Gas (GHG) emissions, as the main measure of environmental impact is too narrow, and fails to account for many important issues affecting the general health and well-being of society and future generations. An expanded footprint methodology that includes and combines GHG, water, land and expended energy is needed to help guide us to better solutions that are truly beneficial and sustainable for society (Čuček et al., 2012). In this paper an expanded footprint methodology is applied to the production of four types of food products: milk powder (dairy), fried rice (grain 1), wheat bread (grain 2) and ground beef (meat). Figure 1 illustrates the system boundary for the study. Dairy and meat products are assumed to be derived from corn and alfalfa silage, and corn meal (grain 3). The assessment is made within the Northern California Agricultural setting, where intensive grain based farm practice is well developed and well researched. The aim of the paper is to demonstrate that different nutritional supply chains can have quite different environmental impacts and that significant food energy nutritional efficiency gains can be made in society by adopting lower carbon, water, land and energy footprint diets. The importance and value of considering options for human nutrition, beside industrial manufacturing and production processes, for footprint reduction is also illustrated in this work. The California Agricultural setting has been selected for the study as it is a region of steady sunlight, advanced irrigation systems, well developed farm, food processing and transport infrastructure, and an agriculturally focused university nearby in University California Davis that provides an excellent repository of reliable reports and data. The investigation considers the environmental footprint of on-farm production, food processing in nearby factories, product distribution to the California market and final food preparation before consumption. Simplifying assumptions are made to ensure a focused and manageable study.

## 2. Environmental Resources and Food Energy Efficiency

### 2.1 Land, water and energy resources in California

The availability of quality land, water and energy resources in California is critical to large scale agricultural food production in the Central Valley Region. These resources are available in abundant supply as shown in

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Table 1. The total land area of California is 423,970 km$^2$. Of this area 9 % is used for irrigated farmland that is highly productive for producing a wide range of agricultural crops, including rice, wheat and corn. An additional 21 % is used for dryland farming and livestock grazing. The remaining 70 % is used for a variety of purposes including urban, water recreation areas, National and State parks, deserts and mountains.

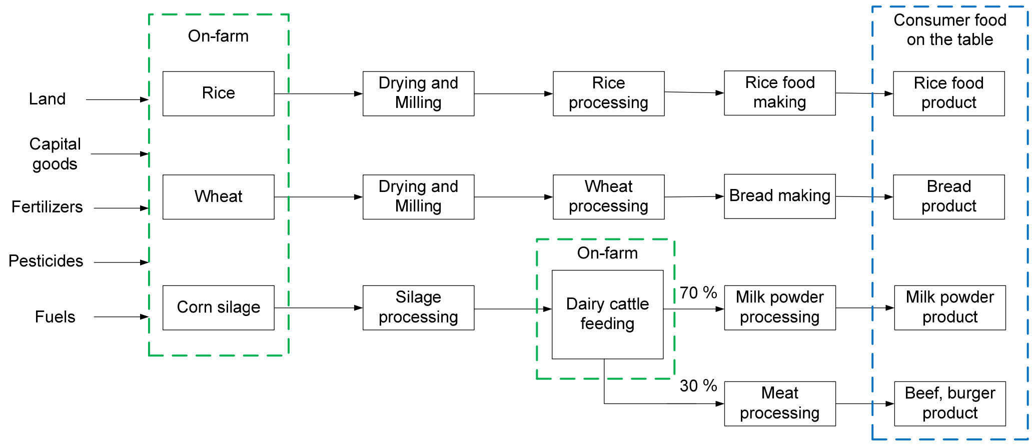


*Figure 1: System boundaries for footprint of food products*

Water resources are abundant due to a mean precipitation of approximately 563 mm/y and over 300 dams and reservoirs collecting up to 40 % of the water and snow melt in the mountainous regions that surround the California Central Valley. Of the collected water, 42 % is used for irrigated agriculture – exceptionally high compared to other regions. Energy resources for food production are less available on a sustainable basis than land and water. Approximately 82 % of primary energy is supplied by fossil fuels and 88 % of NG and 62 % of oil is imported into California. For fertiliser production where energy is a large proportion of the cost, dependence on fossil fuels is a big contributor to GHG emissions. Farming methods that use less fertiliser like genetically modified (GM) seeds and organic farming, are likely to be more sustainable from an energy point of view, but if such methods use more land or water, they may not be the best option in some regions. The expanded footprint criterion presented in section 3 provides a way to evaluate such resource trade-offs.

*Table 1: Natural resources and sustainability factors for California (CADA, 2014; CDWR, 2013)*

| Resource | Description | | Units | Percent |
|---|---|---|---|---|
| Land | Total Land Area of California | 423,970 | km$^2$ | 100 % |
| | Irrigated prime farm land | 36,764 | km$^2$ | 9 % |
| | Dryland farming or grazing land | 90,442 | km$^2$ | 21 % |
| Water | Total annual use (average of 2004-2010) | 103,436 | Mm$^3$ | 100 % |
| | Irrigated agricultural | 42,996 | Mm$^3$ | 42 % |
| | Total annual precipitation (rain and snow) | 238,695 | Mm$^3$ | 231 % |
| Energy | Annual primary energy supply (thermal) | 8,727 | PJ | 100 % |
| | Petroleum for transportation (62 % imports) | 4,776 | PJ | 54.7 % |
| | Natural Gas for heating (88 % imports) | 1,421 | PJ | 16.3 % |
| | Electricity (thermal-eq) (29 % imports) | 2,530 | PJ | 29.0 % |
| People | Population of California 2013 | 37,254,000 | | |
| GHG | GHG emissions | 346 | Mt | |

### 2.2 Food energy production efficiency

Food energy efficiency data used here are presented in Table 2. The resource efficiency of producing foods such as rice (Bockari-Gevao et al., 2005), wheat (Sadras et al., 2012), corn (de Vries, et al., 2010), milk powder (Rad and Lewis, 2014) and ground beef (Wiedemann et al., 2014), is well documented. It is known that meat is more resource demanding to produce than the equivalent food energy value from grains (Pelletier et al., 2011). The environmental impact and Life Cycle Assessment (LCA) of dairy farming and milk products is also well documented (Thoma et al., 2013). Grains such as rice, wheat and corn have high food energy yields per hectare and high energy return ratios (food energy OUT to fossil fuel energy IN). It is not surprising that grains are used extensively in many cultures as staple food sources. Corn silage and alfalfa silage also have very high 'food' energy yield values and are used as key ingredient for livestock along with grains. Products derived from livestock such as milk powder and meat have much lower food energy yields and much lower food energy return ratios. Data in Table 2 are indicative of California. Food energy productivity on farm, however, varies considerably with the farms and locations, as food production is highly sensitive to climate, water availability, soil type and management practice. The scale of operation can also affect efficiency.

*Table 2: Typical nutritional food energy efficiencies in California*

| Food product | Food energy (MJ/kg) | Food Energy Cooked(MJ/kg) | Yield⁺ (t/ha) | Food energy yield (GJ/ha) | Water use ($m^3$/t) | Energy return ratio (PJ/PJ) |
|---|---|---|---|---|---|---|
| Fried Rice | 15.5 | 8.1 | 9.2 | 142.6 | 1,163 | 1.58 |
| Wheat Bread | 13.7 | 10.6 | 7.7 | 105.5 | 509 | 1.24 |
| Corn | 15.3 | - | 15.1 | 231.0 | 405 | 2.40 |
| Milk Powder | 20.8 | 20.8 | 1.33 | 28.0 | 3,650 | 0.40 |
| Ground Meat | 10.6 | 11.6 | 0.43 | 5.0 | 9,163 | 0.34 |
| Corn Silage | 10.8 | - | 60.6 | 654.5 | 101 | - |
| Alfalfa Silage | 10.8 | - | 17.6 | 190.0 | 881 | - |

## 3. Pinch Footprint Methodology

To evaluate multiple environmental footprints a graphical approach similar to the Carbon Emissions Pinch Analysis (CEPA) method (Walmsley et al., 2014) based on analogy with the Pinch Analysis (Klemeš et al, 2014) has been developed. The method is illustrated in Table 3 and Figure 2 for land and water footprint reaching a food energy target of 100 PJ.

*Table 3: Food footprint and emission factors*

| Food product type | Land Footprint ($km^2$/PJ) | Water Footprint ($Mm^3$/PJ) | Expended Energy (PJ/PJ) | Emission Factor (Mt $CO_2$-e/PJ) |
|---|---|---|---|---|
| Grain A | 0.4 | 0.8 | 0.4 | 0.33 |
| Grain B | 0.8 | 0.4 | 0.8 | 0.6 |
| Animal C | 1.6 | 1.6 | 1.6 | 1.8 |

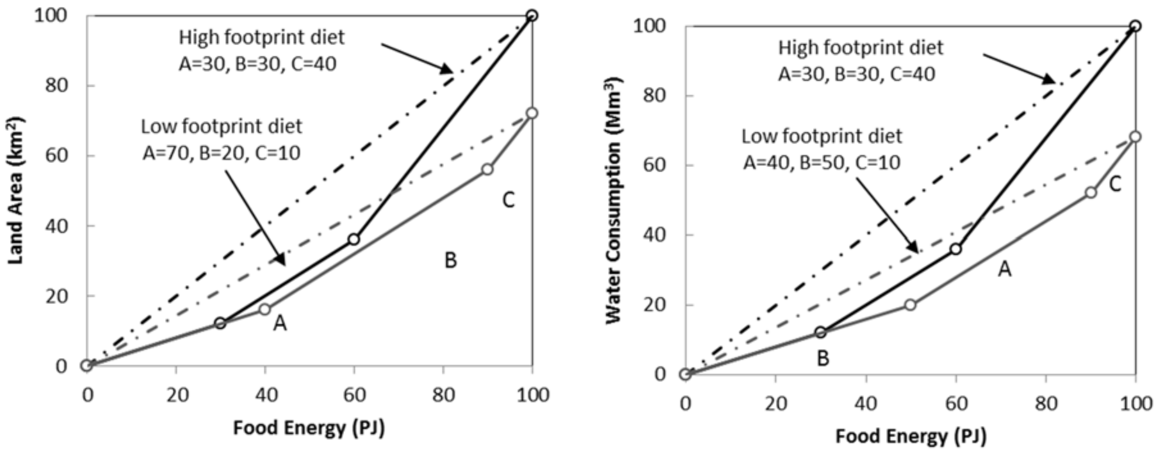


*Figure 2: Land and Water Footprint Composite Curves for high footprint and low footprint diets*

The food energy in PJ is plotted on the x-axis, against the footprints (land, water, energy and $CO_2$-e) on the y-axis. The food product with the lowest footprint is plotted first followed by the next lowest and so forth to create a Combined Composite Curve for each footprint dimension. Diet options for food footprint reduction can then be evaluated graphically (Figure 2) or by spreadsheet using a weighted footprint optimisation criterion.

## 4. California Food Production Case Study

Footprint and emission factors for land, water, energy and carbon emissions were derived through approximate supply chain analysis of the food production system (Figure 1). Significant variation in literature data was observed, even for California, so the results should only be treated as indicative to illustrate the footprint pinch method. Four food products were evaluated to represent common food groups in human diets and the results are presented in Figures 2-5. Fruit and vegetables and processed sugar products were not included to keep the study manageable. Using the Environmental Footprint Pinch method Composite Curves were constructed for each of the four footprint measures for high and low footprint diets options.

### 4.1 Land Footprint

Wheat processed into bread was determined to be the most efficient means of producing food energy from a land use perspective (Figure 3). Rice presented as fried rice requires 16,000 km$^2$ of irrigated land to feed the population of California compared to 14,000 km$^2$ of land for wheat bread. The main reason for this difference is that the food energy of rice reduces significantly from 15.5 MJ/kg to around 8 MJ/kg after cooking compared to wheat that only reduces from 13.7 to 10 MJ/kg when baked into bread. Milk powder on the other hand needs over three times the area of wheat and ground meat needs over 20 times. The larger land footprints for the animal based food products is due to the extra energy conversion process involved in producing food mass on an animal, compared to grains.

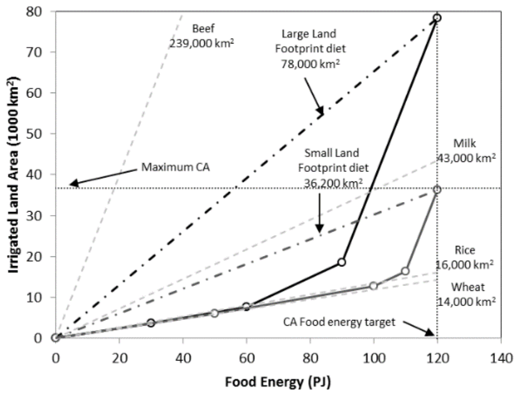


*Figure 3: Land Footprint Composite Curves for irrigated agricultural land producing four food products.*

An equal diet of wheat, rice, milk and beef also produces a land footprint that exceeds the maximum amount of irrigated prime farmland in California. Switching to a low footprint diet by increasing grain intake and reducing meat and dairy intake lowers the land footprint significantly from 78,000 km$^2$ to 36,200 km$^2$ and makes maximum use of the irrigated prime farmland. Using large quantities of prime irrigated land for beef cattle feed production is also clearly not a good use of the limited land area.

### 4.2 Water Footprint

Over 40 % of California fresh water (blue water) is used to irrigate the fertile farm land of the California Central Valley. Excess water used in rice production and food processing is reused downstream as grey water to ensure high levels of water reuse and efficiency. Again the grain based food products and especially wheat had the lowest water footprint compared to ground beef and milk powder (Figure 4). Rice may appear to be a big consumer of water, but through careful management and water reuse the actual water footprint of rice is a little less than double that of wheat. Beef again stands out as the biggest user of water per PJ of food energy created. Most of the water corresponds to water for irrigation, with water for livestock drinking constituting a very small amount (i.e. < 1 %). Reducing meat from a nation’s diet is therefore a good policy that will free up water resources for other more favourable options.

### 4.3 Energy Footprint

The energy expended in food production is closely related to the amounts of nitrogen fertiliser and of water required to maintain good yields. Fixing nitrogen from the atmosphere using the Haber process is very energy intensive. How large quantities of fertiliser will be economic when crude oil could be in short supply is of concern. Low fertiliser farming methods are being explored, including organic farming systems, but with these systems energy is replaced by the need for more land, to facilitate crop rotation and use of natural nitrogen fixing plants like Alfalfa. Other energy uses include tilling the ground, crop protection, weed management, harvesting, transportation and processing. In a full Life Cycle Analysis (LCA) energy expended on making the farm machinery, waste disposal and recycling and maintaining breeding stock are also included. The grain based food products again expend the least amount of energy per PJ of food energy produced.

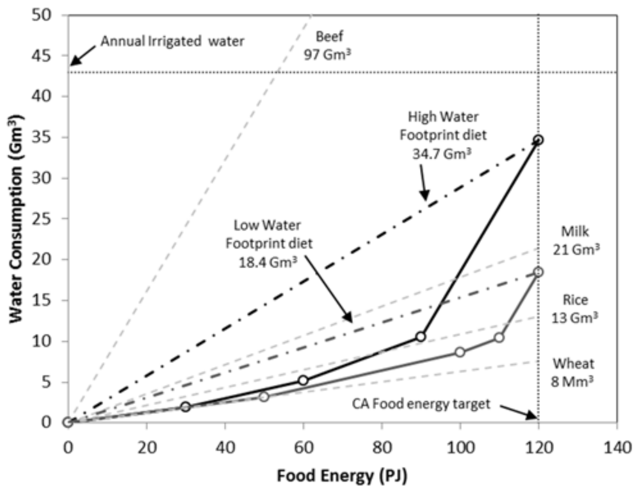


*Figure 4: Water Footprint Composite Curves for producing four food products*

Livestock based food products of milk powder and ground beef had similar energy footprint levels and energy associated with food for livestock account for up to 86 % of energy farm inputs.

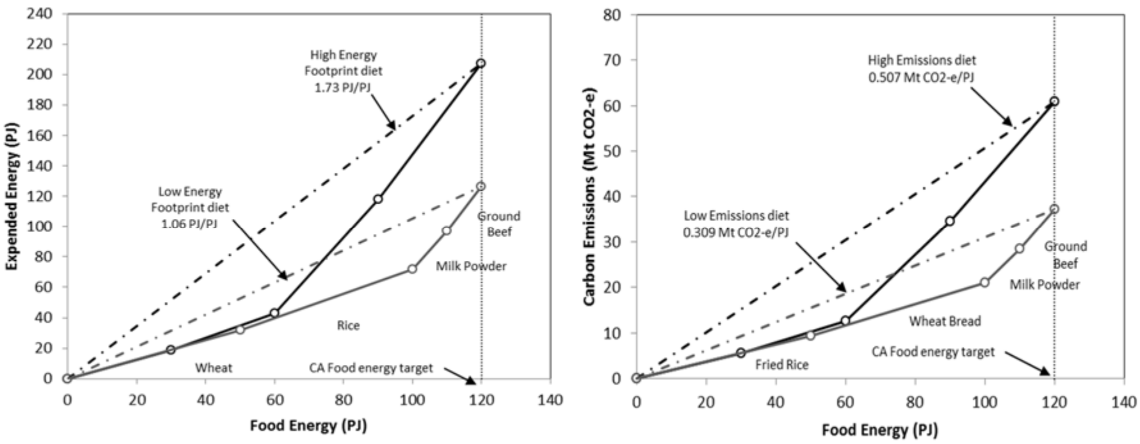


*Figure 5: Energy Footprint and Carbon Emissions Composite Curves*

### 4.4 Carbon Emissions

Grain based foods - wheat bread and fried rice - have lower emissions per unit of food energy produced compared to animal based products - milk powder and cooked ground beef. Animal based emissions of methane due to flatulence and nitrous oxide from fertilisers, add significantly to the on-farm fossil fuel emissions, in transportation to market and in processing facilities. The intensive agricultural methods employed in California, such as high levels of irrigation, chemical fertilising, chemical weed and pest control and mechanisation also contribute to emissions for both grain and animal based food being higher than less intensive farming methods. Transportation distances to market, storage and food preparation methods by consumers also add to emissions, but generally the levels are much less than on-farm emissions and food processing emissions. Overall grain based food clearly stands out as the best option for reducing agricultural emissions. A 40 PJ shift in food energy diet from dairy and meat products (30 PJ to 10 PJ) to more grain products (30 PJ to 50 PJ) results in a 40 % reduction in carbon emissions.

### 4.5 Combined Footprint Perspective

Observing the combined footprints of land, water, energy and emissions provides a balancing view of the environmental impact of energy supply chain practice, human dietary trends and food product options. The interaction between these four factors is complex and a multi-dimensional footprint approach is essential. Examples of the interactions are: (1) Intensive agriculture makes more efficient use of land resources, but generally only at the expense of more water and energy footprint through more irrigation and more industrially produced fertilisers, (2) Higher levels of food processing to add commercial value to grain based foods, e.g. breakfast cereal products, adds to the energy and water footprint without improving nutrition benefits, and also may lower water use and food waste levels.

## 5. Conclusions

This study confirms that grain based foods like rice and wheat are far more environmentally friendly to produce and process than animal based foods like dairy and meat. Footprint differences of up to an order of magnitude exist between those two types of foods. Wise management of land, water and energy resources plays an important role in maintaining a productive agricultural sector as demonstrated on the case of California. Replacing fossil fuel as an energy source and dealing with fluctuating water supply due to climate change stand out as the two biggest sustainability challenges confronting the agricultural sector. Shifting human and animal diet is also a viable way to reduce agricultural emissions and to debottleneck key variables like water, land and energy.

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