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Potential environmental and population health impacts of local urban food systems under climate change: a life cycle analysis case study of lettuce and chicken

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Abstract

Background: Climate change is expected to have an impact on food production, processing and transport systems. While food systems have become globalized in recent decades, interest has re-emerged for local production and consumption to contribute to sustainable and secure food systems in an era of increasing urbanization and climate change. To explore environmental health issues related to the production of local food in an urban setting, a life cycle analysis screening study of two food commodities, chicken meat and lettuce, produced at industrial and civic scales was conducted in Sydney, Australia, as well as interviews with consumers and producers to explore their potential motivation to change.

Methods: Determination of environmental impacts was performed using life cycle assessment (LCA) of two civic and one industrial scale producer for each commodity using SimaPro version 7.3.3. Impacts of global warming potential (GWP), land use and water use from the production of these commodities are reported. With a view to producing holistic insights to sustainable practices in Sydney, interviews with producers and consumers were undertaken to assess sociocultural outcomes including views on environmental food sustainability and other motivators of behavioral change.

Results: Local industrial production of chicken meat was found to have a lower carbon footprint than small scale civic production. Small scale civic production of lettuce had a similar carbon footprint to local industrial production. Other environmental health benefits and risks varied across the production scales. Environmental sustainability was not generally a key concern of producers or consumers.

Conclusions: Action can be taken to retain and promote food production in urban settings as a future means of assisting food security. The scale of production can be an important variable in assessing the environmental health impacts of food production in an urban setting. Currently neither producers nor consumers appear motivated to change practices to promote environmental sustainability.

Keywords: Urbanization, Scale of food production, Carbon footprint, Life cycle assessment

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Background

Environmental factors can impact directly and indirectly on human health, a concept encapsulated in the term 'environmental health'. The loss of biodiversity and human-induced climate change are environmental factors that are likely to create major pressures on human health outcomes [1]. Food production is one functional aspect of society that is under significant stress from such environmental change. This stress threatens food yields, environmental sustainability, producer livelihoods, regional economies and community cohesion, and food security and equity, which in turn threatens human health [1,2]. With a world population of around seven billion and the level of man-made greenhouse gases in the atmosphere continuing to rise [3,4], the need for resilient and environmentally sustainable food systems capable of producing nutritious food available to everyone becomes ever more pressing [5]. The objective of keeping carbon emissions to a minimum, as well as conserving limited water and land resources, is of importance for improving food security and protecting human health. Producing food at lower relative emission rates is both a local and global priority.

Food insecurity, or when people have inadequate physical and economic access to sufficient, safe and nutritious food to meet their dietary needs, affects one billion people around the world [6,7]. Urban communities may be at risk of increased inaccessibility in the future due to declining local production and reduced security of importing food. Access and cost are important factors in people's ability to obtain food, and as local civic or community production operates outside market structures, it has the added potential to improve accessibility by avoiding market food price fluctuations. In addition, while food supply systems have become globalized in recent decades and food is currently transported around the world [8], these global supply lines may become vulnerable to environmental changes in the future resulting in insufficient food reaching populations that rely on an imported food supply [9]. Areas for food production may shift or yields may be significantly reduced due to land degradation, water shortages and climate change [1]. The dual pressure from the need to control carbon emissions and the impending scarcity of fossil fuels means that eventually mechanized production and long distance transport of food is likely to become more difficult and costly in the future [10], making it harder to supply food to urban populations from distant food production areas.

Under these pressures, it is possible that some countries will find the global food system they rely on will become unreliable and they will need to reinvigorate local capacity to produce food. This may cause a shift of food production close to urban centers [11]. Local urban food systems are already common in some areas of the world, such as in parts of Africa [12], Cuba [13] and in developed countries like the UK [14]. Local urban food systems may contribute to security if global food supply lines fail, but with ever growing urban populations, balancing the use of water and land for food production versus the needs for drinking water and land for housing are other important issues for urban food systems. These issues must be taken into account when attempting to find the most efficient and secure food supply systems in the face of global environmental change.

Environmental change can threaten the security of both local and global food production, and there are potential advantages and disadvantages to food production systems at both sites. Some 'perceived' benefits of locally grown food to consumers include a belief in better freshness and taste, lower use of pesticides and chemicals, and the social interaction that can occur between consumers and local producers [15,16]. Locally produced food is also often perceived by consumers to have a reduced ecological footprint, as the distance of production to the consumer is smaller which reduces the energy requirements used in transport. It is not always recognised that energy for other less obvious aspects of production may vary independently from energy used for transport and may contribute a significant component to total production emissions [17]. On the other hand foods imported over longer distances are perceived as providing greater quantities and greater variety in both the range of products available and the degree of processing, including all kinds of fresh fruit and vegetables all year round and ready-prepared meals. To prevent food spoilage, however, transport over longer distances is likely to require energy-intensive logistics systems [18,19]. Research on 'food miles' is contentious depending on study boundaries such as geographical location, food product studied, seasonality and transport scope [17,20-22]. How this contentious debate on 'food miles' relates to Sydney's food supply chain is not clear.

Consumer views form an important potential source of pressure for food producers to change their practices. How consumers view sustainability issues and whether their views are likely to shape their food provisioning practices is often unknown. While a narrowly defined life cycle assessment (LCA) study can offer a sustainability measurement of particular practices, taking a more holistic approach to include interviews and other qualitative material broadens the insights and predictions that can be made regarding the likelihood of future behavioral change and societal willingness to support policy and food system changes in the interest of sustainability.

As well as variation in the locality of food production, there are variations in scale and approach. Apart from the distance between producers and consumers, the food chain from production to plate can take many varied forms [23]. Within a local urban setting, at one end of local food production is a small 'civic' food production system, which can be commercial or non-commercial, but is small scale or backyard. At the other end is a fully industrialized system with a complex and high intensity production-processing-retail chain, which is located in and servicing the local area and often areas many hundreds of kilometers distant. How these small civic systems compare with the larger more complex industrial systems regarding issues other than profit is largely unknown.

A case study of local food subsystems in Sydney, Australia

In order to further explore some of the environmental advantages and disadvantages of local urban food production, and of consumer and producer perceptions which are likely to be critical to motivate changes in production, we undertook a project in Sydney, Australia, as a case example of local food subsystems in an urban population in a developed country. Such information is relevant to policy makers as it is only by assessing the potential importance of local production in urban settings that resources such as land will be made available.

Sydney sits on the eastern coast of Australia in the Hawkesbury Nepean river basin in New South Wales (Figure 1). The Sydney Basin has been a major source of food for Sydney's population since white settlement [23]; however, with vast population increases and rapid development projects [23,24], prime agricultural land has been reduced. In the Sydney area during the period from 1997 to 2006, there was a decrease in the number of businesses across a broad range of agricultural commodities including eggs, poultry meat, pigs, mushrooms, stone fruit, honey and grain crops. While citrus fruit production has actually increased during this period (from 14.8 million kg to 16.1 million kg), the total value of fruit decreased dramatically from AUD$2.5 million in 1997 to AUD$1.4 million in 2006 [25]. There was a dramatic drop in the number of dairy cows from over 12,000 in 1997 to about 2,500 in 2006 [25]. Nonetheless, the Sydney Basin remains an important source of food production for the local urban population, with agricultural land covering approximately 77,000 hectares [25,26].

By evaluating different food production systems in the Sydney Basin, environmental health impacts can be compared. Local urban civic and industrial food production systems were evaluated using one meat (chicken) and one vegetable (lettuce), as a case study in Western Sydney. The selection of these commodities was guided by: 1) high importance in the Australian diet in terms of quantity consumed; 2) nutritional value; and 3) significant production and consumption in Sydney via different food systems.

Chicken meat is an important source of protein with less saturated fats, compared to other meats [27], and in 2010 was consumed more than any other meat in Australia at an average of 41.7 kg per person per year [28]. There are approximately 12 million broilers located in the Sydney region in industrial production, which is about 15% of the national total [29]. In addition, it is known that there are small scale 'civic producers', but the number is unknown.

Lettuce is consumed in Australia at the rate of 9.3 kg of lettuce per capita per year [30]. It has reasonable nutritional value, providing fiber and various vitamins and minerals [31]. Sydney is largely self-sufficient, producing an equivalent of 88% of the total quantity consumed [32]. Lettuce is also a common civic crop. A survey of 137 backyards in Sydney, Wollongong and Alice Springs found that vegetables were grown in 52% of backyards, although a high migrant population in the sample may have inflated this proportion [33].

The main environmental health outcomes of interest for chicken and lettuce production in this project were global warming potential (GWP), land use and water use. Producer and consumer perceptions of these foods were explored, including interest in environmental impact, and considered in relation to other social factors that may impact on health. Both physical and social outcomes were sought regarding different food subsystems in order to contribute to thinking about possible pathways to enhance future environmental sustainability, food security and human health.

Methods

Two main methods were employed to gather information on potential environmental health impacts related to different food subsystems. First, a life cycle approach was used to undertake a screening assessment of three indicators: GWP (global warming potential or warming of the atmosphere due to human induced emissions of specific greenhouse gases, in CO_2 equivalents), land use and water use. LCA has been an accepted approach to estimating environmental impacts of products since the 1990s [34,35]. In this study, we followed the internationally standardized techniques and approaches outlined in International Organization for Standardization (ISO) documents [36,37] and used SimaPro version 7.3.3. We considered the three LCA indicators selected to be important to the setting of urban food production where, in addition to the overarching concern about GWP, contestation for land and water are key issues. We were confident about collecting reasonable primary foreground data for the three LCA indicators selected and did not want to cloud these results with other indicators (such as eutrophication and summary score values) that would have relied heavily on background data. The use

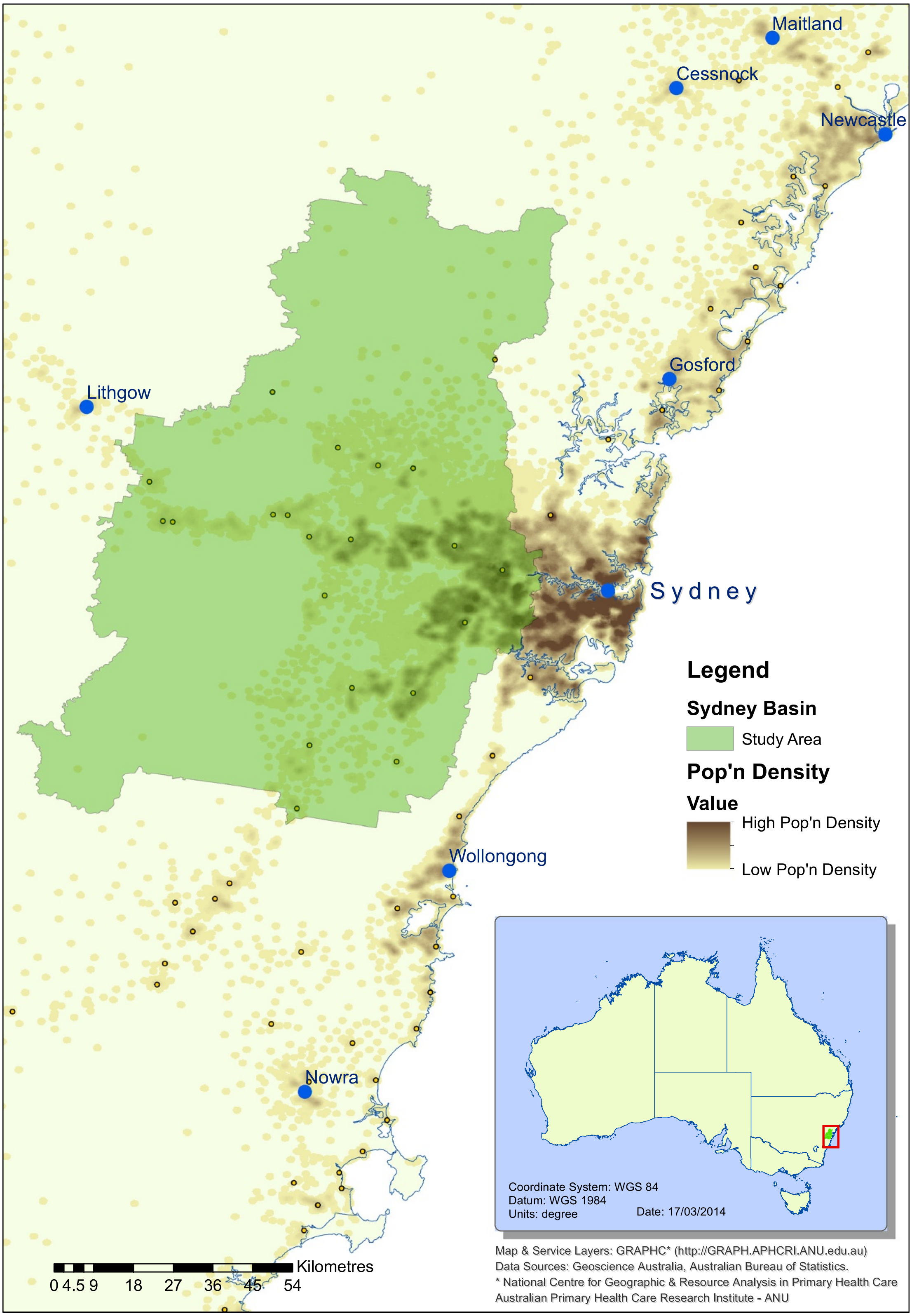

Figure 1 Map of the case study area within the Sydney Basin, Australia.

of quality data that is appropriate to the setting has been emphasized as important to produce reliable life cycle analyses [38].

Second, to complement the LCAs, interviews and focus groups were used to explore views from producers and consumers regarding social and cultural factors relating to environmental sustainability and food provisioning. In particular, motivation to improve environmental outcomes was investigated. Informed consent was obtained from each participant. The study was approved by the Australian National University (ANU) Human Research Ethics Committee, and the industrial lettuce production component was also approved by the University of Western Sydney Ethics Committee.

Criteria for local civic and industrial food subsystems were characterized as shown in Table 1, similar to schema devised by others [39-41]. A food subsystem could be classified as 'civic' or 'industrial' if it met most of the criteria of one or the other. Hybrid systems would contain elements of both.

Participants and data collection

One local medium sized industrial chicken producer agreed to take part in the study and two civic chicken growers provided information suitable for analysis. Industrial lettuce producers were contacted by visiting the Sydney central market and civic lettuce producers were identified via an active gardening group based in Western Sydney. One industrial and two civic producers provided information suitable for analysis. Consumers were contacted by door knocking from three socioeconomic areas. Consumer focus groups were made up of parents of young children who were recruited from local pre-school and day care centers.

Primary (foreground) data were collected from producers in face-to-face interviews using a standard questionnaire. Collecting data at the producer level minimized the use of 'average' background data from publically available databases that may not be appropriate to individual settings and provided a better representation of the different production systems being contrasted with potentially widely different inventories. Using producer-specific data is particularly relevant to land use and transportation, where spatial differentiation is recommended [42-44]. Farm inputs such as agrochemicals, water and transport to the Sydney market are spatially dependent. Verification of data was obtained by re-contacting the producers at a later date. Secondary (background) data were obtained from the Australasian Unit Process Database where possible, and from the ecoinvent database in SimaPro [45] when Australian data were lacking (Table 2).

Life cycle assessment (LCA)

The primary research question for the screening LCA was: Is there a difference in the environmental impact of local 'civic' and local 'industrial' systems of chicken meat and lettuce production? In accordance with ISO standards 14044 on comparative studies [37], for all subsystems studied, an equivalent functional output unit was used. This was 1 kg of product in the consumer's kitchen ready for consumption in Western Sydney. GWP (measured as CO_2 equivalent emissions), land use and water use were selected as three relevant indicators that could be meaningfully compared between industrial and civic producers. GWP and water use are two impact categories for agriculture recommended by the Australian Rural Industries Research and Development Corporation (RIRDC) [46]. GWP is necessary within this comparison if emissions reductions possibilities are to be suggested. Water in Australia is a constrained resource and land in the Sydney region is similarly constrained.

Table 1 Summary characteristics of civic and industrial food subsystems

Criteria	Civic food chain	Industrial food chain
Scale of production	Small scale production with local distribution	Large scale, widespread, high volume production/processing/distribution
Business model	Independent decision making, production highly variable. Probably no business plan, do not make an income or pay tax	Large capital investment for production (hundreds of millions of Australian dollars)
Employees	Likely no paid labour, no workers compensation, no OHS plan or HACCP plan	Paid workforce, worker education, safety plans in place and managed
Value adding	Minimal value adding to food product	Value adding on some products. Use of cooking and freezers is likely
Motivation	Motivation likely to be highly diverse and may include desire for healthy food, preference for organic foods, food taste, saving money, environmental sustainability, enjoyable lifestyle, cultural acceptance	Motivation is primarily monetary profit but other values will also be present
Consumer access	Availability to consumers at same location as production/processing	Available at large retail supermarkets in addition to other food outlets
Location	Location co-exists with house garden or community plot. Urban or residential-rural location	Multiple production and growing sites are likely. Both rural and urban locations

HACCP, hazard analysis and critical control point; OHS, occupational health and safety.

Table 2 Primary (foreground) and secondary (background) data items

Foreground data	Background data (from databases[a])
Product produced: description and amount	Electricity: production and distribution
Co-products: description and amount	Cars and trucks for transport
Land use: area of land used for production, co-uses, provision of any cultural services	Tractors and other machinery in production
Energy use: amount and source of electricity, petrol fuels, gas	Fertilizers and pesticides: manufacture of
Water use: amount and source of water	Wheat, canola and soya: production of
Material use: type, amount and source of other materials, such as pesticides, fertilizers, feed	City water supply
Wastes: type of waste and method of disposal	Waste to landfill
Application of food and worker safety measures	Manure management
Transport used in production	Other

[a]Australasian Unit Process Database and databases available in SimaPro version 7.3.3 software.

As the aim of the study was to conduct a comparative screening assessment of the significance of the potential environmental impacts between two production systems, more certain midpoint modeling was considered appropriate, as opposed to endpoint modeling which would require introduction of additional modeling assumptions [47]. No weighting was performed, as weighting would introduce value choices, as per the recommendation of ISO 14040 [36], ISO 14044 [37] and RIRDC [46]. For the method within SimaPro, the Australian indicator set version 3.01 was used. Greenhouse impacts are 100-year impacts based on the 2007 Intergovernmental Panel on Climate Change (IPCC) figures [48]. Factors for calculating emissions of CO_2 and N_2O in agriculture were taken from the *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006* [49]. Land use and water use were each additive.

The LCA models encompassed the stages of production, processing, retail, consumer acquisition and preparation (Figures 2 and 3). The boundary did not include capital works onsite, but did include waste disposal, and inputs into machinery were generally incorporated through secondary databases. Allocation of inputs and outputs was applied for any secondary co-products.

Five stages were modeled in SimaPro for production of chicken meat: 1) production of eggs; 2) hatching of eggs; 3) growing chickens; 4) harvesting chickens; and 5) preparing for consumption. For both industrial and civic producers, one week of chicken life to produce the egg that led to the actual broiler chicken was the first step modeled. For industrial chicken production, there is an earlier stage of developing fertile elite breeder eggs overseas but this stage was not included in the industrial model. Although this involves an intensive scientific breeding program, one great-great-grandparent accounts for many birds for consumption, in excess of 1,000,000 birds [50]. The production stage focused on inputs for the raising of chickens including feed production, litter production, fertilizer production and its transport, and the raising of chickens on the industrial broiler farm or civic location. The processing stage focused on the slaughtering of chickens and the manufacture of chicken meat products. It included the production and transport of necessary inputs, such as cleaning products and packaging, as well as direct inputs, such as electricity and water and dealing with waste products. The focus for the consumer stage was on storage prior to sale and transport to acquire the product. Cooking the chicken was not included in the models.

Four stages were modeled in SimaPro for production of lettuce: 1) providing seed and growing seedlings; 2) growing and harvesting crop; 3) transporting to market; and 4) preparing for consumption. Seed production and raising seedlings applied to both civic and industrial systems. The growing stage focused on inputs of fertilizer, water and chemicals. Retail did not involve refrigeration, while consumer preparation included acquisition and washing.

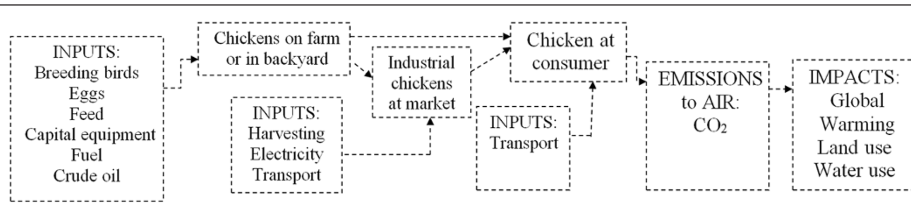

Figure 2 Inputs and boundaries for industrial and civic chicken production.

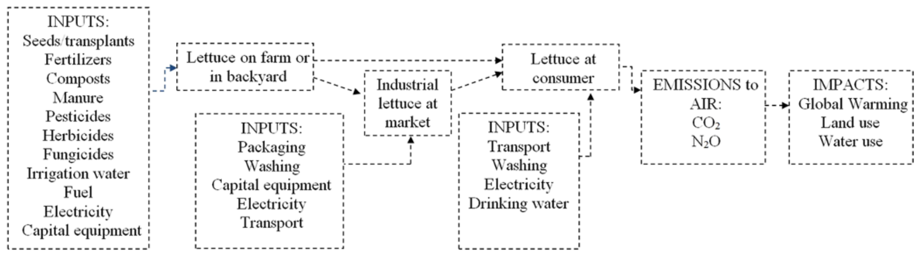

Figure 3 Inputs and boundaries for industrial and civic lettuce production.

Interviews and focus groups on environmental health and sustainability

Our primary research question for producers and consumers was: Are there environmental health motivators and behaviors related to the production and consumption of chicken and lettuce in Western Sydney? Producers were asked about their views on environmental health and sustainability and their motivation for being producers of chicken meat or lettuce. Consumer views related to buying and consuming chicken and lettuce, and were explored through focus groups and door-knock interviews with people living in purposively selected streets in areas of high, middle and low socioeconomic advantage across Western Sydney. Other information from consumers was also collected for a companion project as described elsewhere [51]. The three focus groups each included three to twelve people and in each location at least eight door knock interviews took place. The researcher also accompanied consumers on grocery shopping trips and participants were asked to document their eating and shopping practices in diaries and photo journals. The researcher, a trained anthropologist, analyzed the data with a food sociologist, sharing interpretations of common themes and patterns between various factors and re-reading the transcripts until consensus was reached. This is usual practice in small scale, qualitative research [52].

Results

The LCA models show that industrially produced chicken has less impact on CO_2 equivalent emissions than the civic produced chicken. Industrial chicken produced only 2.6 kg of CO_2 equivalent emissions per 1 kg of chicken meat, compared to the 7.7 kg and 4.0 kg of CO_2 equivalent emissions produced by civic producer 1 and civic producer 2, respectively. In addition, the industrial chicken producer in this study used less land, and less or the same amount of water as the two civic producers (Table 3). The chicken production networks for industrial and civic producers (Additional file 1) show that in both food subsystems, the main contribution to CO_2 emissions was made during the growing stage.

Industrial lettuce production had a similar impact on CO_2 equivalent emissions to one of the civic lettuce producers in this study, with 0.25 kg of CO_2 equivalent emissions for 1 kg of civic produced lettuce, and 0.32 kg of CO_2 equivalent emission produced by the industrially produced lettuce. Civic lettuce producer 2 produced 0.08 kg CO_2 equivalent emissions because of little car transport and use of home chicken manure instead of synthetic fertilizers, which are a large contributor to GWP for industrial lettuce production. The civic producer 2 model does not take account of the chickens to provide manure, as they produce a by-product of eggs. Civic lettuce producer 1 used the least land and water, with civic producer 2 and the industrial lettuce producer exhibiting similar land and usage (Table 3). The lettuce production networks for industrial and civic producers (Additional file 1) show that the main contribution to CO_2 emissions was made during the growing stage.

Producer and consumer views on sustainability and environmental health

Chicken

Interviews with chicken meat producers indicated that views on environmental health and sustainability were not primary motivations for choosing to farm chickens or for selecting particular methods. The two civic producers

Table 3 CO_2 equivalent emissions, land use and water use for local civic and industrial production in Western Sydney per 1 kg of chicken or lettuce production

Production	CO_2 equivalent (kg)	Land use (hectare-years)	Water use (m^3)
Chicken			
Civic producer 1	7.7	0.005	0.17
Civic producer 2	4.0	0.003	0.32
Industrial	2.6	0.001	0.18
Lettuce			
Civic producer 1	0.25	4.0E-06	0.004
Civic producer 2	0.08	1.4E-05	0.004
Industrial	0.32	2.0E-05	0.072

who participated were animal lovers who enjoyed hobby farming as an activity that allowed them to express independence and 'backyard innovation'. However, despite environmental sustainability not being of the first concern, the civic producers employed a number of methods in order to ensure the environmental health of their operations and their land. Civic producer 1 sourced all his necessary water from his own dam and poultry litter was delivered in the same delivery for horse supplies, thus negating the need for extra transport. All egg and chicken wastes were fed to pet dogs. Civic producer 2 used rain water and rarely relied on tap water for feeding chickens, while feed was purchased locally and chickens were also fed kitchen waste.

Views concerning environmental health held by those working in industrial chicken production varied widely across different company employees and contract farmers interviewed. At the company level, environmental health typically emerged in interviews as an important priority, relevant to company efficiency, responsibility and best practice. Cost considerations, however, were primary, as evidenced in encouraging farmers to replace conventional sheds with tunnel sheds due to their greater efficiency, despite the high electricity costs. Health and sanitary regulations also led to environmental costs, such as the use of cheap, polyester protective garments disposed of daily by hatchery employees. Growers did not usually measure value in terms of sustainability outcomes; however, primary motivations, such as making an efficient use of resources and caring for the welfare of the flocks, had significant positive environmental benefit. For some of these growers their most immediate concern was the future security of their livelihood due to increasing council regulation.

Chicken meat consumers discussed purchasing and eating chicken primarily in terms of convenience. Chicken was described as convenient because of its popularity among the family and its ready availability at the supermarket. With very few exceptions, participants purchased their chickens from large supermarkets, although some participants did mention going to the butcher, and one mentioned going directly to a chicken producer (factory outlet). The importance of convenience was seen clearly in the fact that half of the focus group participants (who were exclusively parents with young children) only bought pre-cooked barbecue chicken. Barbecue chickens were firstly described as 'easy' and 'convenient', and secondly as 'tasty'. Those who only bought barbecue chickens often described purchasing raw chickens as inconvenient and/or complicated. When discussing their chicken purchases and eating habits almost none of the participants mentioned the environment as important, although when asked about their waste methods, there was a trend among some consumers to minimize waste by using leftovers in new meals and the bones for creating stock or feeding to pets.

Lettuce

Civic lettuce producers showed the greatest ideological commitment and motivation to environmental health and sustainability. The participating lettuce growers grew a range of fruit and vegetable crops and spoke of their gardening as a positive environmental project. The civic producers had significant rain water and waste management systems, and all spoke of their gardening as having educational benefits for the community by demonstrating the possibilities in backyard gardening or by sharing knowledge in a community garden space. One of the civic producers was particularly careful to limit reliance on cars as a form of transport, including when they were sourcing necessities for the garden. Civic producers were also able to create environmental benefit by picking lettuce just before eating it and not relying on refrigeration. The interviews suggested that currently lack of access and high cost are not strong reasons for people to engage in civic production in the setting of Sydney.

Among industrial lettuce producers, care for the environment was conceived of as an ongoing responsibility necessary to 'good farming'. While environmental health and sustainability were never articulated as primary concerns, farmers expressed a responsibility to the health of their land and to Australian consumers. This was sometimes expressed in monetary terms, as farming practice, or with an intimacy of knowing the land, as farmers who had worked with the land for generations they might know when to use less (or more) fertilizers than those recommended by agronomists. Environmental concerns fit into the larger picture of farmer practice and identity, but were not presented as the most pressing of concerns. The most immediate concern to lettuce producers was that all of their product would be sold 'and not wasted'. On a longer and ongoing basis, the lettuce farmers were highly concerned with the lack of understanding and appreciation of farming by the wider Australian culture without a framework to appreciate their hard work and detailed knowledge.

Lettuce consumer responses to issues of environmental sustainability were more diverse on the topic of lettuce than they were in regards to whole chicken products. As with chicken, the majority of consumers did not consider environmental concerns as their top priority. Across geographic locations and socioeconomic backgrounds, 'price' and 'convenience', followed by 'taste' were considered the key factors when making consumer choices. When asked about the environment, many participants reflected the sentiment that it was not a high enough priority to merit time and effort, such as one focus group member who said, 'I know it probably should be important but honestly I just don't think about it'. However, a minority of participants did express environmental concerns, particularly concerning fruit and vegetable products. Among some of these consumers there was distrust expressed towards food traveling long distances impacting upon the quality of lettuce, such as its 'freshness'. For this reason some consumers chose to purchase lettuce and other vegetables from the market and independent grocers, or grow their own. However, people who grew their own lettuce or used markets and independent growers were just as likely, if not more likely, to do so for reasons that were not expressed as environmental motivations, such as 'supporting the local grocers' or 'a hobby for the kids'. Some backyard lettuce growers explicitly stated that they were not interested in the environment. Lettuce products were typically kept in the fridge for between 2 to 14 days. Wasted lettuce amounts were reported as quite high ranging between 'nothing wasted' to 'about half wasted'. Very few consumers composted their leftover vegetable product, although in one site the council provided 'food waste bins' which were used by the majority of people interviewed.

In summary, environmental concerns were not a strong factor motivating most producers' and consumers' behavioral patterns. However, some motivating factors, such as efficient use of resources and desire for freshness, may have an unintended bonus of being beneficial for environmental sustainability.

Discussion

Chicken meat and lettuce have high consumption and production rates in Australia and in the Sydney Basin [28,30]. In terms of GWP, this study found that local industrial chicken production is more efficient than civic production, and local industrial and civic lettuce production exhibit similar environmental efficiency. Taking into account current and future environmental change, improving the viability and efficiency of all kinds of local urban food production is likely to be fundamental to increasing food security for urban communities. However, our results suggest that generally neither producers nor consumers of chicken and lettuce consider environmental sustainability as a primary motivating factor for their behaviors. Conscious application of environmental sustainability by those who are in the best position to influence better environmental outcomes seems to be still in its infancy.

Although comparison of the civic and industrial food production systems highlighted the areas in both systems that can be improved in order to reduce the impact on GWP, land use and water use, changes are only likely to occur if both producers and consumers consider this a priority. In particular, significantly increased urban production at a civic level is only likely to occur if people are motivated and supported to try this. Currently there is a high reliance on, and acceptance of, the industrial scale producer for both chicken and lettuce. The motivations of producers at the civic and industrial scale were generally both dominated by reasons other than a drive to reduce environmental impacts, illustrating the market nature of society and Australia's long period of reliance being fed by industrial producers [53]. Even among the civic poultry producers, where there was evidence of the adoption of closed loop practices, such as waste refuse for chickens or animals, environmental impact reduction was not necessarily the primary target. Similarly, even without the conscious adoption of sustainability imperatives, one of our case studies found that the business as usual industrial approach to commodity production may have environmental benefits.

Our LCA results indicated that industrial chicken meat production is highly efficient. Supporting these results, average values recently reported for another Australian industrial chicken producer were comparable, at 2.6 kg CO_2 equivalent emissions per 1 kg of chicken meat [54]. Another large Australian LCA of the chicken meat industry found that industrial chicken production was highly efficient, with the industrial average GWP ranging from 1.89 ± 0.15 kg CO_2 equivalent emissions to 2.38 ± 0.16 kg CO_2 equivalent emissions [55]. In our models, chicken meat production was significantly influenced by commercial chicken feed production, which has the greatest impact on global warming potential. The low feed-to-product ratio used by industrial producers contributes to their higher efficiency. Industrial producers used relatively less food mainly due to selection of the breeding stock for feed efficiency, a scientific approach to food composition and partly due to temperature control, reduced movement by chickens in growing sheds and a short lifespan of broiler chickens. Interviews with civic producers showed that they feed their chickens more per day and for longer periods before slaughter. Civic chicken production could improve efficiency by reducing the input of commercial feed through controlling pests and maximizing the use of other feed, such as kitchen scraps. There would be considerable benefit in a system where manure produced on site was used to produce crops that could in turn be fed to the chickens.

The lower use of feed in the industrial setting reflects greater efficiency of the system as a whole, but this could still be improved if electricity usage could be reduced. In a recent Australian LCA of industrial chicken production, the authors recommend utilizing by-products, such as spent litter, as an energy source, in order to decrease reliance on electricity [55]. Renewable energy could also be a cost-effective option for industrial producers, who in interviews describe 'high electricity costs' as a concern. Reducing the feed and electricity inputs would improve efficiency in civic and industrial chicken production, respectively.

Other lettuce LCA studies in Australia show GWP of similar magnitude to our study. Although other studies have not included the consumer contribution to GWP, our study showed that on-farm impacts were dominant and values of similar orders of magnitude were found in Queensland [56] and in an assessment of the Australian vegetables industry [57]. In our LCA study of lettuce, the impact of lettuce production on GWP was most influenced by the use fuel (tractor- and transport-related) and fertilizer (manure and synthetic fertilizer). For industrial lettuce, a combination of poultry litter and synthetic fertilizers were used. Fertilizers are known to make large contributions to GWP due to N_2O emissions [58,59]. Sensitivity to the type of fertilizer was investigated by replacing the poultry litter in the model with the equivalent quantity of synthetic fertilizer, which caused the GWP to increase, primarily due to the increased fossil fuel requirements to produce synthetic fertilizers. The civic producers typically used manures and the same sensitivity was displayed when manures were replaced by synthetic fertilizers. By increasing the efficiency of fertilizer use, lettuce production could become more environmentally efficient. Using home produced composts would further improve environmental efficiencies for civic producers, as fuel for transport to collect manures also contributed to GWP in civic production.

There are a series of issues to consider when evaluating a food commodity in terms of its production and security. While the environmental efficiency of a food production system is one of the most important considerations, a commodity's ability to meet population nutritional needs through availability and resilience is also very important. Food supplies must be sufficient to meet daily requirements, reliable and stable, resilient and diverse on a local scale to ensure healthy diets and food security. Having a range of food available may require production of different forms (from backyard to industrial producer). The industrial production system allows for the efficient production of large amounts of food, approximately 114 g of chicken meat per person per day is already produced in Australia countrywide [28], which is more than a recommended global consumption target of 90 g of all kinds of meat per day [60]. A US study found that industrially produced chicken travels an average of 1,400 metric ton-kilometers per household, which is significantly less than red meat and cereals [17]. Local civic food production adds to the resilience for urban food supplies, in the case of a break down in these food supply lines due to conflict or lack of fuel for transport under environmental pressures. Wartime England promoted home production of all foods where possible [61] and chickens were fed significantly less grain and their feed was supplemented by kitchen scraps. This is one way to maximize the efficiency of civic chicken production and improve the resilience of urban food supplies.

Also for sufficient and resilient food supplies, physical supplies of land and water must be available for production. Civic food production is not possible if people do not live in households with enough land to have chickens or grow lettuce, and local industrial production is not possible if agricultural lands are overrun by urbanization. Most importantly, it is critical to not only have physical results about the most sustainable options but also to have community motivation to change. Our results do not support the concept of strong community concerns about environmental sustainability regarding food. An example of high community motivation to undertake civic food production was wartime England, when many people used available land for local production. However, the current perception of environmental issues does not appear to have reached a critical level that is perhaps required before it might become a strong motivator in current day Sydney. In Sydney's urban environment, there is a limited amount of land, which must be shared between agriculture and housing development [23]. As more land is developed to accommodate a growing urban population, less land is available for agriculture. The 2006 and 2011 Australian censuses show that the proportion of people living in separate houses has declined and the proportion of people living in semi-detached dwellings, flats, units and apartments has increased [62,63], meaning that fewer people have backyards in which they could grow lettuce or raise chickens or other food commodities. Moreover, those in employment in the area under study can have long commutes to work, denying them time to grow food and increasing the acceptability of 'convenience' or shop-bought foods [51]. Increasing land prices also makes it difficult for agricultural businesses to expand and there is increased pressure to sell for both chicken and lettuce farmers [2]. In addition, the local industrial chicken producer faced increasing difficulties of sustaining a local industrial company due to residential complaints about the smell of chicken farms.

Water is another contested resource needed for urban food production, as well as for urban development and drinking. The lettuce producers in this study were stressed by increasing water regulations put in place by councils which favored housing over farming. Under future climate scenarios annual rainfall may decrease and there may be more frequent and severe droughts and storms in New South Wales [64,65], and water may become even more contested, so food production systems using less water will be favored. Grafton and Kompas [66] performed simulations and found that during low rainfall periods, Sydney's current system is already insufficient to prevent water levels from reaching critically low thresholds, as there is an imbalance between supply and demand.

Besides environmental efficiency and resilience, other issues to consider when evaluating the production of a food commodity include food safety, animal welfare, social and cultural acceptance, and cost. As chicken meat can carry pathogens, such as *Campylobacter* and *Salmonella* [67,68], biosecurity is important for evaluating civic and industrial chicken production. Graham *et al.* [69] show how modern methods of poultry production are a threat to biosecurity through pathogen transfer from animals to humans in industrial settings. However, Australian chicken meat companies have reached a high level of adoption of different biosecurity practices to protect their farms against infections [70]. There is limited data on the biosecurity risks of civic chicken production. Pathogen transmission from backyard chickens appears to be low but understanding and adherence to proper hygiene and animal husbandry would be needed to mitigate risks [71]. In addition to biosecurity, social issues and animal welfare are other considerations. Civic chicken production involves chicken owners killing the chickens themselves, which may not be a socially popular practice, although skills could be learnt if motivation is sufficient. Industrial chicken production has been the subject of animal welfare concerns including food restrictions, fast growth requirements and physiological stress during transit [72-74].

As well as being efficient, there are other potential benefits to civic lettuce production. Urban gardens can contribute to a sense of community and add beauty to city environments [75]. In addition, members of the focus groups liked ‘supporting the local grocers’ and some saw growing lettuce in the backyards as a good ‘hobby for the kids’ and a good way to exercise. However, there may be some safety issues with civic lettuce production to consider, as soils in urban areas can contain trace elements, such as copper, zinc and lead, and eating lettuce grown in urban soils could increase the amount of trace elements being ingested [75].

For the GWP, land use and water use endpoints examined in this study, it is possible that the estimates for GWP of 1 kg of simple whole chicken meat for the industrial model may be an overestimation. This is because in reality the industrial production of ‘1 kg of chicken meat’ included some whole chicken and some processed product. Some resources in the model would have been used to ‘value add’ to the carcass, for example, by chopping it up. Another limitation is that there is some uncertainty in the inputs. For example, the chicken production models had to rely on some overseas data for some feeds, as there is limited Australian feed data. Capital goods were only assessed for industrial lettuce production, for cool rooms and irrigation infrastructure. However, inclusion of capital goods into the industrial lettuce model did not alter the top contributors to environmental impact results. There are mixed views about the importance of capital infrastructure [76,77].

It is important to note that the study of chicken and lettuce in Sydney is a case study, and may not be representative of all civic and industrial meat and vegetable production. Such case studies are, however, a good place to start examining the viability of civic and industrial food production systems in an urban setting. The efficiency of civic and industrial chicken and lettuce production in our study were based on GWP, land use and water use; there are other endpoints for environmental health outcomes and food security that could be examined.

Conclusions

We developed models of food production systems for industrial and civic production of chicken meat and lettuce that allowed for assessment of the contribution of these foods to GWP, land use and water use. We also explored producer and consumer views and attitudes to these foods as these are important to facilitating improved production practices. Per kg of product, industrial chicken meat production had less environmental impact than civic production of chicken meat, primarily due to the fact that industrial producers had very low land use and slaughtered chickens much younger than civic producers. This led to a consequent reduced amount of feed per kg of chicken meat produced and feed is a key component of GWP for this system. In terms of lettuce production, carbon use was similar between civic and industrial producers, with the main influences on carbon efficiency being the use of fertilizers and manures, and tractor use in the industrial system. Using composts and manures instead of synthetic fertilizers appears to benefit GWP results for both civic and industrial producers. Maximizing environmental resource use efficiency in production systems at both the industrial and civic scale will be needed in order to ensure food security and thereby safeguard human health and well-being in the face of environmental change.

Tools such as LCA can serve to measure environmental impacts of different production systems and provide evidence that may be used to support the drive for improved environmental outcomes such as emissions reductions. However, interviews with producers and consumers showed that generally both were more influenced by reasons other than a drive to adopt practices that better support sustainability and environmental health. The results from measurements need to be aligned with motivation in a population for whom sustainability is important in order for change to be enacted. Given the current apparent lack of interest in environmental sustainability by both producers and consumers, steps may be required to encourage this. These might include a shift in market mechanisms to make resource-hungry foods more expensive as well as new regulations to reward the conscious application of sustainability practices.

Additional file

Additional file 1: Network diagrams. Life cycle assessment (LCA) network diagrams of CO_2 equivalent emissions, land use and water use for two civic chicken producers, two civic lettuce producers, one industrial chicken producer and one industrial lettuce producer.

Abbreviations

ANU: Australian National University; GWP: Global warming potential; HACCP: Hazard analysis and critical control point; IPCC: Intergovernmental Panel on Climate Change; ISO: International Organization for Standardization; LCA: Life cycle assessment; OHS: Occupational health and safety; RIRDC: Rural Industries Research and Development Corporation.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

The whole team contributed to all aspects of the study. Members led the following components as follows: conception of the idea by GH, JD and SH; overview and design by GH; data collection by BI and AR; data analysis by TG, AR and BI; and interpretation and report writing by GH, LF, AR and MK.

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