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Supplementary Information for

Small scale urban agriculture results in high yields but requires judicious management of inputs to achieve sustainability

Robert McDougall, Paul Kristiansen and Romina Rader
Robert McDougall
Email: robert.n.mcdougall@gmail.com

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Supplementary text (S1-S19)
References for SI reference citations

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Supplementary Information Text

S1 Study Sites

The climate of these cities is warm temperate, with mild winters, warm to hot summers and rainfall throughout the year (1), allowing year-round growth of agricultural crops. The mean minimum temperature across the year is 13.5^{o}C, with a mean maximum of 22.3^{o}C and an annual average rainfall of 1083.4mm, spread throughout the year with slightly higher amounts in winter (2).

UA in New South Wales exists primarily as an informal, small scale activity (3); whilst it is promoted by some local governments and supported via the provision of extension staff and land for community gardens (e.g. 4) there is no official body that oversees or compiles data on the sector as a whole. Where governments are involved in UA it is primarily seen as a social or environmental issue, with provisioning value not factoring heavily into the discourse (5). The majority of UA in these two cities is carried out for non-commercial purposes (e.g. self-provisioning), whilst commercial agricultural activities are carried out on the cities' peri-urban fringes (6).

S2 Garden Data Recording

Self-reporting of yields is commonly used in studies of UA production (e.g. 7, 8, 9). Whilst this methodology may result in measurer bias, it has the benefit of permitting a greater number of gardens to be examined than a researcher could directly monitor and allows for more typical production values to be determined.

Gardeners were recruited by contacting gardening organisations throughout Sydney and Wollongong and asking them to circulate an email inviting research participation. This non-random method of participant recruitment enabled the selection of interested gardeners that were more likely to provide the labor and effort required to carry out the project reliably.

Participating gardeners were asked to keep records of the time they spent working on food producing activities in their gardens (including associated activities such as carrying out maintenance of productive garden beds) the types and quantities of materials used (excluding water, as accurate measurement of this was judged to be too onerous for most gardeners) and the amount of produce harvested. The logbook used is shown in S3. Gardeners were provided with scales to weigh produce and material inputs, however some records were returned using units other than weight, such as volume, number or financial cost, and were converted to weight where appropriate by weighing samples of similar materials and produce of the same type, as per Codyre *et al.* (8), or through onsite observation.

Average water use for vegetable production in the Sydney Basin was reported by Dunlop (10) to be 670L m^{-2} $year^{-1}$ and gardeners were assumed to use water at this average rate. Gardeners were asked where they obtained their water (e.g. municipal supplies, rainwater tanks) and economic and emergy values for the quantity of water estimated to be used were assigned based on the method by which it was obtained.

27 gardeners originally volunteered to participate. These gardeners worked in a range of community, private and allotment-style market gardens, some working separate plots in the same gardens, resulting in a total of 15 different sites being covered by this study. These 15 sites were located in park margins (n=5), private yards (n=3), waste-ground (n=3), former industrial sites (n=2), a university campus (n=1) and a former commercial nursery (n=1). Apart from two of the three waste-ground sites, all others were unsuitable for more major development as a result of being on contaminated or flood prone land or due to development likely being detrimental to adjoining land uses (e.g. ruining the amenity value of parks). All gardeners identified themselves as adhering to organic gardening practices, although none were formally certified as such.

Of the 27 gardeners who initially volunteered, only 13 remained involved with the study over a full year, with the remainder either failing to return any logbooks or ending their involvement part way through the year. Additionally, one of those 13 gardeners returned data that only gave input and output figures as total cost of materials and labor and total quantity of produce, without specifying types of materials or produce, meaning that those data could be used to assess yield per m^2 and yield per hour but could not be used as part of the economic and emergetic analysis.

The compliance rate achieved in this study is better than that reported by Taylor and Lovell (11), who had to abandon a similar study due to low completion rates by volunteers, worse than that reported by CoDyre, Fraser (8), who began with 56 volunteers and had 50 complete the study, and equivalent to Reeves, Cheng (7), who received yield data from 10 gardeners. A similar study across two years by Birkman (12) had a much worse response rate in the first year (19 of 52 volunteers returned complete data) and a similar rate to this study in the second year (12 out of 20 interested gardeners returned data). However all of these studies were carried out in cool temperate climates (northern USA, Canada and UK) with shorter growing seasons, meaning that entire annual production took place in only a few months and thus making participation less onerous for volunteers. It was anticipated prior to commencing this study that not all gardeners who began would remain involved for the entire year and thus the number initially recruited exceeded the minimum number judged to be necessary for a robust study.

Gardens were visited approximately every 6 weeks throughout the study period to assess the accuracy and completeness of reported data. The log books of all gardeners that completed the full year of data recording appeared to reflect the on-ground situation in their plots. For purposes of this study the term ‘plot’ refers to the space used by a participating gardener for growing food crops while the term ‘garden’ refers to the entire block covered by the same tenure. All measurements based on area relate to the size of the plot.

Whilst a proportion of UA consists of greenhouses or indoor ‘vertical farms’, the isolation from the surrounding environment and high level of human management that these systems experience makes these factors more relevant to their functioning than their location within an urban or rural area (13). They also come with much higher capital investment costs than more basic outdoor farms or gardens (13) and thus we have not included such systems within our analysis, focusing instead on more basic open air farming systems which are growing in popularity in the developed world (14).

Climate data

Data on natural inputs to the study sites, used for emergy analysis, were obtained from the Australian Bureau of Meteorology (15). The closest weather station to each site was used with MJ m^{-2} of sunlight and mm of rainfall recorded for the period that the site was being studied. These values were multiplied by the area of the plot studied to determine the total amount of sunlight and rain falling on the site over the study period.

Site establishment

This study did not assess the inputs involved in establishing the plots and gardens as all sites were already established when the study began. However in a number of cases the inputs of materials and labor that gardeners recorded included those required to improve or maintain garden ‘infrastructure’ (e.g. material to rebuild garden beds). This study assumes that, when averaged across all sites, these improvement and maintenance costs are typical of costs of this type incurred in a normal year and that they represent the depreciation of the costs of establishment of the garden system spread across its lifetime.

S3 – Gardener Logbook

Date →					
Hours worked this visit or this week					
Materials used (estimated weight, volume or number of any that apply)					
Compost					
Mulch					
Fertiliser (organic)					
Fertiliser (synthetic)					
Seedlings					
Seeds					
Pesticide (organic)					
Pesticide (synthetic)					
Other (please specify)					
Crops harvested (weight, volume or number)					
Did you use power tools or machinery? Type and estimated time used					

Any comments					

S4 – Gardener Survey

Personal information

Age:
18-30 31-40 41-50 50-65 65+

How many years experience have you had with gardening (both in this garden and others):

On a scale of 1-5 (1 being very novice, 5 being expert) how would you rate your skills as a gardener?

What is your main occupation?

Gardening Practices

How many hours would you spend working in the garden in an average month?

Which of the following have you done in the garden in the last year:

- Sowing
- Mulching
- Making compost
- Applying fertiliser (please specify type e.g. compost, Dynamic Lifter etc.)
- ‘Cultivating’ soil
- Applying pesticide (natural or synthetic, please specify type)
- Treating pests (other than with pesticide, please specify method)
- Weeding

Please list all plants you have grown in your plot in the last year:

Do you try to follow any specific production system (e.g. organic, reduced tillage, permaculture) in your plot?

How do you water your garden and where does the water come from (e.g. mains supply, rainwater tanks etc.)?

What have you done to improve the quality of the soil in your garden?

Do you have any specific practices used to increase the amount of productive space available in your garden (e.g. use of trellises etc.)?

What do you do to control weeds, pests and diseases in your garden?

What sources have you obtained seeds and seedlings from in the last year?

Reasons for gardening

On a scale from 1-5 (1 being not at all important, 5 being very important) how important are the following factors in motivating you to work in the garden:

- Access to food that is fresh and healthy.
  1 2 3 4 5

- Access to food produced in an environmentally sustainable manner.
  1 2 3 4 5

- Access to food that is cheaper than buying it at the shops.
  1 2 3 4 5

- Reducing personal environmental footprint (other than through sustainable food).
  1 2 3 4 5

- Getting exercise
  1 2 3 4 5

- Spending time outdoors
  1 2 3 4 5

- Learning useful skills
  1 2 3 4 5

- Socialising
  1 2 3 4 5

- Cultural Reasons
  1 2 3 4 5

- Other (please specify)

  1 2 3 4 5

  1 2 3 4 5

  1 2 3 4 5

General comments

Do you have anything else you'd like to say about your garden or your experience of working in the garden?

S5 – Criteria for Development of ‘Permaculture Index’

A yes answer = +1 point, a no = 0 unless marked with an X, in which case a yes answer is -1 point.

Soil sourcing:
Build own soil
Purchased from commercial outlet X
Recycled (e.g. from a building site)
Native soil only

Soil improved using:
Commercial synthetic fertilisers X
Commercial organic fertilisers X
Homemade compost
Worm castings
Homemade fertilisers (other than compost)
Locally sourced animal manure
Locally grown green manure

Weeds, pests, diseases controlled in the last year by using:
Commercial synthetic pesticides X
Homemade natural pesticides
Soap X
Measures to attract beneficial animals
Keeping animals (e.g. letting chooks eat pests)
Companion planting
Using highly diverse plant species
Maintaining healthy soil (e.g. solarisation)
Crop rotating

Type of mulch used:
Don’t use mulch X
Commercial mulch/compost X
Self-produced compost
Un-composted waste from within garden
Newspaper or other recycled waste product

Animals kept in the garden?
Chickens
Bees
Worms
Other

Water conservation strategy(s) – which have been used in the last year?
Relying on natural rainfall only (plants only irrigated in exceptionally dry periods – maximum of one month) (yes = +6 and don’t ask other water conservation questions, no = 0)
Rainwater tanks
Mulching
Low water-use plants

Water saving irrigation (e.g. drip irrigation)
Swales/capture run-off from outside garden

Seedlings sourced from:
General commercial outlet X
Organic commercial outlet
Swap with other gardeners

Seeds sourced from:
General commercial outlet X
Organic commercial outlet
Swap with other gardeners
Sourced from plants within garden

Other
Is multi-strata planting employed?
Are any measures carried out specifically to attract pollinators?

S6 – Glossary of Emergy Terms

Emergy

A contraction of “embodied energy”, emergy, sometimes referred to as “energy memory” is a measure of how much available energy was directly and indirectly required to produce an object or allow a process to occur; a measure of the energy consumed in its supply chain. As virtually all processes on the earth are ultimately powered by solar radiation, joules of solar energy required (solar emjoules – sej) is used as a common unit, allowing the emergy of any material or process to be compared to any other.

Transformity

The amount of energy of one type required to produce one unit of another kind of energy, material or process, typically measured in sej $unit^{-1}$ (e.g. sej J^{-1}, sej kg^{-1}). Comparing the Transformities of two similar materials or processes can indicate which is the most efficient or simple, with a lower transformity indicating less energy was consumed in the supply chain for that material or process.

Renewable/Non-renewable

In emergy analysis an input is considered renewable if it meets one of two criteria; either 1) it is provided freely by the natural environment and its use does not impact on its future availability or, 2) its rate of use does not exceed its rate of replacement (16). An example of a renewable input in this study that meets the first criteria is rainwater, as this falls on a surface regardless of whether or not it is captured and utilised, whilst an example of an input that meets the second criteria is homemade compost, as the rate of production of organic waste in Australian cities currently exceeds the rate it is used (17). Inputs that do not meet either of these criteria are considered non-renewable.

Labor is generally considered to be partly renewable and partly non-renewable in proportion to the renewable fraction of the economy of the nation within which it takes place as it is assumed that that labor is supported by that nation’s economy (18).

We considered all materials purchased from commercial outlets to be non-renewable, even if some gardeners used a renewable analogue of them (e.g. compost was self-produced by some gardeners and purchased from garden supply stores by others) as we assume that a high level of non-renewable inputs such as transport and packaging are required to produce a commercially saleable version of the product.

S7 – Classification of Inputs for Emergy Analysis

Along with their classification as renewable or non-renewable, emergy analysis classifies all inputs to a system, based on their means of provision, as environmental services, human services or tangible materials, and these are used to calculate a number of emergy indices.

Indigenous Inputs (I) - inputs provided by the environment without human intervention, primarily weather phenomena. As all weather is ultimately the consequence of solar radiation interacting the with the atmosphere, earth and oceans, only the weather process with the largest emergy value is included in any particular analysis in order to avoid double counting (19) – in the case of this study, the chemical potential emergy of rainfall was the largest weather input. This input is considered renewable.

Emergy analyses of agricultural systems often include soil loss as a non-renewable indigenous input (20). However, unlike in many rural farming systems UA systems often conserve soil quality compared to other urban land uses (21). Therefore, changes in soil quality as a result of the presence of the plots studied was assumed to be either neutral or positive, and thus soil loss was not considered a cost in this analysis (22).

Services (S) - for purposes of this study services included only human labor provided by gardeners, measured in hours of work. Human labor can be considered partly renewable as it is ultimately supported by an economy that is itself partly renewable (18). The Australian economy in 2016, and thus human labor, was considered 14.6% renewable based on calculations by Centre for Environmental Policy (23) for the year 2008 updated to reflect growth in Gross Domestic Product between 2008 and 2016.

Materials (M) – this category includes all physical inputs to a system including consumables and objects that become permanent parts of garden infrastructure. Materials were considered renewable or non-renewable based on the criteria outlined in S6. Non-renewable materials were further classified as ‘substitutable’ if they could be replaced with a renewable substance that served a similar function without requiring gardeners to significantly alter their gardening methods. If a material or a close analogue to it was sourced renewably by any gardeners, then this material was considered substitutable for all gardeners. The classification of all materials used as renewable, non-renewable and substitutable is shown in S9.

Figure A gives an indicative outline of the flows of emergy within the studied systems.

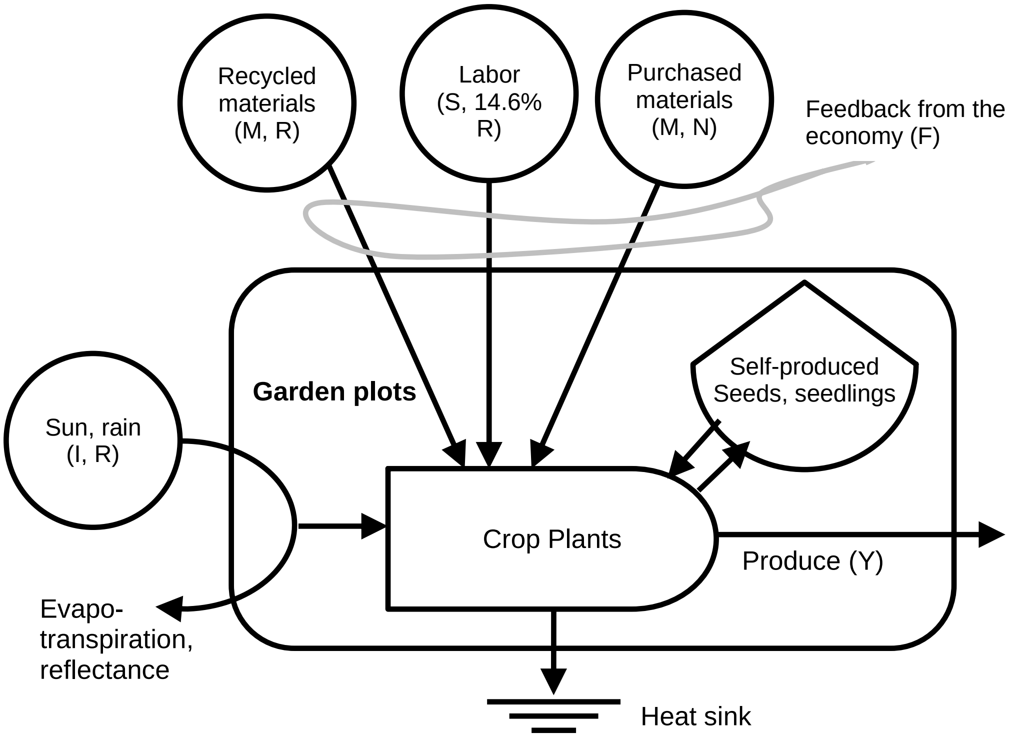


Figure A – Generalized Emergy Systems Diagram for the studied sites. Recycled materials include compost, worm products and other materials produced locally from renewable resources. Purchased materials include all other materials introduced into plots, including purchased analogues of recycled materials and seeds and seedlings not produced within plots, as outlined in S9.

S8 - Calculation of emergy indices

Two main emergy indices were calculated for this analysis, the Emergy Yield Ratio (EYR) and the Environmental Loading Ratio (ELR).

EYR indicates the efficiency of a system in utilizing freely provided natural emergy inputs. Its formula is:

$$EYR = Y/F$$

Where Y is Yield, the emergy leaving the system which is itself calculated as the sum of all emergy that entered the system and F is Feedback, the sum of emergy of all inputs to the system fed back from the economy (in this case all Services and Materials; $F = S+M$). An EYR in this context cannot have a value less than 1 and higher values indicate a system that takes greater advantage of naturally provided inputs, whilst lower values indicate a system more dependent on anthropogenic inputs.

ELR indicates the level of impact that a system has on the environment relative to the total emergy used within it. Its formula is:

$$ELR = N/R$$

Where N is the total emergy of non-renewable inputs into a system and R is the total emergy of renewable inputs, with a lower ELR indicating a system less dependent on non-renewable inputs and thus generally more sustainable, both in terms of their ability to function without substantial external inputs and the level of stress they impose on the environment. As a general principle, systems with an $ELR > 10$ are considered unsustainable, those with an $ELR < 2$ are considered sustainable and those in between are moderately sustainable (16), however such numbers rarely tell a complete story and must be interpreted in the context of the system in which they operate.

S9 – Transformity Values of Inputs

As the majority of sources of information for transformity data used in this analysis were based on the 1996 estimated global emergy baseline of 9.44E+24 seJ, data below has been presented using that baseline to remain as close to as many of the original sources as possible. All values presented in the main body of the paper have been multiplied by 1.27 in order to make them consistent with the 2016 re-estimated global emergy baseline of 12E+24 seJ (24).

Dollar values in this table refer to $AUD used for calculation.

Input	Unit used	Transformity	Source	Renewability	Notes
Services					
Labor	Hour	4.7E+12 sej/Hour	Lagerberg (25)	14.6%R/ 85.4% N	
Indigenous					
Sunlight	J	1	By definition	R	
Rain	L	8.99E+7 sej/L	Odum (19)	R	
Materials					
Blood and Bone/ Fishmeal	kg	7.39E+11 sej/kg	Lagerberg (25)	N – non-substitutable	Value is based on the mean value for blood meal and bone meal.
Bokashi	L	1.55E+12 sej/L	Self-calculated, see notes	22%R, 78% N – substitutable.	Assume the only non-renewable component is bokashi fermentation mix as everything else is made from waste, assume labor required to produce it is negligible. Assume 1kg of bokashi fermentation mix produces 20L of solid + liquid in total, so 1L of either requires 0.05kg bokashi fermentation mix and 0.6kg of organic matter. 1kg of fermentation mix costs $11.95, therefore, 1 L costs $0.60, = 1.21E+12+ (0.6*5.59E+11) = 1.67E+12 + 3.35E+11= 1.55E+12 sej/L.
Compost (self-produced)	kg	5.59E+11 sej/kg	Nakajima and Ortega (26)	R	Self-produced compost is assumed to be primarily derived from the garden, neighborhood and home of the gardener, with material obtained from the plots considered to make up only a negligible proportion of inputs due to the small size of plots.

Fuel (gasoline for power tools)	L	2.7E+11 sej/L	Beck, Quigley (20)	N – non substitutable	
Gypsum/Lime	kg	1.04E+12 sej/kg	Lagerberg (25)	N – non-substitutable	
Fertiliser (purchased)	kg	3.8E+12 sej/kg	Beck, Quigley (20)	N – non-substitutable	
Manure	kg	2.39E+11 sej/kg	Lagerberg (25)	N- non - substitutable or R, see notes	By default manure is considered a non-renewable input as it is not readily available in most urban neighborhoods except through purchase from a commercial outlet. Exceptions occur for chicken manure in the case of plots 6 & 7 as these are located within a community garden where chickens are kept and cow manure in the case of plots 3 & 4 as these are located within 2km of paddocks where cows are kept.
Mulch (bark)	kg	5.3E+11 sej/kg	Beck, Quigley (20)	N – substitutable or R	Mulch is assumed to be purchased and non-renewable unless noted otherwise.
Mulch (straw)	kg	8.69E+11 sej/kg	Beck, Quigley (20)	N – substitutable or R	Mulch is assumed to be purchased and non-renewable unless noted otherwise.
Pesticide	kg	1.5E+13 sej/kg	Johansson, Doherty (27)	N – non-substitutable	
Peat	L	1.14E+11 sej/L	Lagerberg (25)	N – non-substitutable	
Sand	kg	1.00E+12/kg	Beck, Quigley (20)	N - substitutable	
Soil Conditioner	$ value	2.02E+12 sej/$	Centre for Environmental Policy (23)	N – non-substitutable	
Seedlings	$ value	2.02E+12 sej/$	Centre for Environmental Policy (23)	N or R- substitutable	Values presented here are for seedlings obtained from sources beyond garden plots (e.g. purchased). Seedlings propagated within gardens are considered to have an emergy value of 0 as the emergy used to produce them is contained

					within the inputs recorded for that plot (Figure A). Where a gardener indicated that they both propagated their own seedlings and purchased seedlings we assumed seedlings used were produced in an even ratio between the two methods unless further information was provided. Seedlings propagated by a gardener outside the garden (e.g. in the gardener's home in the case of community gardeners) are considered to have their full emergy cost as the inputs are not accounted for in garden inputs, however they are considered renewable.
Seeds	g	1.32E+9 sej/g	Ulgiati, Odum (28)	N or R-substitutable	Values presented here are for seeds obtained from sources beyond garden plots. Self-produced seeds (e.g. from seed saving) are considered to have an emergy value of 0 as the emergy used to produce them is contained within the inputs recorded for that plot (Figure A). Where a gardener indicated that they both engaged in seed saving and purchased seeds we assumed seeds used were produced in an even ratio between the two methods unless further information was provided.
Soil (purchased)	$	2.02E+12 sej/$	Centre for Environmental Policy (23)	N - substitutable	
Metal Wire	kg	3.45E+12 sej/kg	Brown and Buranakan (29)	N- non-substitutable	
'Teas' (e.g. comfrey, weeds)	L	2.98E+10/L	Self-calculated, see notes	R	Assume weed tea requires 1kg of organic matter and 20L water to make 20L. = 5.59E+11 + (1.88E+9*20) = 5.97E+11 per 20L, =2.98E+10 per L (Teas were used by only two gardeners, both of whom relied solely on tank water. Thus, we have used the transformity for tank water here, rather than the average of tank and municipal water).
Water (from municipal supply)	kL	3.29E+12 sej/KL	Tam, Tam (30)	N - substitutable	Emergy cost based on $ value per KL.
Water (from	kL	1.88E+12	Tam, Tam (30)	R	Emergy cost based on $ value per KL.

rainwater capture)		sej/KL			
Wooden stakes	kg	1.14E+12 sej/kg	Brown and Buranakan (29)	N - substitutable	
Worm 'tea'*	L	4.26E+10 sej/L	Self-calculated – see notes	R	Assume worm tea requires 1L of castings to produce 20L (along with 20L of water) =[(2.58E+9)*20] +8.00E+11 = 8.51E+11 per 20L /20 =4.26E+10 per L
Worm castings*	L	8.00E+11 sej/L	Self-calculated – see notes	R	Assume a worm farm requires 13 hours per year of labor (15 min per week), 250L of water and 400kg of organic matter to maintain. Assume a worm farm produces 400L of castings per year (assume a typical worm farm is 140L and fills up most of the way in 3 months). Average price of a three-tier worm farm is $AU85.45 and assume a 5 year life (some gardeners use homemade worm farms made from wood or recycled materials, these would have a lower cost but shorter life). =(4.7E+12*13)+(2.58E+9*250)+[(85.5/5)*2.02E+12] +(5.59E+11 * 400) = 3.20E+14 per worm farm per year, /400 = 8.00E+11 per L of worm castings.

*Whilst there are non-renewable inputs embedded in worm products we consider these products overall to be renewable as they result in the diversion of organic matter from the waste stream, where it would result in an environmental and financial cost. Labor involved in the production of worm products is also considered renewable under all scenarios as it is considered to part of domestic waste management activities that would take place regardless of what purpose that waste was put to.

S10 - Potential explanatory variables for production output

Variable	Source	Abbreviation (S11,12,14,15)
Gardening experience of gardener (years)	Gardener survey	Exp
Total mean food related motivation for gardening (mean of three 1-5 scale measurements 'fresh food' 'sustainable food' and 'cheap food')	Gardener survey	Total Food
Permaculture Index	Gardener surveys and onsite observation	Perm Index
Labor invested per m^2 of garden area	Gardener logbooks	Labor per m2
Size of plot	Onsite observations	Plot Size

S11 – Models Tested to Explain Yield Per Hour

Explanatory Variable	Relative Importance	Model Number	Variables	AICc	Wi	Cumulative Weight	Delta AICc
labor per m2	0.92659	**13**	**labor per m2**	**3.61**	**0.62405**	**0.62405**	**0**
total food	0.12224	**16**	**labor per m2 + total food**	**7.35**	**0.09618**	**0.72023**	**3.74**
plot size	0.08440	**3**	**plot size + labor per m2**	**8.2**	**0.06288**	**0.78311**	**4.59**
experience	0.07957	**14**	**labor per m2 + exp**	**8.26**	**0.06102**	**0.84413**	**4.65**
permaculture index	0.08020	**15**	**labor per m2 + perm index**	**8.27**	**0.06072**	**0.90485**	**4.66**
		1	**nil**	**9.23**	**0.03757**	**0.94242**	**5.62**
		26	**total food**	**12.12**	**0.00886**	**0.95128**	**8.51**
		2	plot size	12.33	0.00797	0.95925	8.72
		24	perm index	12.69	0.00666	0.96591	9.08
		20	exp	12.8	0.00630	0.97222	9.19
		9	plot size + labor per m2 + total food	13.33	0.00484	0.97705	9.72
		17	labor per m2 + exp + total food	13.56	0.00431	0.98136	9.95
		19	labor per m2 + perm index + total food	13.56	0.00431	0.98567	9.95
		8	plot size + labor per m2 + perm index	14.38	0.00286	0.98854	10.77
		7	plot size + labor per m2 + exp	14.45	0.00276	0.99130	10.84
		18	labor per m2 + exp + perm index	14.53	0.00265	0.99395	10.92
		25	perm index + total food	15.83	0.00139	0.99534	12.22
		6	plot size + total food	16	0.00127	0.99661	12.39
		22	exp + total food	16.75	0.00087	0.99749	13.14
		4	plot size + exp	16.82	0.00084	0.99833	13.21
		5	plot size + perm index	16.95	0.00079	0.99912	13.34
		21	exp + perm index	17.4	0.00063	0.99975	13.79
		12	plot size + total food + perm index	21.51	0.00008	0.99984	17.9

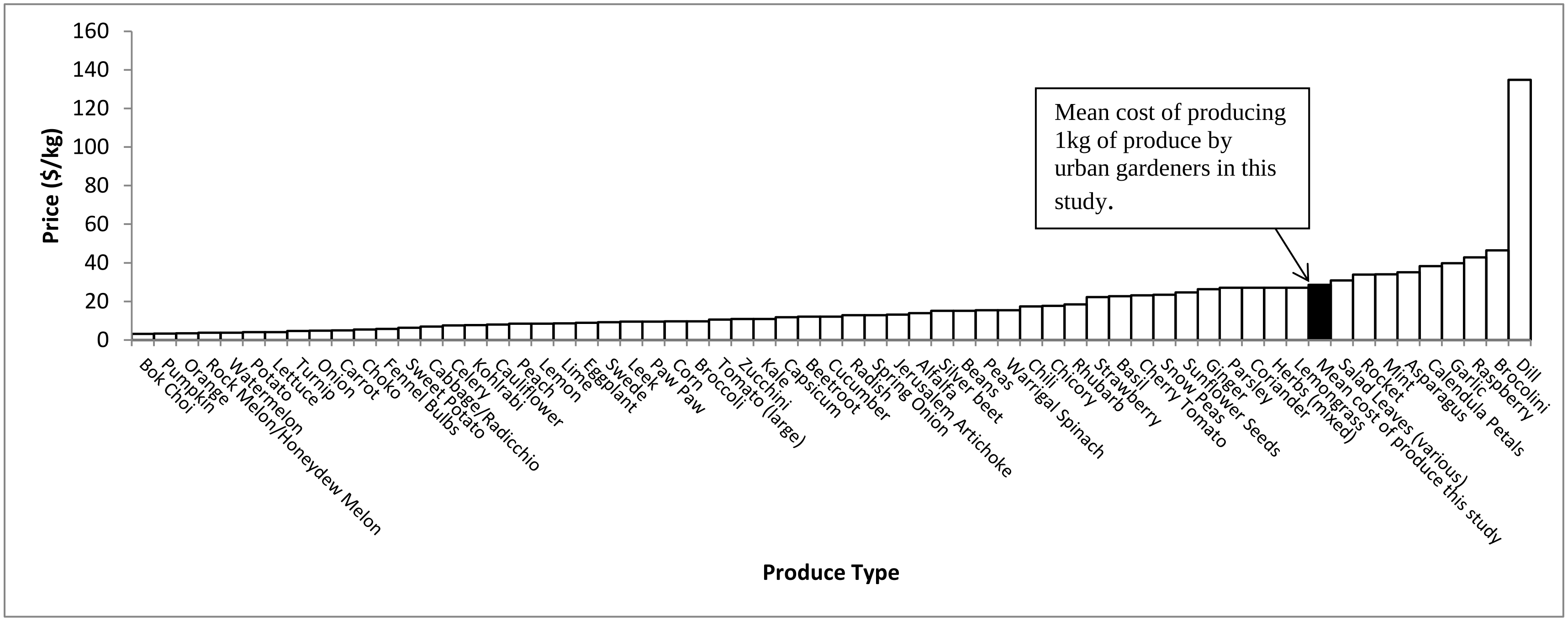
		23	exp + perm index + total food	21.93	0.00007	0.99990	18.32
		11	plot size + exp + total food	22.03	0.00006	0.99996	18.42
		10	plot size + exp + perm index	23.1	0.00004	1.00000	19.49

S12 - Models Tested to Explain Yield Per m^2

Explanatory Variable	Relative Importance	Model Number	Variables	AICc	Wi	Cumulative Weight	Delta AICc
plot size	0.279012	1	**nil**	**7.89**	**0.351321156**	**0.351321**	**0**
labor per m2	0.222066	2	**plot size**	**9.55**	**0.153193339**	**0.504514**	**1.66**
total food	0.1301	13	**labor per m2**	**10.15**	**0.113488417**	**0.618003**	**2.26**
experience	0.118076	20	**exp**	**11.14**	**0.069179237**	**0.687182**	**3.25**
permaculture index	0.102972	26	**total food**	**11.15**	**0.068834205**	**0.756016**	**3.26**
		3	**plot size + labor per m2**	**11.48**	**0.05836409**	**0.81438**	**3.59**
		24	**perm index**	**11.55**	**0.05635668**	**0.870737**	**3.66**
		6	**plot size + total food**	**13.41**	**0.022235737**	**0.892973**	**5.52**
		5	**plot size + perm index**	**14.06**	**0.016065928**	**0.909039**	**6.17**
		4	**plot size + exp**	**14.09**	**0.015826738**	**0.924866**	**6.2**
		16	**labor per m2 + total food**	**14.25**	**0.01460992**	**0.939475**	**6.36**
		14	**labor per m2 + exp**	**14.65**	**0.011961591**	**0.951437**	**6.76**
		15	labor per m2 + perm index	14.83	0.010932071	0.962369	6.94
		22	exp + total food	15.41	0.008180071	0.970549	7.52
		21	exp + perm index	15.76	0.006866818	0.977416	7.87
		25	perm index + total food	15.82	0.006663873	0.98408	7.93
		9	plot size + labor per m2 + total food	16.18	0.005566134	0.989646	8.29
		8	plot size + labor per m2 + perm index	17.75	0.002538824	0.992185	9.86
		7	plot size + labor per m2 + exp	17.77	0.002513562	0.994698	9.88
		11	plot size + exp + total food	19.52	0.001047808	0.995746	11.63
		12	plot size + total food + perm index	19.7	0.000957625	0.996704	11.81
		19	labor per m2 + perm index + total food	20.07	0.000795886	0.9975	12.18
		17	labor per m2 + exp + total food	20.31	0.000705888	0.998206	12.42
		10	plot size + exp + perm index	20.32	0.000702367	0.998908	12.43
		18	labor per m2 + exp + perm index	20.67	0.000589607	0.999498	12.78

		23	exp + perm index + total food	20.99	0.00050243	1	13.1

S13 Commercial Prices of Harvested Products



Commercial prices of harvested products ($US/kg) in comparison with cost of production in study sites. Values for organic produce have been used where these vary from conventional produce prices.

S14 - Models Tested to Explain Benefit to Cost Ratio

Explanatory Variable	Relative Importance	Model Number	Variables	AICc	Wi	Cumulative Weight	Delta AICc
labor per m2	0.430579482	**1**	**nil**	**11.22**	**0.264777**	**0.264776995**	**0**
total food	0.201003657	**13**	**labor per m2**	**11.49**	**0.23134**	**0.496116869**	**0.27**
perm index	0.178770249	**26**	**total food**	**13.12**	**0.1024**	**0.598516996**	**1.9**
plot size	0.099299603	**15**	**labor per m2 + perm index**	**13.64**	**0.078956**	**0.677472775**	**2.42**
exp	0.09673792	**24**	**perm index**	**14.11**	**0.0624**	**0.739892913**	**2.89**
		16	**labor per m2 + total food**	**14.34**	**0.0556**	**0.795532111**	**3.12**
		2	**plot size**	**14.74**	**0.0456**	**0.841085633**	**3.52**
		20	**exp**	**14.88**	**0.042474**	**0.883559455**	**3.66**
		14	**labor per m2 + exp**	**15.98**	**0.024505**	**0.908064719**	**4.76**
		3	**plot size + labor per m2**	**16.2**	**0.021953**	**0.930017371**	**4.98**
		6	**plot size + total food**	**17.46**	**0.011692**	**0.941709173**	**6.24**
		25	**perm index + total food**	**17.72**	**0.010267**	**0.951975691**	**6.5**
		22	exp + total food	17.82	0.009766	0.961741506	6.6
		5	plot size + perm index	18.46	0.007091	0.968832942	7.24
		21	exp + perm index	18.57	0.006712	0.975544882	7.35
		19	labor per m2 + perm index + total food	19.38	0.004477	0.98002159	8.16
		4	plot size + exp	19.45	0.004323	0.984344323	8.23
		18	labor per m2 + exp + perm index	19.72	0.003777	0.988121164	8.5
		8	plot size + labor per m2 + perm index	19.8	0.003629	0.991749913	8.58
		17	labor per m2 + exp + total food	20.36	0.002743	0.994492462	9.14
		9	plot size + labor per m2 + total food	20.54	0.002507	0.996998964	9.32
		7	plot size + labor per m2 + exp	22.27	0.001055	0.99805433	11.05
		12	plot size + total food + perm index	23.53	0.000562	0.99861641	12.31

		11	plot size + exp + total food	23.75	0.000504	0.99911994	12.53
		23	exp + perm index + total food	23.98	0.000449	0.999568769	12.76
		10	plot size + exp + perm index	24.06	0.000431	1	12.84

S15 – Models Tested to Explain Transformity

Explanatory Variable	Relative Importance	Model Number	Variables	AICc	Wi	Cumulative Weight	Delta AICc
labor per m2	0.598958717	**13**	**labor per m2**	**13.68**	**0.404002**	**0.404001675**	**0**
plot size	0.127885703	**1**	**nil**	**15**	**0.208809**	**0.612810479**	**1.32**
experience	0.107061173	**2**	**plot size**	**17.69**	**0.054403**	**0.667213464**	**4.01**
permaculture index	0.101498307	**14**	**labor per m2 + exp**	**17.82**	**0.050979**	**0.718192731**	**4.14**
total food	0.094839964	**3**	**plot size + labor per m2**	**17.87**	**0.049721**	**0.767913316**	**4.19**
		16	**labor per m2 + total food**	**18.23**	0.04153	**0.809443439**	**4.55**
		24	**perm index**	**18.27**	0.0407	**0.85015121**	**4.59**
		15	**labor per m2 + perm index**	**18.37**	**0.038722**	**0.888873641**	**4.69**
		20	**exp**	**18.62**	**0.034172**	**0.923046065**	**4.94**
		26	**total food**	**18.64**	**0.033832**	**0.956878469**	**4.96**
		5	plot size + perm index	22.2	0.005705	0.962583903	8.52
		4	plot size + exp	22.4	0.005162	0.967746393	8.72
		6	plot size + total food	22.4	0.005162	0.972908883	8.72
		21	exp + perm index	22.49	0.004935	0.97784421	8.81
		25	perm index + total food	22.96	0.003902	0.981745936	9.28
		22	exp + total food	23.31	0.003275	0.985021267	9.63
		18	labor per m2 + exp + perm index	23.6	0.002833	0.987854502	9.92
		7	plot size + labor per m2 + exp	23.78	0.002589	0.990443883	10.1
		17	labor per m2 + exp + total food	23.94	0.00239	0.992834184	10.26
		9	plot size + labor per m2 + total food	24.06	0.002251	0.995085284	10.38
		8	plot size + labor per m2 + perm index	24.15	0.002152	0.99723733	10.47

		19	labor per m2 + perm index + total food	24.52	0.001789	0.999025904	10.84
		10	plot size + exp + perm index	28.33	0.000266	0.999292085	14.65
		12	plot size + total food + perm index	28.45	0.000251	0.999542764	14.77
		23	exp + perm index + total food	28.58	0.000235	0.999777667	14.9
		11	plot size + exp + total food	28.69	0.000222	1	15.01

S16 – Individual Plot Emergy Balance Sheet

Plot	Labor input (sej)	Natural Inputs (sej)	Non-recycled Material Inputs (sej)	Recycled Material Inputs (sej)	Total Input sej (Y)	Total Output (Joules)	Produce Transformity	EYR	ELR	Substitable Materials (sej)	Non-substitutable materials (sej)
1	6.60E+13	5.22E+11	2.43E+14	2.37E+13	3.33E+14	9.05E+07	3.68E+06	1.00	8.83	2.53E+14	1.37E+13
2	8.06E+13	5.22E+11	6.53E+13	5.06E+13	1.97E+14	1.24E+07	1.59E+07	1.00	2.13	1.06E+14	1.00E+13
3	3.60E+14	5.51E+12	5.00E+14	2.66E+13	8.92E+14	9.59E+07	9.30E+06	1.01	9.53	4.09E+14	1.18E+14
4	7.98E+14	9.14E+12	1.29E+15	1.17E+14	2.22E+15	2.54E+08	8.74E+06	1.00	8.15	1.27E+15	1.43E+14
5	1.91E+14	5.25E+11	8.30E+13	1.01E+13	2.85E+14	3.10E+07	9.18E+06	1.00	6.39	9.18E+13	1.32E+12
6	6.64E+13	5.87E+11	1.51E+14	6.09E+13	2.79E+14	8.19E+06	3.40E+07	1.00	2.91	2.09E+14	2.54E+12
7	2.96E+14	1.96E+12	4.74E+14	4.84E+13	8.21E+14	5.18E+07	1.58E+07	1.00	7.76	5.00E+14	2.25E+13
8	8.06E+15	1.20E+13	1.80E+16	2.38E+15	2.84E+16	2.95E+08	9.64E+07	1.00	6.96	9.98E+15	1.04E+16
9	5.59E+14	9.23E+11	1.96E+14	2.86E+14	1.04E+15	1.36E+08	7.68E+06	1.00	1.83	4.26E+14	5.60E+13
10	1.80E+14	6.29E+11	3.57E+14	2.89E+14	8.27E+14	9.68E+07	8.55E+06	1.00	1.62	6.40E+14	6.23E+12
11	2.89E+14	7.52E+11	2.67E+14	2.99E+14	8.56E+14	2.63E+07	3.26E+07	1.00	1.50	4.52E+14	1.13E+14
12	4.84E+14	3.82E+12	1.90E+15	4.12E+14	2.80E+15	1.36E+08	2.06E+07	1.00	4.76	7.26E+14	1.59E+15
mean	9.53E+14	3.07E+12	1.96E+15	3.34E+14	3.25E+15	1.03E+08	3.16E+07		5.82	1.26E+15	1.04E+15
median	2.93E+14	8.38E+11	3.12E+14	8.88E+13	8.41E+14	9.32E+07				4.39E+14	3.92E+13

Note: All values used here are based on the 2016 Global Emergy Baseline. EYR = Emergy Yield Ratio, ELR = Environmental Loading Ratio.

S17 – Yield Values Recorded in Previous Studies of UA systems

Location	Yield (kg m^{-2} year $^{-1}$)	Crop	Study Type	Labor (hours m^{-2})	Source
USA (cool)	4.8	tomatoes	experimental plot		Reeves, Cheng (7)
Austria	2.34	mix of fruit and vegetables	experimental plot	0.42	Vogl, Axmann (31)
Kenya	0.3	mix of fruit and vegetables	observation		Foeken (32)
Burkina Faso	16.9	mixed vegetables	observation		Sangare, Compaore (33)
	39.9	intensive lettuce crop			
Italy	18.9*	mixed vegetables	experimental plot		Orsini, Gasperi (34)
USA (cool)	10.17	tomatoes	experimental plot		Sullivan, Hallaran (35)
	1.73	cayenne pepper			
	1.68	kale			
USA (arid)	1.69	mixed vegetables	experimental plot	1.76	Cleveland, Orum (36)
Canada	0.59	mixed vegetables	observation		Duchemin, Wegmuller (37)
Canada	1.43	mixed vegetables	observation	3.03	CoDyre, Fraser (8)
USA (cool)	2.85	mixed vegetables	experimental plot	2.16	Beck, Quigley (20)

USA (cool)	5.85	mixed vegetables	observation		Gittleman, Jordan (9)
Brazil	5.96	mixed vegetables	experimental plot	7.28	Berquist (22)
USA (cool)	2.74**	tomatoes	experimental plot		Beniston, Lal (38)
	2.2**	chard			
	2.6**	Sweet potato			
Philippines	3.0	mixed vegetables	observation		Hara, Murakami (39)
France	1.18	lettuce	experimental plot		Grard, Bel (40)
	3.1	tomato			
Mean	**6.19**				
Median	**2.74**				

* Orsini, Gasperi (34) used a range of growing media, including soil-based substrate, floating hydropic and nutrient film systems. Figures shown here are for soil-based substrate only.

** Figures are mean of different soil amendment trials. Beniston, Lal (38) also included control figures for yields from unamended soil in recently vacated residential lots that were much lower but have been excluded from this analysis as they do not represent realistic scenarios of UA practice.

S18 – Comparison of Transformities Found between this and other emergy analysis of fruit and vegetable production systems

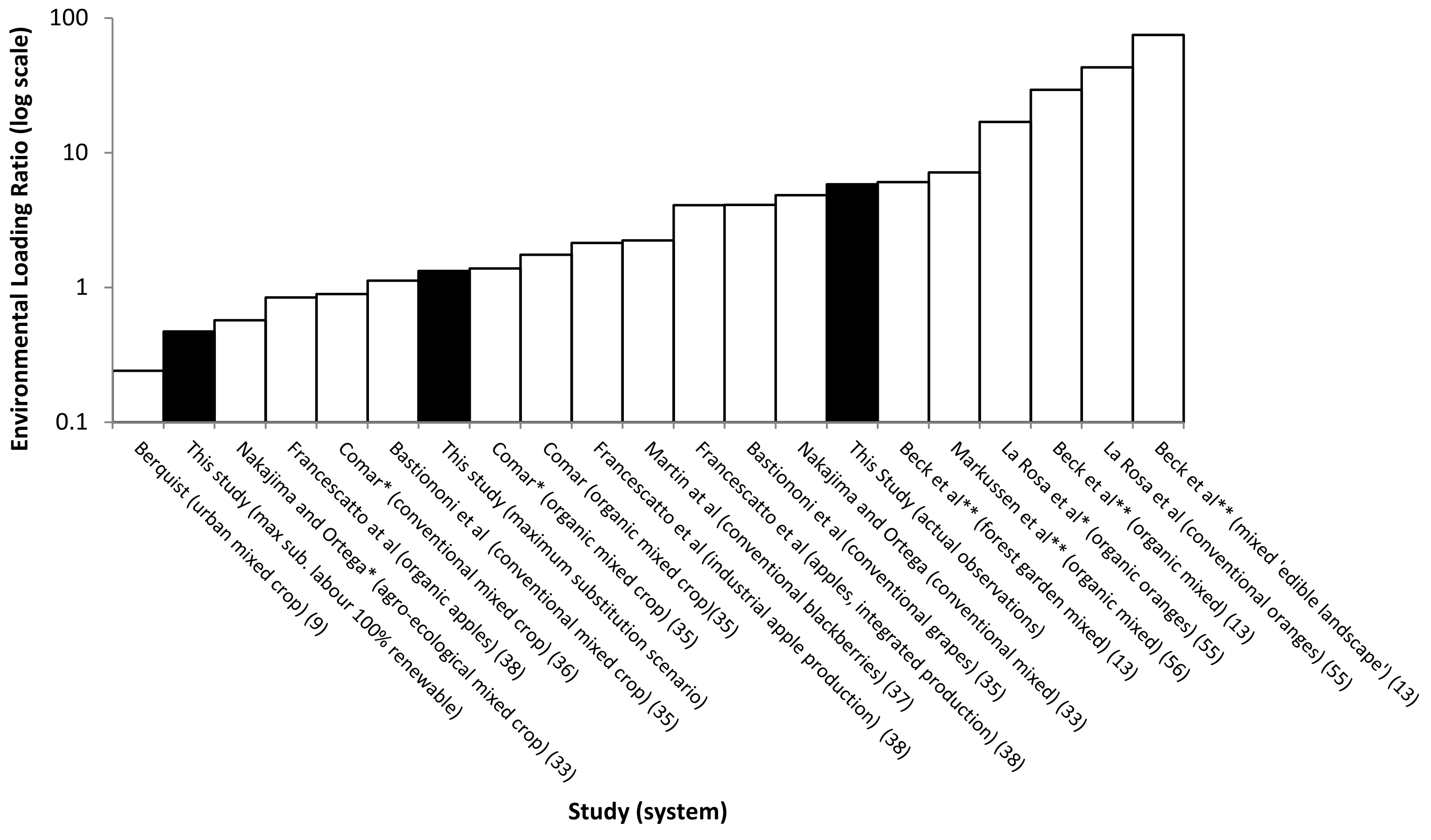
Study	Transformity	Crop	Location
Bastiononi, Marchettini (41)	2.02E+04	Corn (conventional)	Italy (rural)
Brandt-Williams (42)	2.90E+04	Watermelon (conventional)	Florida, USA (rural)
Cheng, Chen (43)	5.05E+04	Mixed Cropping (conventional)	Three Gorges, China (rural)
Bastiononi 2001	5.43E+04	Sunflower (conventional)	Italy (rural)
Brandt-Williams (42)	8.28E+04	Oranges (conventional)	Florida, USA (rural)
Brandt-Williams (42)	9.58E+04	Corn (conventional)	Florida, USA (rural)
de Lima Fernandez Pereira and Ortega (44)	1.34E+05	Oranges (conventional)	Brazil (rural)
Brandt-Williams (42)	1.35E+05	Potatoes (conventional)	Florida, USA (rural)
Martin, Diemont (45)	1.76E+05	Blackberry (conventional)	Ohio, USA (rural)
Comar (46)	1.80E+05	Mixed Vegetables and Fruit (conventional)	Brazil (rural)
Brandt-Williams (42)	2.06E+05	Cabbage (conventional)	Florida, USA (rural)
Comar (46)	2.49E+05	Mixed Vegetables and Fruit (organic)	Brazil (rural)
Bastiononi, Marchettini (41)	2.64E+05	Grapes (conventional)	Italy (rural)
Wu, Wu (47)	4.53E+05	Cucumber and Balsam Pear (combined system)	North West China (rural)
Wright and Østergård (48)	5.02E+05	Mixed Cropping (organic)	France (rural)

Bastiononi, Marchettini (41)	5.10E+05	Olives (conventional)	Italy (rural)
Brandt-Williams (42)	5.20E+05	Cucumber (conventional)	Florida, USA (rural)
Brandt-Williams (42)	5.86E+05	Bell Peppers (conventional)	Florida, USA (rural)
Brandt-Williams (42)	6.34E+05	Lettuce (conventional)	Florida, USA (rural)
Brandt-Williams (42)	6.51E+05	Tomatoes (conventional)	Florida, USA (rural)
Brandt-Williams (42)	9.12E+05	Green Beans (conventional)	Florida, USA (rural)
Nakajima and Ortega (26)	1.20E+06	Mixed Cropping (agro-ecological)	Brazil (rural)
Francescatto, Agostinho (49)	1.44E+06	Apples (organic)	Brazil (rural)
Wright and Østergård (48)	1.73E+06	Mixed Cropping (organic)	Italy (rural)
Nakajima and Ortega (26)	2.20-4.19E+6	Mixed Cropping (conventional)	Brazil (rural)
Nakajima and Ortega (26)	2.24-2.26E+6	Mixed Cropping (organic)	Brazil (rural)
Francescatto, Agostinho (49)	3.12E+06	Apples (integrated)	Brazil (rural)
Berquist (22)	3.21E+06	Mixed Vegetables and Fruit	Brazil (urban)
Beck, Quigley (20)	3.31E+06	Mixed Vegetables and Fruit (organic)	Ohio, USA (urban)
Beck, Quigley (20)	4.62E+06	Mixed Vegetables and Fruit (forest garden)	Ohio, USA (urban)
Beck, Quigley (20)	4.64E+06	Mixed Vegetables and Fruit	Ohio, USA (urban)

		(edible landscape)	
Nakajima and Ortega (26)	4.77E+6 - 2.37E+7	Mixed Cropping (agro-ecological)	Brazil (rural)
Francescatto, Agostinho (49)	4.86E+06	Apples (industrial)	Brazil (rural)
Wright and Østergård (48)	6.17E+06	Mixed Cropping (conventional)	Portugal (rural)
This Study	**3.16E+07**	**Mixed Fruit and Vegetables (organic)**	**Australia (Urban)**

All values in this table are presented as the 2016 Global Emergy Baseline 12E+24 seJ.

S19 Comparison of Environmental Loading Ratio found in this study with other studies.



*Listed values represent the midpoint of a range of values presented.

**These studies used a different method to calculate ELR and thus presented different figures. Figures presented here were produced by recalculating based on the same methodology used in this paper.

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