


The true cost of food

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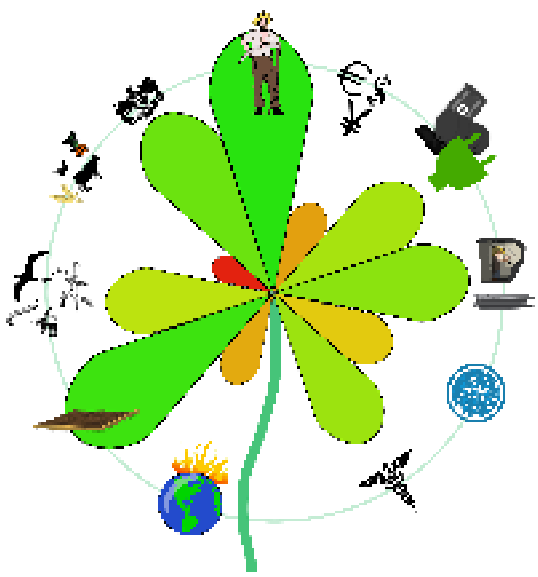
July 8, 2023

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For those interested: a pdf with more figures and graphs can be found at https://github.com/EricSeynaeve/landwijzer_werkstuk/raw/master/text/manuscript-tech-en_screen.pdf.

This work is dedicated to Marc Laga
(1930 - 2021).

A man of integrity and a fine father-in-law.
We all miss his insights and genuine interest
in what you do.

Acknowledgments

A creation does not spawn from a void. It is made possible by people who give you the freedom to create something and is build on others who inspire.

Thank you dear Anne for being there. For giving me the space to follow my heart. It is not always easy when I am absent again, both literally and figuratively. Let's not forget to move and celebrate life in a dance.
Also, my thanks go to our wonderful children who had to miss their father too much while writing this work. Although I had less time, my love for you is as strong as a bear.
The first steps in life are important for all that follows. My parents deserve credit for that good start and the self-confidence they imparted. Thank you for being there and believing in me during this rather extraordinary career change.

Those who should definitely not be missing are the (trainee) farmers Jonas, Nik and Sam from "De Wakkere Akker". They have made it possible that an experiment with the system of Ferme du Bec Hellouin could already happen, albeit on a very small scale. This made it possible to test the belief and theory in this system in real live. It gave necessary experience and data that both indicate a hopeful direction.

Many people, without knowing it, contributed to this paper. First, the authors of the works I went through. Thank you to Meino Smit, Gerald Leach, Steinhart and Steinhart, Amory Lovins and so many others.
Many thanks to Charles & Perrine Hervé-Gruyer for their inspiration, both in terms of perseverance, beauty and the sacrifices they make on a personal level to introduce everyone to their inspiring system. What you have set up is such a strong inspiration, both for today and for the future.
Indirectly, Rob Hopkins also contributed to this body of work by starting the Transition movement. Especially it's positive narrative is an inspiration.
To all the individuals who contributed to create the software that allowed me to write this piece, thank you. You have selflessly put time into software that can be freely used by everyone. The same goes for the people who put the drawings on freesvg.org which I gratefully could use to lighten up this work.

Thank you to the group at Landwijzer for providing a fertile ground. Everyone contributes in his/her own way to this unique group. Special thanks to Evert the fine illustrations of Umbalio's story.
Lien and Eva, thank you for plowing through the technical work. Thanks to your necessary and justified comments, a more accessible text has emerged. For this more accessible work, the comments of Anne and Koen have proved valuable.

Finally, I also thank Colruyt for giving me the opportunity to take time for the Landwijzer training.

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Part I

Introduction

Hello dear reader. Thank you for taking a hold of this treatise. Let it take you on a journey of discovery through the food chain. You're going to learn a lot about the costs of the food we consume. This will give you an insight into where, among other things, agriculture has an impact. For the farmers among you, it can also provide arguments to justify your price.

1.1 The conception of this paper

This paper is a child of the Landwijzer training to become a biodynamic farmer. What was the motivation for me to start that training and then choose this topic?

The reason for starting the training was a concern about the state of our Earth. Call it a mid-live crisis, but around my 45stI wanted to realize something really good. Something that lets you say: „the world is a little better off now".

But why agriculture when I was all about computer science? That's a process that had been going on for a while.

It all started after I got in touch with the Transition movement[1]. From here permaculture came on my path and so the interest in agriculture grew. Especially the example of Ferme du Bec Hellouin[2] inspired me: a project with beauty, permaculture, improvement of nature and also commercially viable.

Agriculture is super important, of course. A smartphone is something we can actually do without, but not food. Just read „Collapse" by Jared Diamond. In it he argues that a society cannot continue to exist if nature is destroyed. And given the close relationship between nature and agriculture . . . .

Many are trying to reduce the impact of agriculture on the world. But can't we use agriculture to heal the damage already inflicted instead of being happy just to do less damage? That has become my mission.

And now, why this particular topic? That grew while getting into permaculture.

A first seed was the documentary „A Farm for the Future" by Rebecca Hosking [Hos09]. In it she mentions, after removing a sandwich from its plastic coffin, that in order to put 1 calorie of the sandwich in your mouth, it takes a total of 10 calories of oil. This is a statement that comes up regularly in permaculture.

There are other memes that you'll also find on a regular basis: „15 000 l water needed for 1 kg beef" or „2 700 l water needed for 1 T-shirt".

With my scientific background, I was stimulated. Where do these numbers come from? What do they mean? Aren't they being misused?

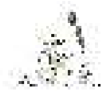
By coincidence, clues came my way regarding the source of Rebecca Hosking's statement. After some exciting (?) detective work, it was possible to sink my teeth into that sandwich's energy.

On the other hand, over the years, the realization grew that organic food is not expensive. It is the current mainstream food that is too cheap. Why? Because there are more costs in conventional food that are not passed on (e.g. loss of biodiversity, health impact of pesticides, . . .) compared to organic farming.

But which costs are there in agriculture (conventional and organic)? How are they calculated? Do they have a big impact or not? The scientist in me wants to know, which is why I felt the urge to delve into this. In this way, bio and non-bio can be compared in a more objective way.

[1] `https://transitionnetwork.org/`
[2] `https://www.fermedubec.com/`

An understanding of this matter will later help to explain and justify the prices of my products.



1.2 What can you expect from this paper

My hope is that when you have read through this paper, you will have experienced the following:

- a sense of wonder about the costs involved in farming. At least for me, light bulbs went off.
- that reality, like a diamond, has many facets. You can look at the part energy or water or economy or . . . . Each way of looking sheds a different light.
- that finding out the real cost is not a simple matter. There is no single method that covers everything[3].
- that the impact of indirect costs change the picture that the „Green Revolution" is super efficient.
- that there are different agricultural systems where a lot are destructive but others build up natural resources.
- an understanding on how agriculture should be practiced in the future.

This will be done through a literature review. That sounds like a great alternative to counting sheep on a sleepless night. Hopefully, we managed to keep the style light-hearted.

This treatise is by no means exhaustive. A number of selected works will be discussed. These will give a good idea of different perspectives in determining the cost of agriculture.

Furthermore, this version is approaching things as conceptually as possible. For enthusiasts, there is another version of this piece with more technical details [Sey22].

Finally, I do not have the background to do an in-depth analysis of those works. That is fodder for specialists who have been in the field for years. So if you have questions about certain assertions or figures cited, it's time to pull out the original works and check them for details. Or to look up the specialists cited.

1.3 Presentation of the problem

Every human activity has an impact, whether in agriculture, education or any other sector. This impact can be a consumption of energy, investment of time, use of land, consumption of water, ... You can assign to that impact a cost in energy (joules), time (hours), ...

This cost is either directly attributable to the activity, a direct cost, or is incurred through dependencies necessary for the activity, an indirect cost. For example, to manufacture machinery, raw materials must be mined, water is used, ...

[3] You can feel free to have the impression that the title is „click-bait" because it makes it seem as if you are going to see all the costs for once and for all. Nothing is further from the truth.

Social costs are costs born by society. Consider, for example, environmental pollution.

Some costs that are incurred are not passed on in the price of a product or service. These are external costs. They can be internalized by either passing them on directly or collecting them through levies.

An example makes this dry explanation much clearer.

Let's introduce Umbalio. Umbalio is a peasant woman who is going to help us clarify the concept of cost[4].

1.3.1 Broadening the view

We meet Umbalio in figure 1.1.

Figure 1.1: Say hello to Umbalio

You can see that she is a bit on her own. But of course that is not true. She has relationships with her surroundings (figure 1.2).

Figure 1.2: Umbalio in her surroundings

Here the picture is already more complete. Umbalio is enjoying the sunlight and the rain. She breathes in oxygen and exhales carbon dioxide and water vapor. She eats leaves and meat. She feeds her environment with urine and excrement. In this way, of course, we can think of quite a few more direct relationships with the environment.

You can go a step further and see what the relationships are of the things Umbalio consumes and produces (figure 1.3).

[4] For the historians and other scholars among us, this is a completely fictional story with a number of historical, geological and other facts completely ignored. Please turn a blind eye to this. The rest of this paper will be less imaginative.

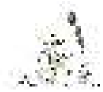


Figure 1.3: Umbalio and the relationships of her surroundings

The leaves come from a tree. The meat from a rabbit.

The droppings are used by a dung beetle for its larvae. The urine makes the plants in that place grow a little better.

One step further, the trees in the forest also make use of the same sun and water. The roots have symbiosis with mycorrhiza. Earthworms convert waste into compost. Trees absorb carbon dioxide and give off oxygen.

You can keep going expanding the relationships and find that everything is connected to everything.

This, of course, is going too far. We would then drown in the amount of relationships. These are interesting for an ecologist but we are now only looking for relationships that we, as humans, influence. Hence all „simple" natural relationships are not going to be considered.

We have learned the following:

- an organism (e.g., a person) is connected to other organisms and processes.
- these are in turn connected to still other organisms and processes. This allows us to continue to expand our view.

1.3.2 Use of a natural tool

Umbalio obviously wants to do something. Grow food. Oh yeah, forgot to mention: Umbalio lives in prehistoric times. To prepare the ground, she uses a stick she found in the forest. Let's sketch this in figure 1.4.

Now Umbalio uses something that does not belong to her own body: the stick. With it, she prepares soil to grow plants.

She partly eats the harvest herself, partly she shares it with her clan. But both portions come from the soil through her labor and the natural miracle of farming. So we must count both as harvest.

The stick doesn't just come out of nowhere because a tree made it. Should we look at that tree along in the relations, as in figure 1.5?

This is not necessary because for the growth of the tree there was no human intervention, only a divine one.

The time Umbalio has to put into producing the food is not just the time she spends on the land. You must also include the time she puts into finding the right stick. This time must be spread over the crops for which the stick is used.

We learned a few new things:

Figure 1.4: Umbalio is preparing the ground with a stick

- part of the harvest can be used for one's own needs. But it still remains part of the harvest.
- the time it takes to have a harvest is not just the time spent on the land, but also in preparing the tools.
- The time spent in preparing the tools should be spread over the crops for which the tool is used.

1.3.3 Indirect costs

We are a few years further on and Umbalio has made an invention: a hoe with a stone head. This allows her to both prepare the soil faster and remove weeds faster, and it also lasts longer. This ensures that she can grow more and therefore more food becomes available. This is shown in figure 1.6.

You can see that because of the larger harvest, the part that Umbalio itself uses has become relatively less.

The hoe is made from a stick and a piece of flint (we're still in prehistory!). To get the flint in the right shape, Umbalio needs help from Gornan, the expert flint cutter of her clan. This is an additional relationship that we must take into account as shown in figure 1.7.

As before, we have to include some of the time Umbalio put into making the hoe in order to figure out the number of work hours for the harvest.

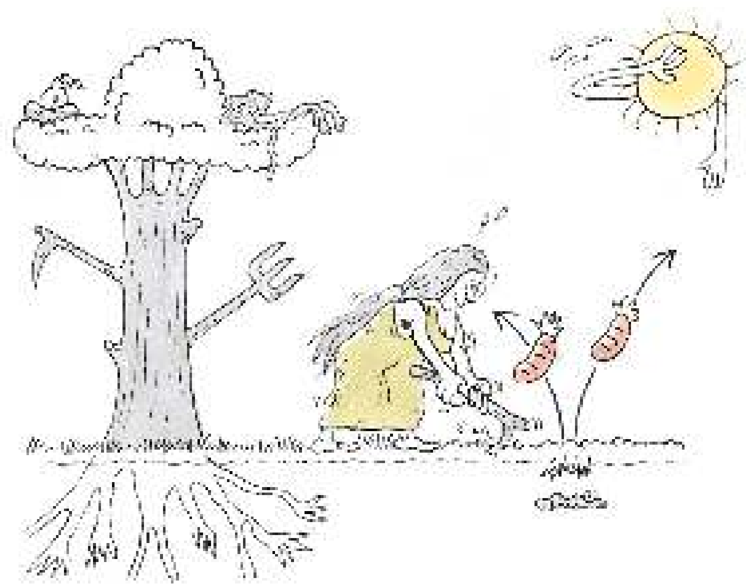
However, a new factor has been added: the time Gornan put into preparing the stone head, including some of the time he took to learn to chop stones.

As long as this indirect cost is not charged, it is an external cost. If it is charged, it is internalized.

We see something else special. Gornan eats part of Umbalio's harvest so that he has energy to make the chop! But even taking that into account, there is going to be more harvest left for the rest of the clan.

Again, we learned new things:

- the right tool increases the efficiency of the farmer.



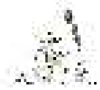


Figure 1.5: A dead stick giving live

- you have to take into account the indirect cost (time or food) required to produce tools.
- as the system becomes more efficient, the discussion of whether consumed crop should be included or not becomes less relevant.

1.3.4 Social costs

We now take a jump in time to the Bronze Age. A great-great-granddaughter of Umbalio (who also happens to be named Umbalio) uses an improved hoe with a bronze head. This was prepared by Borjan, a great-great-grandson of Gornan.

To make bronze, Borjan needs copper and tin ores mined by Kalian and Mapran in an above-ground mine. He also needs clay to make a furnace and wood for the fire.

Kalian and Mapran in turn need shovels and picks. To transport the ores to Borjan, they use a carrying system made of twig baskets and wood.

A classic way of looking at it is shown in Figure 1.8. Doesn't it look fantastic, the technology that man can develop?

With this you can see that the indirect costs of growing the food have increased. More people are needed to make the tools.

But not everything is so rosy. Even in prehistoric times there was an impact on the environment. So the reality is rather like in figure 1.9.

The metallurgy of Borjan creates pollution from soot, CO_2 emissions, ... It consumes wood which depletes nearby forests.

Kalian's and Mapran's mine is causing deforestation of the surrounding area and stone waste. Nature will eventually repair this damage but it will be very slow because fertility must be rebuilt.

These are indirect costs that harm the entire clan and thus are born by all. Again, these costs can be external, i.e. not passed on, or internalized, i.e. included in the price of the product.

We have gained a lot of insights again:

Figure 1.6: Umbalio invents a hoe

Figure 1.7: Umbalio needs Gornan to make a hoe

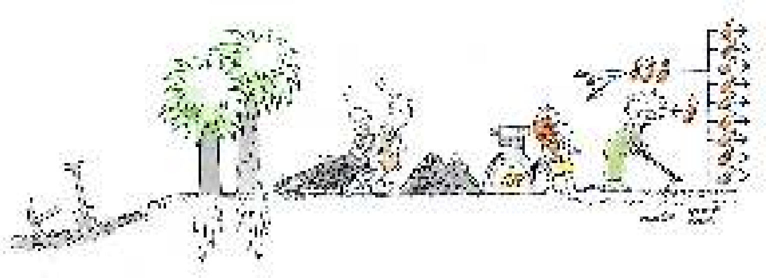
- the more technological things become, the more external factors you need to be able to fulfill the main task.
- transportation lines usually require technology as well.
- certain indirect costs are born by society.

1.3.5 A jump to today

Do you know dance class videos? First they show the basic dance steps, then suddenly, boom, complicated figures are taught that make your mouth drop. Well, we are now also making such a giant leap by looking at today's situation.

Umbalio (yes, yes, the great-great-great-great-…-great-granddaughter of) now drives around in a tractor to work the land (figure 1.10). Cozy, right? Because she believes in the „Green Revolution" she does what is customary in our farming systems. This allows her to produce more per hour she works in the field.

But to be able to do agriculture in this way, she needs some things like fuel, fertilizer and pesticides (figure 1.11a). The tractor and harrow were made in a factory, so that relationship should be included.



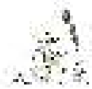


Figure 1.8: More technology requires more input

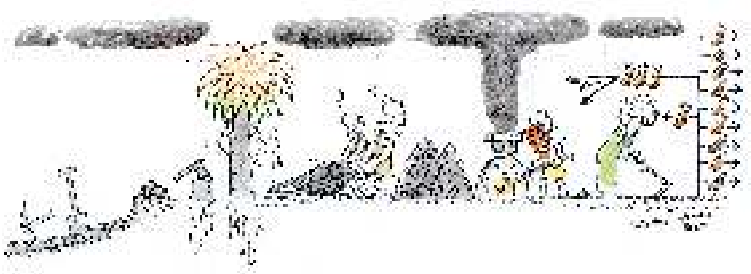


Figure 1.9: The start of environmental pollution

One step further (figure 1.11b) you need iron ore. And building materials to make the factory. The factory itself also uses energy. Fertilizer is made from gas. Pesticides need fossil fuels for production.

But none of this occurs naturally either (Figure 1.11c). You need oil fields and drilling rigs. Refineries must make crude oil usable. Mines provide raw materials. Just about everything needs fossil fuels. And to close the loop, factories and raw materials are needed to build and maintain the oil fields and drilling rigs.

Many relationships involve transportation. There are people everywhere working to make the relationship possible.

You notice, it takes a whole web of dependencies to make sure Umbalio can produce food. If something goes wrong somewhere, the threads unravel.

Throughout this web we also have social costs such as polluted water, CO_2, NO_x, ... (figure 1.12). There are medical expenses. There is waste. There is a need for irrigation. And then we forget a lot of factors.

We clearly see what we have already noted. The more technological your solution becomes, the more you need to be able to perform your main task (in our case: growing food).

You might wonder whether it is all progress because:

- there are more indirect costs.
- there are more social costs. When and by whom will they be paid?
- your system becomes more vulnerable to failures.
- at some point, you run the risk that the social costs will outweigh the benefits society derives from the main task.

After the produce leave the farm it is usually still processed into, for example, flour, jam, preserves, ... This was less so in the past because food was eaten raw or after simple preparations. Now new sectors are emerging such as processing and distribution.

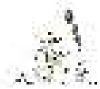


Figure 1.10: Umbalio as a modern peasant

In all these sectors, costs are incurred that are necessary to bring food to our plates.

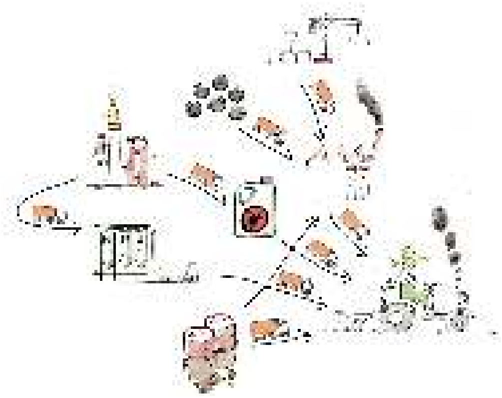
1.4 Is that all?

Now that we have an idea of what it is all about, I give you, dear reader, the choice. Either you stop here and have a grasp of the basics. Or you're hungry for more and can continue reading. What's left on the menu?

- First, a fuller picture of energy consumption is served. This is important because energy consumption is very closely related to the greenhouse effect. This part is mainly about the search for the truth behind the statement „1 calorie of food requires 10 calories of fuel".
  - We will first use an example to gain insight into possible factors at play.
  - Then we will look at the considered studies to see if the above statement holds true.
  - From different farming systems (arable, horticulture, livestock, hunter/gatherer, slash&burn, ...), the energetic efficiency is compared. It will be seen that we then begin to get a totally different picture of the „Green Revolution".
- The title of the paper is about the *costs* of agriculture, not energy. Many people will think of money when they think of costs.
  However, there are many types of costs possible in life. For example, consider the statement that someone has a rich inner life. You can also pay someone in time like in LETS[5] systems.
  A number of social areas such as land use, labor, water, biodiversity, culture, ..., are clearly influenced by agriculture. A overview of these costs are given.
  The question is also raised whether the impact of those factors can be summarized in 1 number, such as Euros.
- What insights do we get when indirect costs are included?

[5] Local Exchange Trading System `https://en.wikipedia.org/wiki/Local_exchange_trading_system`

(a) What Umbalio needs to farm . . .



(b) . . . is more than you think.

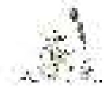
(c) Even much more!!!

Figure 1.11: The complexity of agriculture grows

- To what extent does the inclusion of indirect costs change the narrative of the „Green Revolution”?
- Can this give us an insight how to better manage natural resources?

The studies considered included the entire agricultural sector. So the distinction between organic and non-organic agriculture has not been made. Therefore we cannot compare costs of these systems.

In this treatise, all of this is addressed conceptually. It is possible to use a lot of graphs, statistics and tables. However, this has been kept to a minimum to make the message more manageable. For those who want to see more figures: there is also a technical version of this treatise that contains more figures. This can easily be found on the internet [Sey22].



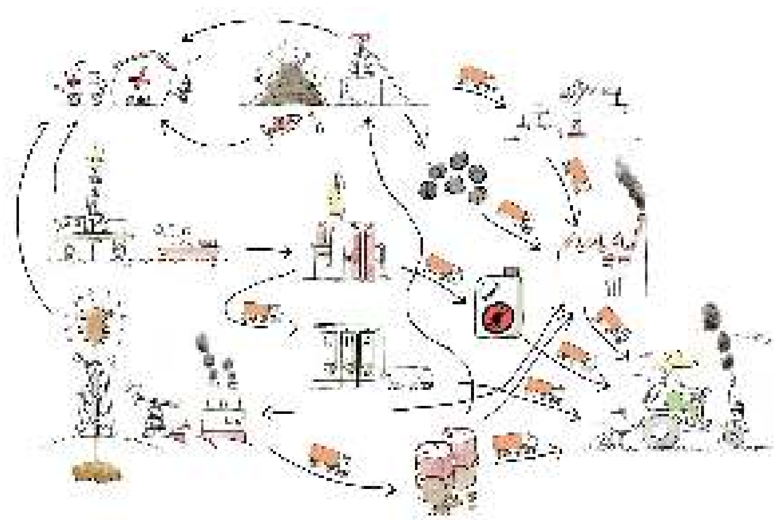


Figure 1.12: The incomplete, polluted, picture

Part II

Energy consumption

Chapter 2
Give us this day our daily bread

To get into it, let's take the example that Leach worked out [Lea76, p. 28] and which we can all relate to: a loaf of bread.

2.1 The view of the farmer

In order to bake a 1 kg loaf of bread, 934 g of grain is needed. Nature gives us a lot of free energy through sunlight, but conventional agriculture gives additional inputs to the grain. In Leach's study, he identifies the following:

- fuel for tractor and other machinery.
- fertilizer.
- chemical pesticides.
- drying of grain.

This requires a total of 4.02 MJ for the given amount of grain.

Let's dwell on this list for a moment. Typically, only the fuel for the tractor and other machinery is included, as well as the fuel required for drying grain.

But fertilizers and pesticides also require fuels. This is consumed in factories to create them, needed for mining (e.g. phosphorus and potash mines for the P and K of fertilizer) but also as a raw material itself (the N of fertilizer is extracted from natural gas). This indirect use of fuels must also be included. In this case, even more indirect fuels are used than direct ones.

A certain amount of energy as a nutritional value can be placed against the energy needed as an input. This is called energy efficiency or also Energy Returned On Energy Invested (EROEI, see also appendix A.3). In this case, there is an EROEI of 10.6[1]:4.02 or 2.64:1. Almost three times as much energy comes out of the bread than is put into it.

2.2 A broader view

But wait a minute, something is not right here. Above, we have as the final product 934 g of grain. That's not bread at all.

So there are additional processes to look at before we can speak of a loaf of bread.

[1] A loaf of 1 kg has a nutritional value of 10.6 MJ.

First, the grain must be milled. This requires energy from the milling process, there is transportation to the mill, the grain and flour must be packaged, the plant and machines must be maintained, you need offices that must be lit, ...

Next, the bread must be baked. The baking process itself requires (a lot of) energy. Besides this, energy is needed again for transport, packaging, maintenance of machines and buildings, ...

Finally, offering a loaf of bread in the store also requires some energy. Once more for maintenance of the building, possibly a refrigerated counter, lighting, ...

Taking all this together, a loaf of 1 kilograms requires 20,7 MJ of energy.

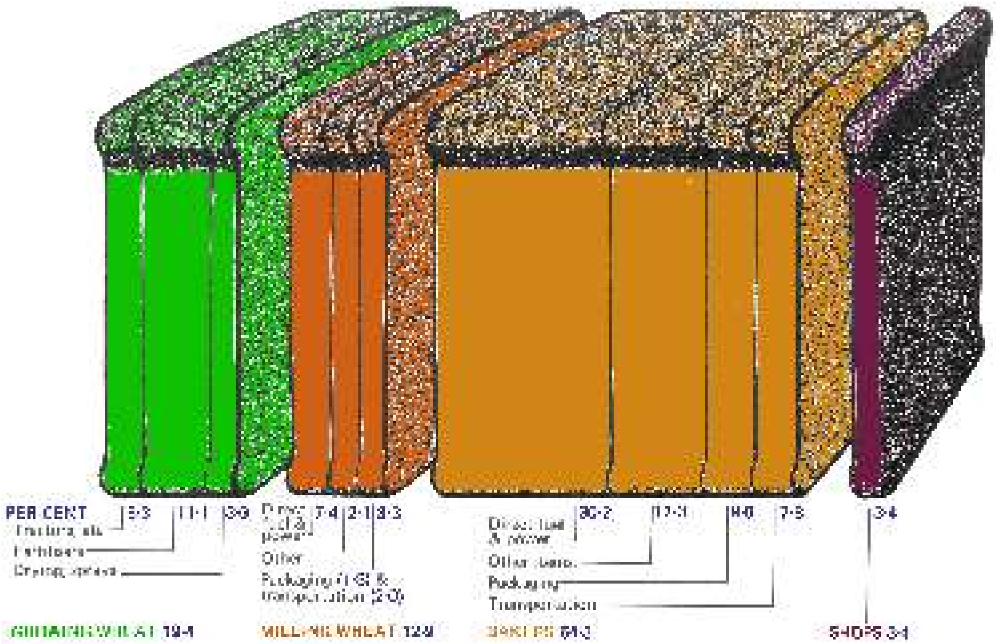


Figure 2.1: Distribution of the energy required by a loaf of bread

Figure 2.1 is a schematic representation of this. The figures are the percentages of energy required for that particular category. So you see that agriculture itself only requires 20% of the entire energy picture.

All in all, bread has an EROEI of 10.6:20.7 or 1:1.9. In other words, almost twice as much energy must be spent to sell a loaf in the store than comes out in nutritional value!

And that's not considering the transportation from the store to home. Leach indicates that if the store is 1 km away and you take the car just to go get a loaf of bread, there is another 8 MJ to be added. Here the EROEI drops even further to 1:2.7. So taking the car instead of going by bike or on foot lowers the energy efficiency from about 1:2 to 1:3!

Now, with a loaf of bread, not everything is said about agriculture and the food system. Let's see what can be found in the studies around energetic inputs.

Chapter 3
Energy use in agriculture

In this chapter we will look at a number of studies to see which factors have been identified as inputs for agriculture [Smi18; Lea76; SS74; LLB84]. More details such as how these figures were determined can be found in the more technical treatise.

We start with Meino Smit's study because it looks at very many factors. He also looked at the evolution of Dutch agriculture between 1950 and 2015 which gives interesting insights.

Next we look at the situation around the 1970s in the United Kingdom and the United States of America. Although these studies are more than half a century old, they remain relevant. As Patrick Whitefield describes it:

> „[...] it's safe to assume that the general picture remains the same. Any increase in mechanical efficiency will have been swallowed up by increases in mechanization, and especially in long-distance transport."

3.1 Dutch agriculture between 1950 and 2015

In the doctoral thesis of Meino Smit [Smi18] 14 factors required for agriculture are considered. These are presented in figure 3.1.

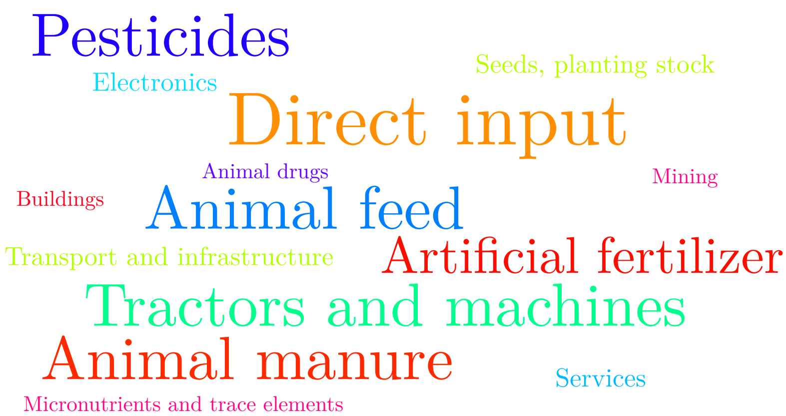


Figure 3.1: Factors of energy input used by Meino Smit

These factors have been estimated by him to the best of his ability, which he succeeded in doing to a greater or lesser extent for the various sectors. How this was done is beyond the scope of this paper but is indicated in the technical counterpart of this treatise.

One factor I do want to highlight is the energy stored in materials. For example, if you take a wall, energy has been required on many levels to create it. To make the brick, you have to mine raw materials such as clay. These must then be transported after which the brick is pressed into a form and baked. For baking and transport, ovens and trucks are needed, and the energy used must also be attributed to the brick. Further is transportation and storage before it arrives at the construction site. Then there is cement used to make the wall, scaffolding and mortar. Adding all this up, along with a few more factors that I'm just losing track of right now, shows how much energy was actually required to make the wall.

Special attention is given by Meino Smit to electronics and mining and how this together makes him not believe in the use of renewable energy at „business as usual". This discussion is summarized in appendix C.

He also mentions that energy and raw materials are strongly linked: you need energy to extract raw materials but you also need raw materials to produce energy (e.g. to produce windmills, transformers, refineries, power lines, ...).

The evolution of the energy input for Dutch agriculture between 1950 and 2015, as determined by Meino Smit, is shown in figure 3.2.

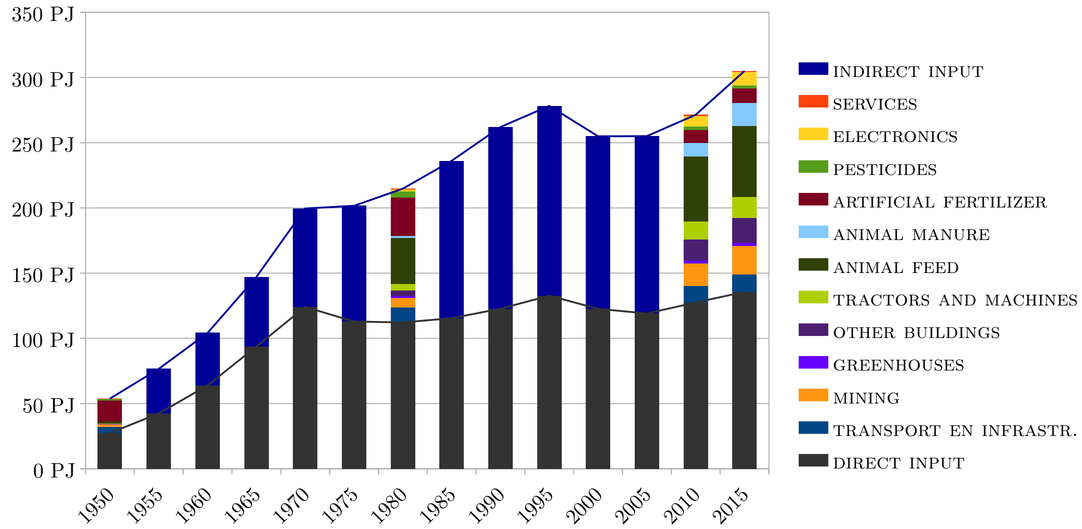


Figure 3.2: Evolution of energy input of Dutch agriculture

The following trends can be seen:

- Direct inputs rise until the early 1970s and then more or less level off. Is this the result of a changing consciousness after the oil crises in that period?
- On the other hand, we see that the indirect input is gaining in importance. Since the 1980s, indirect inputs have actually become larger than direct inputs and this trend has only intensified.
- The proportion of artificial fertilizer has fallen sharply while that of animal manure has risen.
- Animal feed is an important sector among indirect inputs. This is quite apart from it's direct input.
- Mining, buildings and electronics have all increased in share.

To put the values in perspective, the total yearly consumption of electricity in Belgium is around 288 PJ[1]. In other words, Dutch agriculture consumes as much energy as the entire electrical consumption of Belgium!

[1] `https://www.febeg.be/statistieken-elektriciteit`

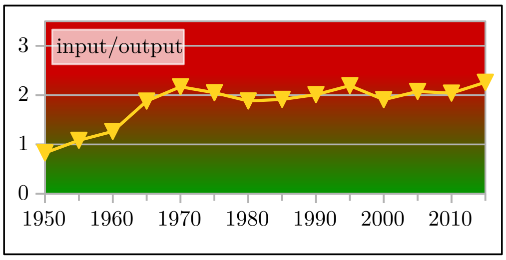


Figure 3.3: Energetic *in*efficiency of Dutch agriculture

Meino Smit also determined the energetic output of agriculture: the amount of food energy contained in the harvested fruits, vegetables, field crops and livestock.

From this, the energy efficiency of Dutch agriculture can be determined. In figure 3.3 the inverse relationship, i.e. the energetic *in*efficiency, is plotted.

It can be seen that in 1950, at the beginning of the industrialization of agriculture, more energy was taken out of agriculture than was put into it. This worsened until it stabilized in the early 1970s. From then on, to produce 1 calorie of food, it takes 2 calories of energy (EROEI of 1:2).

3.2 UK agriculture in the early 1970s

Leach studied the situation of agriculture in the United Kingdom (UK) in the early 1970s [Lea76]. The following factors were considered:

- Direct energy
- Fertilizer
- Machinery, buildings, ...
- Cattle Feed

As with Meino Smit, Leach sees an increase in inputs needed in agriculture as shown in figure 3.4.

Interestingly, Leach draws the parallel with heavy industry. Depending on how many people you allocate to agriculture (only direct or direct+indirect labor), between 150 and 330 GJ/year and per worker is used. This is consistent with heavy industry which uses between 170 and 300 GJ/year per worker. We would never think that agriculture would require as much energy per worker as heavy industry!

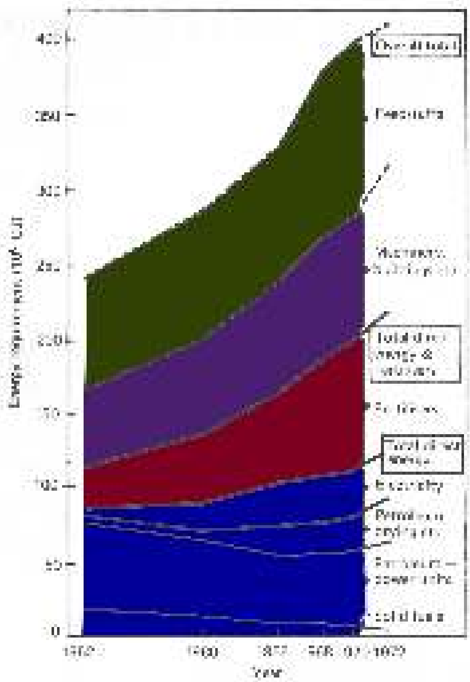


Figure 3.4: Evolution of the energy input of UK agriculture

The EROEI of agriculture in the UK, according to Leach's calculations, fell from 1:2.2 in 1952 to 1:2.9 in 1968. So in 1968 it took 3 calories of energy to produce 1 calorie of food.

Leach sees the reason for this primarily in the use of animal feed. He has found that only 6% of the energetic output of plant agriculture goes directly to the consumer. The rest is all used as livestock feed. At the end of the day, only 12% of the energetic output of agriculture (both plant and animal) is available for human consumption.

Is it bad, however, that so much goes to animals? Leach points out that animals are useful:

- they provide essential nutrients,
- they process agricultural products that humans cannot digest (grass, hay, ...),
- they help maintain soil fertility, and
- they can be used on soils that are otherwise unusable (too wet, too steep, ...). That's about 1/3 of the agricultural area in the UK.

But, too much is too much. Halving meat consumption would make the UK self-sufficient and increase EROEI to 1:1.4. That's quite apart from the health benefits that would occur.

The factor that surprised me is the energy required to dry hay and grain.

3.3 USA agriculture in the early 1970s

Finally, we look at the United States of America (USA) in the early 1970s. For this we use studies by Steinhart and Steinhart ([SS74]) and from Lovins *et al.* ([LLB84]).

From the study by Steinhart and Steinhart, the share of different factors on energy consumption within agriculture are given as in figure 3.5.

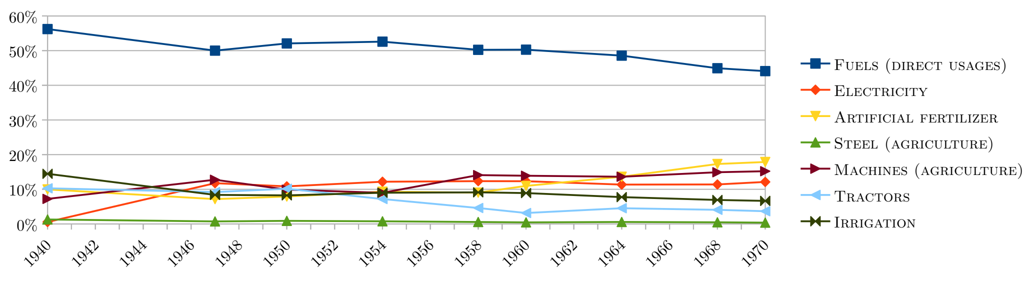


Figure 3.5: Evolution of the energy input of the USA agriculture

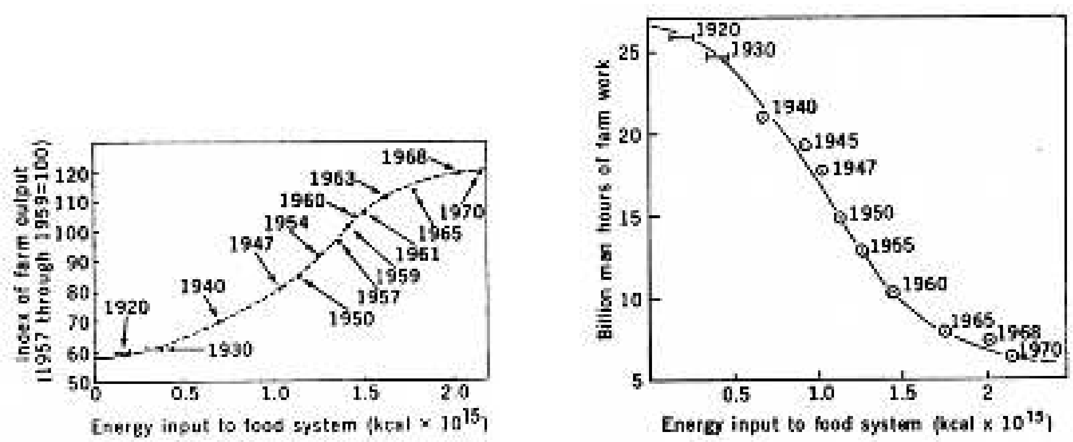
A number of factors such as fuels (direct inputs), fertilizer and steel have been discussed above.

A new factor is irrigation which, as we see, for the USA accounts for 6 to 12% of the agricultural energy budget (pumping and distributing water). This is a factor that did not surface with Leach and Meino Smit. Probably because the Netherlands and the UK are rather wet countries, while in the USA agriculture is done in very dry parts. What we have seen in recent years is that the importance of irrigation is also increasing here. Accordingly, this will also become a bigger part of the energy input of agriculture.

Lovins *et al.* indicate that with irrigation there can be a problem of increased energy requirements. If you pump out more than is naturally replenished, you will have to pump from deeper layers in subsequent years. This requires not only extra energy for pumping, but also for the heavier infrastructure (extraction and production of raw materials). This is quite apart from the ecological impact on the wider environment that pumping from deeper layers has. The need to pump from deeper layers is a trend that we have also noticed in Flanders in recent years. It is important to reverse this as soon as possible.

It is also striking that cattle feed is not included. This is an important part of the energy balance of agriculture in both the Netherlands and the UK. For the reason for this I have but to guess. Have they not considered this? Is the US self-sufficient in feed? The latter is contradicted by Lovins *et al.* who attribute 7% of the energy input to this.

An interesting finding by Steinhart and Steinhart is that they show that the efficiency of additional energy used in agriculture has decreased over time.



(a) Loss of efficiency of agricultural output with increased input

(b) Loss of efficiency in labor hours with increased energy input

Figure 3.6: Loss of efficiency in agriculture

We're getting a little ahead of ourselves here, but let's consider figure 3.6 . The input here is the input to the entire food system (i.e., not just agriculture). The first figure shows that with increased inputs, there was first a sharp increase in the output of agriculture. At the same time, there has been a sharp decline in the labor hours required on the farm. This was obviously due to the industrialization of agriculture (increased use of fertilizers, pesticides and machinery). This increase peaked in the late 1950s. After that, we see that the increase becomes less with increased input until there is a tendency for this to almost level off: additional input gives a much smaller increase in output. In the field of pesticides, Lovins *et al.* indicate that there is even a negative trend: in 1948, 7% of the crop was lost to insects. In the early 1980s, 6 times as many pesticides were used, but 13% of the crop was lost to insects.

We see something similar in figure 3.3 where you see that there was a decline in the efficiency of Dutch agriculture between 1950 and 1970 after which the efficiency leveled off. In other words, putting an extra MJ into agriculture had twice the effect in 1950 than it did after 1970.

The EROEI of agriculture in the USA is estimated to be 1:2.2. This is comparable to the Netherlands and better than the UK.

3.4 Conclusion

It is clear that there are very many factors to consider in order to know the full cost of agriculture.

Just looking at the directly consumed energy does not give the full picture. Especially since we see that the indirect energy needed for agriculture has become greater than the direct energy.

Factors that I personally found remarkable were animal feed, mining, electronics, drying and irrigation. It is also striking that the contribution of artificial fertilizer in the Netherlands has decreased enormously in recent decades.

What is also striking is that until the 1970s there was a huge increase in inputs that went hand in hand with a decline in energy efficiency. The increase in input then continued to grow more slowly, while the efficiency stabilized. All in all, we see that more and more energy is being pumped into agriculture, but that yields do not follow suit.

We actually consume more energy in agriculture than we produce. In the Netherlands by a factor of two, in the UK even by a factor of three. Since food is a basic need, it is temporarily justifiable to pump more energy into it than you get out of it. But that is not a strategy that can be sustained over the long term. What do you do when energy becomes scarce? This can be due not only to depletion of oil wells but also to geopolitical situations where the supply of energy stagnates[2]. It is therefore important for the stability of a country to strive for an energy efficient agriculture, taking into account all the factors that have an influence. It is a pity that this is not recognized today and therefore we continue on a path of increasing energy dependence.

Lovins *et al.* provide an explanation for why we continue to move down a path that is clearly going in the wrong direction:

1. capital accumulation has grown gradually and has now become so large that it is difficult to switch. If you have already invested in larger machinery, stables, . . . it's difficult to phase them out. Especially if the loans for these investments are not payed off.

2. At first there was a positive effect of the use of fertilizers and pesticides. However, this effect is now much less but this reduction has not really been noticed. Only the „hurrah" story of the early years has stuck.

3. The power of agribusiness. Here we should not draw a picture.

4. With the replacement of muscle power by mechanization, it has now become difficult to make the reverse. First, there are far fewer people working in agriculture so there is less muscle power. In fact, the use of animal muscle power has all but disappeared. On top of that, the direct energy required has also increased over time. This means that there should be more people and animals working in agriculture compared to the era before the industrialization of agriculture.

[2] That this is not an unlikely scenario has been seen in the 1970s with the oil crisis, in the 1990s in Cuba ([Mor06]) and today with the war in Ukraine.

The EROEI we find here is between 1:2 and 1:3 for the most recent decades. Those are values to worry about, but not the 1:10 ratio that Whitefield cites. But Whitefield also says the following about this:

> Most of the ecological impact of food is generated in transport, processing and retailing, not on the farm.

The example of the loaf of bread showed agriculture responsible for only 20% of the energy input. So it is important to look at what happens to food after it leaves the farm.

Chapter 4
Energy use of the food chain

4.1 From the farm and the table

Between the farm and the dining table there are roughly 3 steps:

- food processing.
  This include pressing to juice, making sausages, grinding grain, preparing lasagna, canning or glassing, ... The list is very long.

- selling food.
  Also known as the distribution sector. This is where food is transported, stored, and sold in stores.

- usage of food.
  This takes place in households, restaurants, ... In the example of a loaf of bread, we have seen an extreme situation where transportation between the store and home adds almost 50% extra energy. But there are more factors at play.

4.1.1 Processing

Of course there is transport between the farm and processing facilities. Products are also shipped between facilities (e.g., the flour to the baker).

But the energetic input does not stop here.

- You have the actual processing (milling, baking, cooking, drying, steaming, pressing, freeze drying, . . .).

- Energy is also needed to make and maintain buildings and machines.

- What is striking is that the energy costs of packaging are rather high. For canned goods in particular, the energy required is as high as 25% of the energy needed for processing!

The picture becomes somewhat more difficult because you also have to take into account residual flows from processing that go to agriculture, usually in the form of animal feed. Some of it is also destined directly for export and therefore does not need to be included.

4.1.2 Distribution

As can be expected, most of the energy (about half) is due to transportation. Further energy is needed for storage (buildings and refrigeration), packaging (e.g. washing bins or repackaging as a private label), heating of offices and warehouses, building and maintenance fo retail buildings.

4.1.3 Consumption

What struck me very hard is that the refrigeration needed to keep food and cooking requires so much energy. Together with the energy needed to make appliances like refrigerators, kitchen robots, microwave ovens and the infrastructure like a kitchen or storage room, we have to count an extra 30% to 40% on top of the energy needed in the chain up to that point!

4.1.4 Food losses

This explains why it is so important to minimize food losses. If, for example, at the end of the chain half a jar of ravioli is thrown in the garbage, this is not only a loss of ravioli itself, but also of all the energy that has been put into it up to that point, from the farmer to the processor, driver and retailer.

Leach outlines the types of food loss he sees:

1. losses inherent in the process. These are, for example, harvest losses.
2. losses that are unavoidable. For example, the weight of eggs includes the eggshell which, however, cannot be consumed.
3. losses that are typical. For example, the peels of vegetables that are not used.
4. losses due to carelessness. For example, discarded meals.

The first three types are usually included in studies.

Unavoidable and typical losses can only be dealt with if new outlets are created. Consider, for example, the rise of mushroom cultivation on coffee grounds or the use of cocoa shells as a ground cover. Ideas for this can certainly be drawn from the past where every part of an animal was used. This ranged from using the skin in clothing (leather), hair in brushes (shaving brushes made of pig hair) or construction (horse hair in mud walls) over eating organ meat to bone glue.

We can reduce the other two loss factors much faster and more actively. This is such an important topic that the FAO has even devoted a complete study to it [FAO14].

4.2 Overview of costs

How do all these costs in the food chain relate to each other? Below we present this as given by a number of studies.

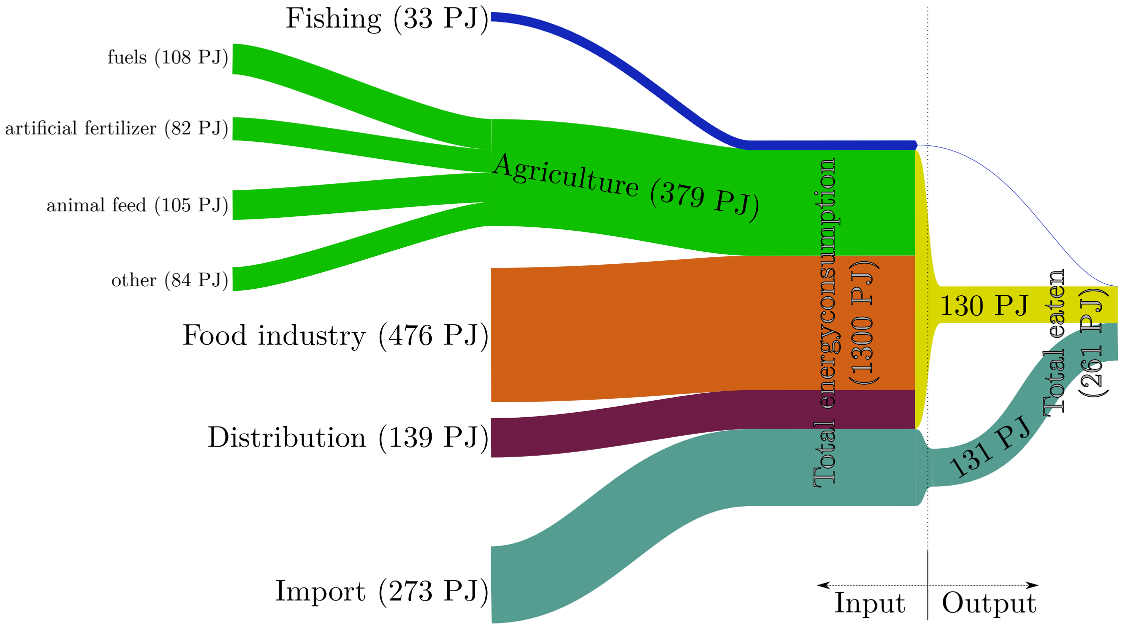


Figure 4.1: Energy flows in the food chain (UK 1968, [Lea76, fig. 9])

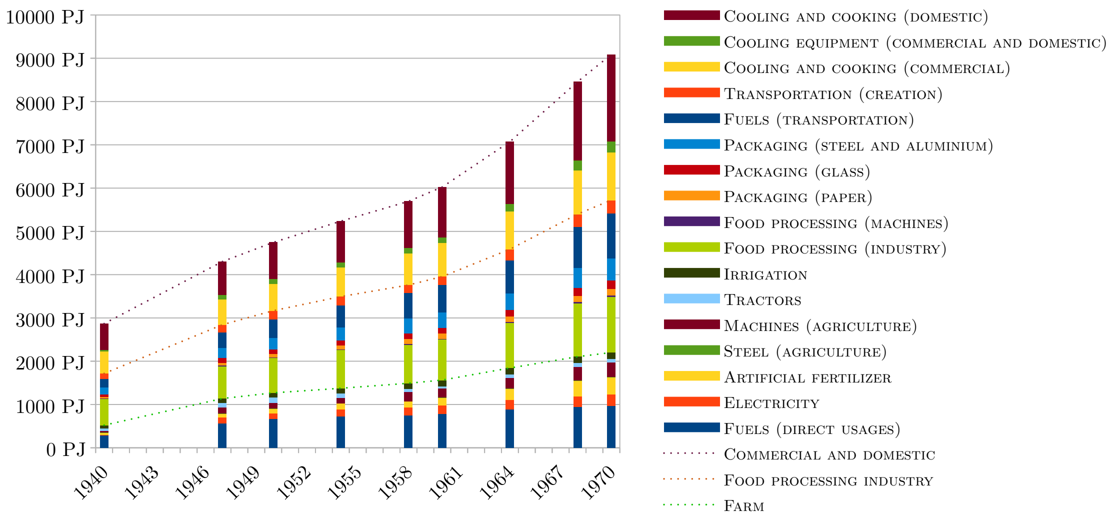


Figure 4.2: Energetic inputs to the food chain (USA 1940-1970, [SS74])

In the study of Leach (figure 4.1) we see that agriculture contributes about 33% of the energy of the food chain. If the consumption at home and in restaurants is also taken into account, this drops to about 20%.

It is quite clear that processing requires the largest energy input in the entire food chain.

We see something similar with Steinhart and Steinhart (figure 4.2). Here agriculture has a share of 25% and processing a share of 40%. The large share of cooling and cooking at home is also evident (about 22% of total energy consumption).

If energy use in the food chain is to come down, it is clear where the biggest gains can be found:

- a chain that is as short as possible so that the impact of processing is reduced. This will mean a shift to more individual transport and cooking. But we gain energy because a lot of packaging is eliminated (10% of total energy consumption) and because things do not have to be kept in a refrigerator as long.

Consider, for example, the ravioli from above. It first has to be prepared in a factory, is served in an aluminum dish, has to be cooled all the time (both in the store and at home) and then reheated at home. If we prepare it at home directly from lasagna leaves and fresh products, I think it will require much less energy and be more nutritious and tasty.

- it will be an always recurring remark, but reducing meat consumption also has a large impact on energy consumption. In paragraph 3.2 we already saw that much of what agriculture produces goes to livestock. Also, animal products need extra care to limit possible diseases. This all requires extra energy.
- Ensure that as little as possible is lost in the chain. It is estimated that 30% of all products are lost somewhere in the chain. If we can avoid this, we will gain a lot of efficiency.

4.3 Eureka

Now that we have the entire food chain in view, we can take another look at the energy efficiency.

Figure 4.1 shows that an input of 1 300 PJ and an output of 130 or 261 PJ, depending on whether you include the consumed imports or not. With the first value of 130 PJ, which is the most cited in Leach's study, the EROEI is 1:10.

The more technical counterpart of this paper looks at these numbers in even more detail by taking into account imports, exports and energy use at home. Depending on the scenario that is taken, I then arrive at an EROEI between 1:7 and 1:12.

In the studies for the USA, the EROEI for the food chain is 1:9.

These are values for the late 1960s, early 1970s. As Whitefield points out and we can infer from Meino Smit's study[1], this ratio will not have changed much since the 1970s.

So the meme that „1 calorie of food requires 10 calories of input" is certainly valid. Eureka.

4.4 What does this mean for agriculture?

If the goal is to have an energy neutral food system, it is clear that agriculture cannot suffice with an EROEI of 1:1. The rest of the food chain will also require energy, on top of that of agriculture.

We have seen above that agriculture gives an energetic contribution of 25 to 33% to the total food chain. A fair effort from agriculture indicates that its EROEI should be between 4:1 and 3:1 in order to give a neutral food system.

However, we have seen that the EROEI of agriculture is currently between 1:3 and 1:2. Thus, it is not even possible to establish an energy-neutral food system with the currently prevailing agriculture.

Analogously, we can see that the rest of the food chain has an EROEI that is not sustainable. As a result, it is not possible for agriculture to absorb this, no matter how large the EROEI.

[1] In figure 3.3 we see that the EROEI in agriculture itself has stabilized since the early 1970s. It is likely that the same will be true for the entire food chain.

Every part of the food chain must be sustainable for the entire chain to be sustainable. This is a clear case where the chain is only as weak as the weakest link. And currently all the links are broken.

Where does this poor relationship come from? Is there a difference between the different sectors such as livestock versus arable farming? Are there other farming systems known and what is their energy ratio?

4.5 Conclusion

Figure 4.3 provides an overview of the various identified factors that influence energy consumption in the food chain.

Figure 4.3: Wordcloud of the factors considered in energy.

Agriculture is only one part of the food chain and not even the one that requires the most energy. That honor is reserved for processing.

The impact of packaging, drying, irrigation and households was a big surprise to me. The impact of livestock production was expected.

Further, it made me think a lot about the use of raw materials and electronics. This has made me more cautious about technical solutions in agriculture. This is surprising because I come from a very technical background (master in physics and also working as an IT professional for a long time). I don't want to write off technology but will definitely think twice about it.

It has also been found that the meme that triggered this treatise holds true. Indeed, you can consider that, in the current system, it takes 10 calories of fossil fuels to consume 1 calorie of food. This is not a sustainable situation.

So the search is on for an agricultural system that will turn this ratio on its head. Can we indeed find a system that yields 3 to 5 times more energy than is put into it? Fortunately, the studies are already providing some pointers.

Chapter 5
There is agriculture and there is agriculture

5.1 Comparing farming systems

Both Leach and Steinhart and Steinhart compared the energy efficiency of different farming systems. The results can be found in figures 5.1 and 5.2.

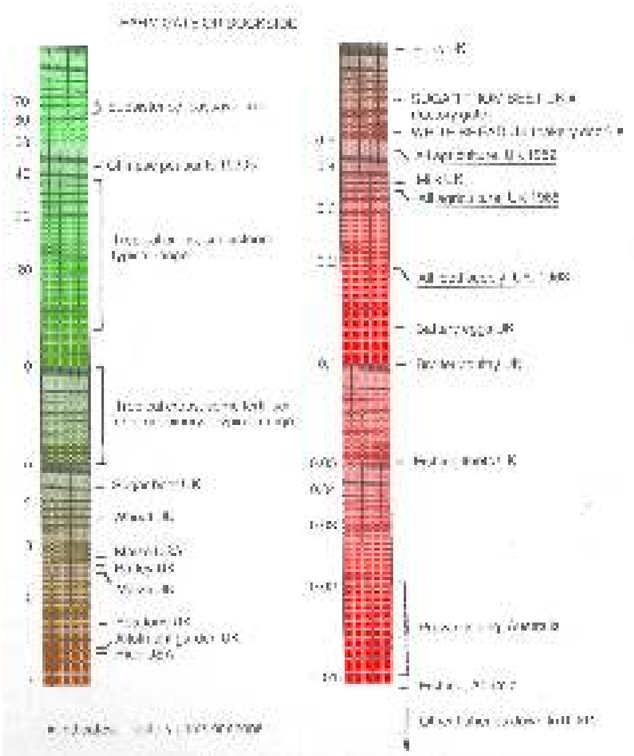


Figure 5.1: Energy efficiency of different farming systems ([Lea76, fig.1])

The first figure shows the EROEI of the systems, the second the inverse relationship. To make this clearer, I have colored the backgrounds: the greener, the more efficient the system is.

What is striking is that the more modern systems do much worse than the old farming systems. For example, you can see in figure 5.2 that cow farming on a prairie („range-fed beef”) has a ratio of 2:1. More intense is the system that was used here in Europe: pastures with arable crops to feed the cattle („grass-fed beef”). The EROEI now drops to about 1:3. Intense livestock production has an

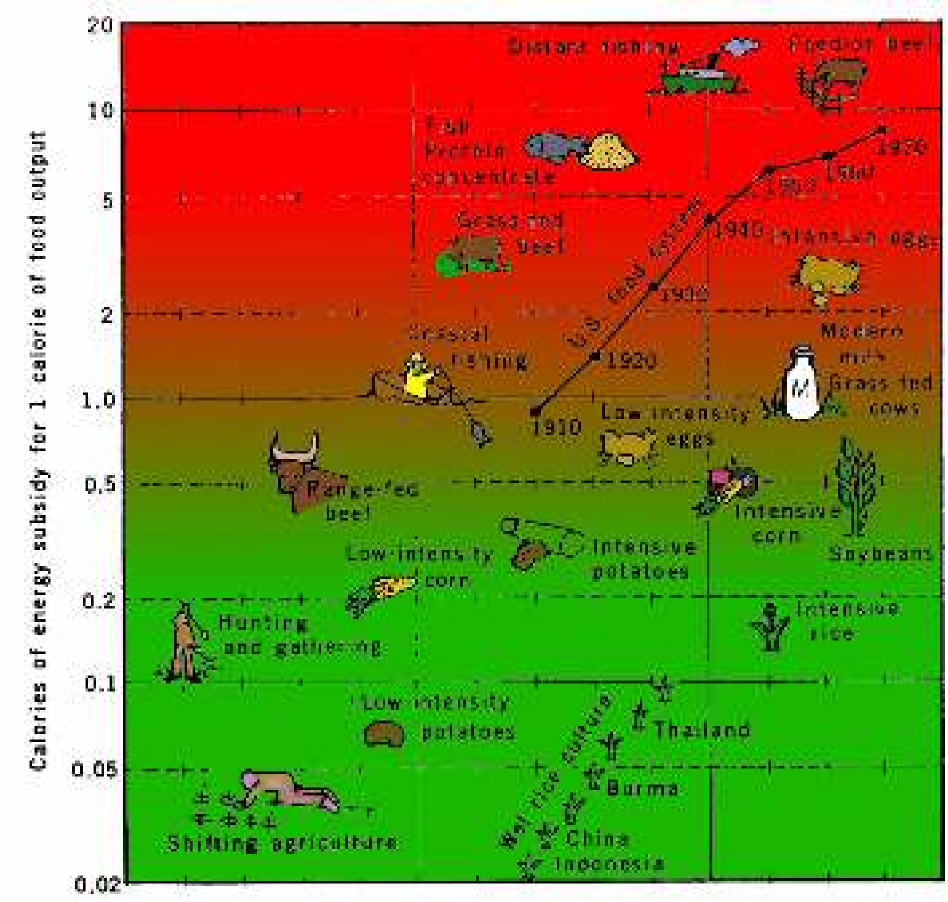


Figure 5.2: Energetic *in*efficiency of different farming systems ([SS74, fig. 5])

even worse ratio of about 1:11 („feedlot beef"). Something similar can be seen for chicken, potatoes and rice.

It is also striking that fishing scores so poorly. This has mainly to do with the distances fishing boats have to travel to have a full hold. Because larger boats have to travel much longer, Leach has found that they score worse which seems counter-intuitive in our system of „the bigger, the better".

Finally, it is worth noting that of the modern farming systems, only arable and livestock systems were considered. Fruit and vegetable farming is not included here. My expectation is that these are between arable and livestock systems.

Leach's work suggests that the more energy comes from muscle power (human or animal), the better the EROEI. Also, on mixed farms, the EROEI drops as animals contribute more to the energetic output. As an explanation, he sees the following:

- if you keep animals, much of the harvest of the system goes to the animals rather than to human consumption.

- with mechanization, the proportion of indirect energy needed for the system grows. This is something that Meino Smit has also demonstrated for Dutch agriculture.

The inset in figure 5.2 shows the evolution of the inverse EROEI of the food system in the USA. It can be clearly seen that it gets worse as the years go by and was at an EROEI of 1:9 in 1970.

These studies were done in the 1970s. We have already mentioned above that the conclusions drawn then are in all likelihood still valid today.

5.2 Separating the wheat from the chaff

It is interesting to look now, based on the figures, at which farming systems can feed the population in a way that does not deplete natural resources. From the studies, we can only say something about energy and land use. Of course, many other aspects, such as water, air pollution or working conditions are also important. But due to lack of data on these aspects in the reviewed studies, they are not covered here.

5.2.1 On the basis of energy efficiency

It has been indicated above that the energetic efficiency of an agricultural system must be better than 3:1 or 4:1 in order for the entire food system to be energy neutral. Which modern farming systems are above 3:1?

From the study of Leach, we see that only growing sugar beet and grains meet this. It is notable that no animal products have a ratio above 1:1.

Looking at Steinhart and Steinhart, we see that potatoes (both intense and low intense), low intense corn, and rice (both intense and low intense) are above 3:1 (note: figure 5.2 shows the inverse ratio and then again in a logarithmic scale!). Soybeans are about on the borderline. Here we must take into account that rice is a tropical grain where a lot of energy comes through the sun and heat and a lot of water is needed, so not suitable for our context. Also, low intensity crops are still hardly practiced.

So the modern farming systems and the food chain in our western world is not capable of feeding the population in a sustainable way. They require more energy than what can be extracted.

If we look at older farming systems, it is noticeable that many of them overwhelmingly achieve the required energy efficiency. The hunter/gatherer, rotational crops of the past but also well maintained slash-and-burn systems have efficiencies in excess of 4:1. Of course, we have to remove from the list the systems that are only possible in the tropics and sub-tropics, because they cannot thrive in our temperate climate.

Leach emphasizes 2 systems that he believes are outliers:

vegetable gardens (allotment gardens) These have an energy efficiency that is surprisingly good. Not good enough but that, according to Leach, is due to the use of fertilizers and the choice of low energy crops such as lettuce. He also refers to the successful use of allotment gardens during World War II („Victory Gardens”).

chinese agriculture in 1930 This system is described in detail in [Kin11]. It is about farmers who achieve very high production on small pieces of land. The success here is due to the high use of organic fertilizers, a very intense vegetation (pre- and post-crop, combination crops) and a very intense succession of crops. This is similar to what Charles Hervé-Gruyer writes about Parisian farmers in the 19th century [HG18].

5.2.2 Based on land use

If we want to feed the population, agriculture must produce enough energy from the available agricultural area.

As humans, we need about 4 GJ of energy per year[1]. In Belgium, about 0.13 ha of agricultural land is available per person[2]. We only count the direct available land because the goal is to have a self-sustaining agriculture. This means that each hectare should be able to feed about 7.8 people and thus produce about 30 GJ/year. If we only take Flanders, then the figures are 0.10 ha/inhabitant and 40 GJ/year.

Leach's figures show that of the modern farming systems this is only achieved in arable systems[3]. Systems with animal products do not reach this value[4]. Of course, one could argue that modern, non-land-based, industrial livestock production can achieve this. The problem, however, is that, as we have seen with Meino Smit, these require a large indirect energetic input (and, as we shall see later, land use as well). If you include everything, it is very questionable whether they would still make it.

The very worst score is for the hunter/gatherer. To feed 1 person, no less than 13. km^2 is required. That's about the area of Kessel-Lo!

The two systems highlighted above are not doing badly at all:

vegetable gardens These can feed about 15 people per hectare.

chinese agriculture in 1930 This is really the topper. The annual yield here is 280 GJ/ha which is enough to feed 70 people. No system discussed by Leach even comes close to this result!

5.2.3 Additional caveats

5.2.3.1 Food Security

In many historical systems, little food was stored. A disappointing catch or harvest had an immediate impact[5]. It was important for our region to avoid lean periods such as winter or the beginning of spring (the „Hunger Gap"). We can do this by growing crops whose consumption can be delayed. This is either because they can be stored for a long time (tuber and root crops, cereals, cabbages) or because the slaughter can be staggered.

5.2.3.2 Social status

So you would think that a system like the one in ancient China would be ideal. However, if you read King's account, it seeps in that the farmers were at the bottom of the social ladder. Also, the intensity of this system required many farmers. An

[1]This corresponds to 11 MJ/day or about 2 500 kcal/day

[2]There is about 1 400 000 ha of agricultural land for a population of about 11 million inhabitants.

[3]Since horticulture is not included, it is not clear whether it would meet this requirement.

[4]The best animal farming system is a large mixed dairy farm with an output of 22 GJ/ha

[5]The question is, of course, whether we are better off today. It is said that there is only a 3-day supply available if all import or transport is lost. Whether this is really true we will leave to one side, but it is clear that a situation such as a lockdown or war immediately causes panic. So there is not much confidence in the self-sufficiency of the food chain.

average plot was 0.25 ha! So it took a very large number of farmers to feed the population. As you can calculate, there was 1 farmer for every 17 inhabitants.

If we want to introduce such a system here, it is necessary to encourage many people to go back into farming. That social position and prestige of farmers improve will be an important factor for this.

5.3 Conclusion

It is striking how much difference there is between different farming systems. So just looking at the average of a country hides very much.

We now have two criteria that an agricultural system must meet in order to achieve an energy neutral food system on the one hand (EROEI above 3:1) and on the other hand to ensure that we can be self-sufficient (yield above 30 GJ per year and per hectare).

No viewed system with animal production meets any of these conditions!

Some arable systems meet both conditions but provide a rather one-sided diet of grains and sugar. Because horticultural systems were not included in the studies, it is not clear whether they can meet the conditions.

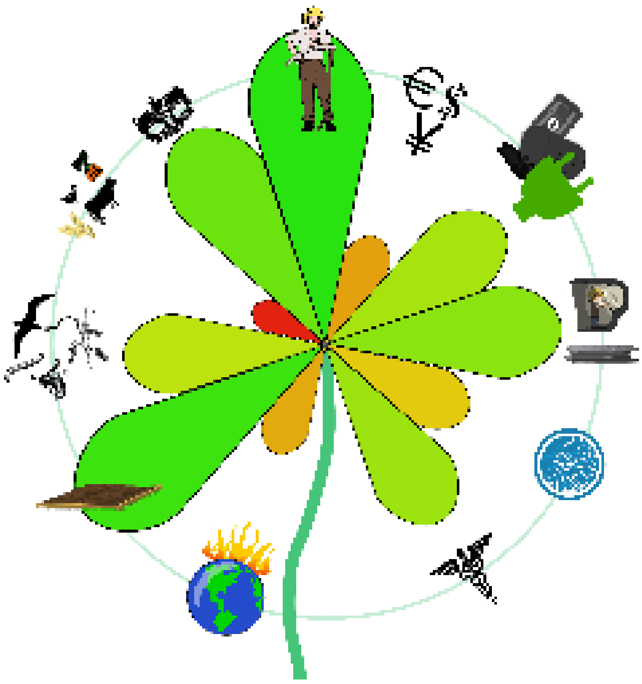
Going back to older systems such as hunter/gatherer is not feasible with current population densities.

What is a good basis, however, is starting from systems such as allotment gardens and Chinese agriculture. These are already good, or even excellent, at filling the energetic needs.

Of course, life does not consist only of energy. There is also a need for water, space, people, air, fun, ... In the next section we will look at the impact of agriculture on this.

Part III

Life is more than just energy



Chapter 6
Water in all colors of the rainbow

Water. It is a miraculous substance. In chemistry, it occupies a prominent role. In the quest for extraterrestrial life, it is considered an indispensable element[1]. Even outside of hard science it is considered a miraculous substance as in homeopathic dilutions or Emoto's ice crystals. And yet we treat it so carelessly.

Within agriculture there is a need for just enough water. But how much is the impact of agriculture outside the field taken into account? For example, declining groundwater levels may be caused by overuse within agriculture.

Water costs are viewed from a standpoint of scarcity. Excess water can also cause problems such as erosion or loss of soil life. However, these are considered different costs.

Blue water, green water? Gray water, black water? Heavy water, light water? What is all that?

Half of these are concepts used in looking at the water footprint. The water footprint is a concept analogous to the ecological footprint, the carbon footprint, ... [HH02, p. 15].

Now, not every type of used water is equivalent. It is important to distinguish between them in order to get, on the one hand, a full picture on the impact of humanity on the water, and on the other hand because you get absurd numbers otherwise.

The terms blue water and green water were introduced in 1995 by Malin Falkenmark [Fal95]. Gray water was introduced as a concept in 2006 by Chapagain, at that time called dilution water [Cha+06].

A good introduction can be found in section 3.1 of „The Water Footprint Manual" [Hoe+11].

6.1 Blue water

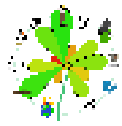
Blue water, simply put, is flowing water. It is the liquid water in rivers and under the ground (aquifers).

The blue water footprint is the use of it by humans. Think drinking water, showers, irrigation, ...

Consumption of blue water has until recently been the main focus around water consumption.

[1]It would not surprise me, however, if one day life forms were discovered that did not need water. Nature is much more resourceful than our minds can conceive!

6.2 Green water



It was only in the late 1990s and early this century that people began to realize that the water in the unsaturated layer of soil, which can be used by plants, can play an important factor in the overall water management. This water is called green water.

The green water footprint is the portion of the green water that is used. Most of it evaporates through plant transpiration or evaporation (collectively called evapotranspiration). A small portion of it is used by plants to grow and propagate.

6.3 Gray water

Gray water is meant to indicate the degree of pollution. It does not directly correspond to physical water unlike blue and green water.

Let's keep its definition as simple as possible: gray water is the amount of water needed to bring pollution below the acceptable standard.

An example. Imagine 5 liters of water. Let it contain 2% of a toxic substance. However, the acceptable standard is only 0.2% of that substance. Then to get the dilution 10 times smaller, the total volume of water must become 50 liters. So we would have to add 45 liters of water to get the contamination below the standard. Those 45 virtual liters is the value of the gray water.

6.4 Black water, heavy water and light water

These terms have nothing to do with water management. They do sound good though, don't they?

For the fans:

- black water is water contaminated with feces (e.g., from toilets).
- Heavy water and light water are terms from nuclear physics.

6.5 Cow 42 is thirsty . . .

Do you remember that on page 2 the statement was made that 15 000 l of water is needed for 1 kg of beef? You can find that out for example on VLEES.NL[2]. For a two-year-old cow, this amounts to about 10 000 l per day. A cow doesn't drink nearly as much[3]!

Now it turns out that of those 15 000 l, the vast majority is green water because cow 42 is allowed to graze happily on the pasture for a long time. For that pasture, the evapotranspiration is counted as green water footprint.

You may then wonder if that green water footprint is bad. That's a very good question. As long as there is enough rainfall, I don't think the green water footprint plays a decisive role. It's only when there is too little rainfall that water evaporation and transpiration becomes important.

[2] `https://www.vlees.nl/themas/milieu-techniek/footprint-water/`

[3] This is also the main argument from people who regard the water footprint as a popular hoax to shove an ecological dictatorship down our throats.

For blue and gray water footprint, there is more consensus that they play a role in sustainability.

6.6 ... and nuts have a problem

Let's take the values found on VLEES.NL and plot the blue and gray water footprint for different produce (figure 6.1). This yields a surprising result.

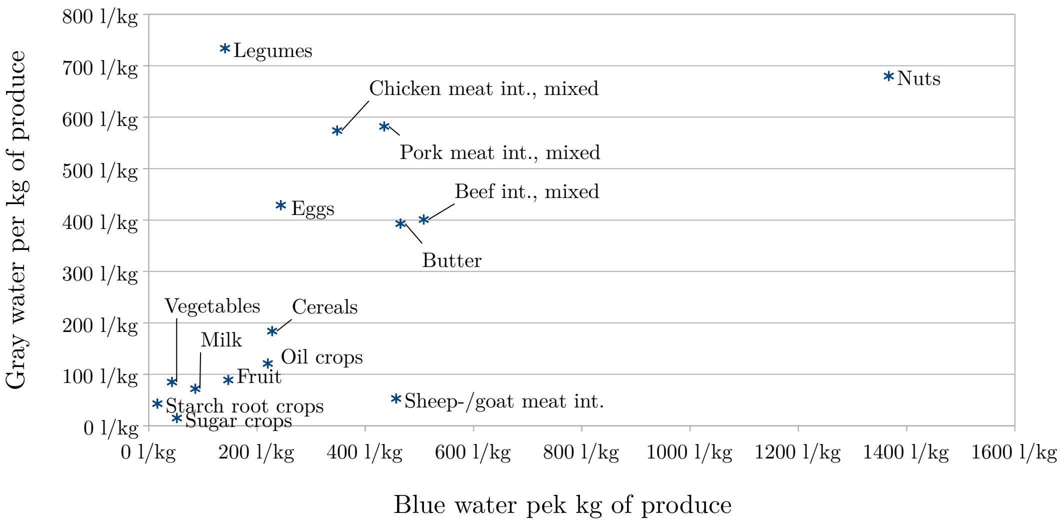


Figure 6.1: Blue versus gray water footprint for different agricultural products

You'll notice that, without taking into account the green water footprint, animal products generally score worste than plant-based products.

The big surprise, however, are nuts. You can see them there at the very top right (the „bad" corner). This is mainly due to irrigation and crop protection products. It is claimed that 1 almond nut corresponds to 10 liters of water! And research shows this to be not far from the truth, especially during dry years in California (where a significant portion of almond nuts are grown).

6.7 My problem with all those colors of water

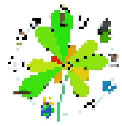
At first glance, the split into different forms of water use is a good thing. It gives more nuance to the debate. But I do have a number of problems with the way it is handled[4].

6.7.1 The water footprint is too simplistic

The water footprint is expressed as a single number where everything adds up equally. So a liter of blue water is equated to a liter of gray water. Like the proponents of the water footprint, I am in favor of always explicitly naming the different colors of water. However, it's only human to want to lump everything together under one value, losing (important) nuance.

[4]There is also criticism of this approach within the scientific community. Some of this criticism and its refutation can be found on the website of the Water Footprint Network and in [HFP18].

Why do even the proponents of the water footprint do the same? Although they don't say why they suddenly leave the nuance behind, they justify the 1-to-1 addition by arguing that working with weights gives a subjective assessment of the colors to water. I find this an odd argument because implicitly they are using a subjective assessment where all forms of water use are considered equal.



6.7.2 The water footprint tells nothing about the sustainability of a product

You notice that the water footprint is used to compare products. „Your meat burger has a bigger water footprint than my nut burger. Shame on you, how dare you burden the environment like that."

On the one hand, this is linked to the criticism above ("the water footprint is too simplistic"). On the other hand, I think it is also because the concepts of gray and green water have some caveats. These caveats are not present with blue water because that is clearly linked to a physical reality on the one hand and a tangible process involved[5].

6.7.2.1 Gray water is virtual water

As you saw in the definition of gray water, this value depends on legal standards. These standards change over time.

This means that, for example, the nuts above have a relatively high gray water footprint. But if the legislation changes, they suddenly have a different gray water footprint. The real impact on the environment hasn't changed however!

6.7.2.2 A green water footprint is not always bad

In the water cycle, the great water cycle is well known. This is the cycle where water evaporates from the sea, passes over the land as clouds, precipitates and then flows back to the sea.

During the course of the Landwijzer training, we also learned about the small water cycle. This involves forests evaporating water which causes water to precipitate further inland. If you break this small water cycle, then there is an increased chance of desertification further from the sea.

It is the restoration of the small water cycle that explains the successes in various places in the world where trees have been planted again, resulting in the restoration of rivers and streams. This made plots of land downstream more humid, which in turn made agriculture possible. Think for example of the successes filmed by John D. Liu or the work of Geoff Lawton.

Here in Flanders, on the other hand, one is familiar with the usage of trees to make fields drier. Whether this is still desirable I will not say, but clearly the evapotranspiration has the reverse effect as described above.

In both examples there is a high green water footprint. In one case, the water supply is replenished in an indirect way. In the other, the groundwater table is lowered. So it is clear that the consequences of a high green water footprint are not unambiguous. It depends a lot on the local situation: is there a surplus of precipitation or not.

[5] Every drop of blue water used is measurable and lost to natural water cycles.

6.7.3 Focusing on water footprint can promote unnatural systems

When comparing the water footprint of different types of livestock farming, it was noticed that for cattle, industrial systems have a lower water footprint than systems where cows are allowed to graze freely.

This has to do with the following factors [GMH13]:

- cows are quite inefficient at converting food into meat.
- In an industrial system, food is converted into meat more efficiently. This is due to the following factors:
  - the animals are bred for efficient conversion of food into meat.
  - the animals can move less so they grow faster for the same amount of food.
  - the animals are consequently slaughtered at a younger age which means they require less feed.
- on the other hand, in an industrial system, more concentrated feed is used. Concentrated feed requires more water per kg dry weight. This can be reduced by using scrap and other residual streams.

When you take all factors into account, industrial systems come out better than free grazing. So this leads to a water footprint for industrial livestock which scores better than more natural systems.

In vegetable farming, we can do similar calculations and see that a system such as „Vertical Farming" requires little external water because it recycles a lot.

So you notice that the further away from natural processes one goes, the better the water footprint seems to become. However, to what extent is the impact of the system itself (e.g. concrete, production of recycling salts, production of electronics, . . .) included? If this is not done, apples and oranges are compared.

6.8 Can the indication of water footprint be improved?

A way to make the different uses of water visible is, in my opinion, a good thing. To reduce the problems cited above, a number of adjustments can be made. These are certainly not exhaustive but can provide an impetus for improvements.

- Determine the green water footprint based on the surplus the system has. If a system has a surplus of water, evapotranspiration is less of an issue. However, if the system lacks water, we want to store as much water in the ground as possible.
  So the problem is not so much evapotranspiration itself, but how well the system handles water. How much pavement is there? Is the small water cycle being maintained?
- Calculate the gray water footprint not by legal standards but by the amount of water needed to eliminate pollution.
  Time and time again, it has been found that nature can eliminate many types

of pollution, if not with the help of humans. How much water is needed to do this (for example, to grow oil-eating bacteria) seems to me a more stable and realistic indicator of the gray water footprint.
The advantage here is that the use of substances that cannot be broken down (such as PFOS) have an insurmountable impact. This will make people think twice about using these substances.

- With the above change, the tendency to simply add up the types of water use will already become much smaller. This will preserve the nuance of the debate.

- Count all water consumption, including what is consumed indirectly.

Chapter 7
Firm footing

Although the population is increasing, the agricultural area in NL is slowly decreasing. As a result, the available agricultural land per inhabitant is decreasing. Meino Smit cites that between 14 and 21 are per person is needed. [Smi18, p. 63]. The evolution of the available agricultural area in the Netherlands is shown in Figure 7.1 where the yellow bar indicates the limits mentioned above.

For some time now, the available agricultural land per capita has been below the minimum standard. So how is it possible that the Dutch population is not dying of starvation?

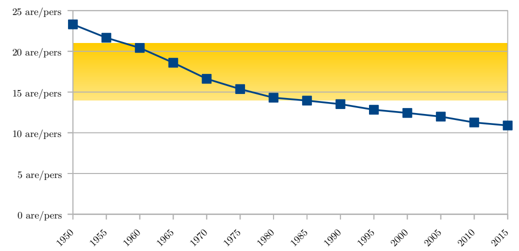


Figure 7.1: Direct agricultural area per capita in the Netherlands

Indeed dear reader, land is used indirectly. Meino Smit's study shows that in 1950 this was minimal. But this indirect land use has risen sharply over time. By the end of the 1960s, there is as much indirect land use as direct land use. This increase continued until the 1980s after which it stabilized.

Analysis indicates that this additional land use is almost entirely attributable to livestock feed, as shown in figure 7.2. The infamous soy from Brazil but also, for example, grain from other European countries and corn from the USA.

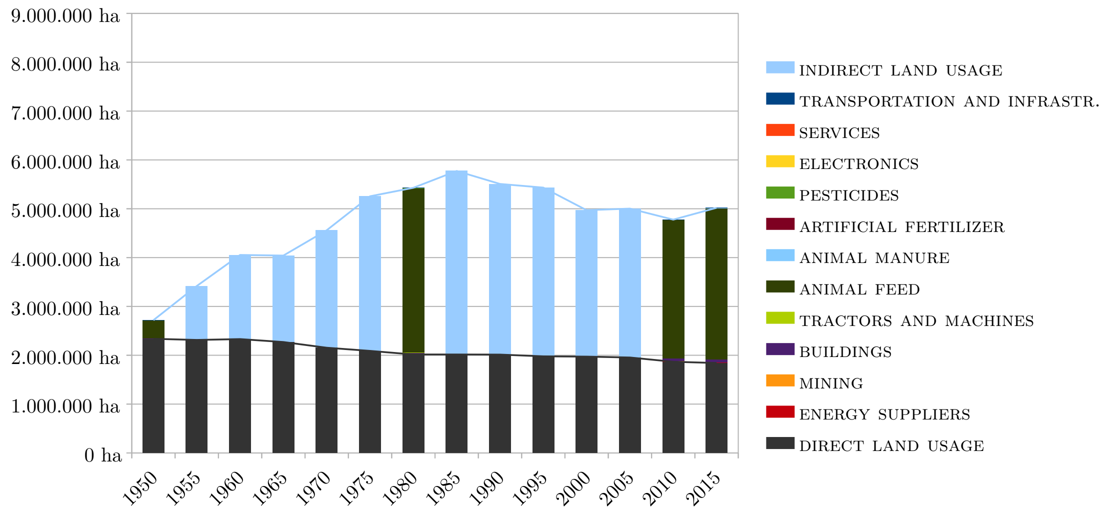


Figure 7.2: Total used agricultural area of Dutch agriculture

In total, 1.7 times as much land is currently needed outside the Netherlands as within it. This is the value for all agricultural sectors combined. If we were to look at this only in the livestock sector, we would see that for every hectare that a cow occupies in the Netherlands, a multitude of land is needed abroad.

If we take this indirect land use into account, then there is more than enough agricultural land available per capita, as shown in figure 7.3. However, it is questionable whether this is sustainable because it assumes that the import of cattle feed can continue undisturbed and remain at an acceptable price level. This is apart from the additional energy cost for it's import.

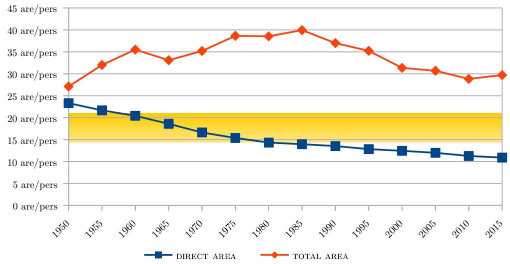


Figure 7.3: Total agricultural area per capita in the Netherlands

Chapter 8
By the sweat of your brow

The number of farmers in the Netherlands has been in decline for years. There were five times fewer people directly employed in agriculture in 2015 compared to 1950.

Now that you already have experience with indirect shares, dear reader, you naturally wonder how many people are indirectly employed in agriculture. Bravo, you've been paying attention.

These indirectly employed people are not only the farmers abroad who grow fodder, but also workers in mining, agricultural consultants or workers of rubber factories who make tractor tires.

Meino Smit has fortunately figured this out for us. The share of indirect labor continues to rise. In fact, each Dutch farmer currently needs an average of 1.7 other people to do his or her job. Meino's estimate is, in his own words, rather conservative due to flawed figures. The number of people employed indirectly is likely to be higher.

The main sectors providing indirect labor to agriculture are animal feed, mining and services, together accounting for more than three-quarters of indirect labor. These workers are partly in the Netherlands itself (e.g. civil servants), partly outside the Netherlands (e.g. miners).

Even taking into account indirect labor, the number of people employed in total in Dutch agriculture has declined over time, as shown in Figure 8.1. This has to do with the mechanization of agriculture, both within the Netherlands and abroad.

Meino Smit makes a few more interesting observations about labor:

- there is always a dependence on human labor. This can be very indirect, such as the programmer of a milking robot without whom that milking robot cannot work at all.
- Are we spending our time, energy and resources in a useful way? Why should so much work be put into a system of automatic plant recognition when it can be learned so much faster by a human?
- Human muscle power can be used much more efficiently by applying knowledge. For example, the use of simple tools such as a hoe or aids such as ball bearings.
- has the replacement of human labor by machines been accompanied by an increase in job satisfaction, health and meaningful work?

- the food required to perform human (and animal) labor is indirectly a use of fossil fuels in our current society.

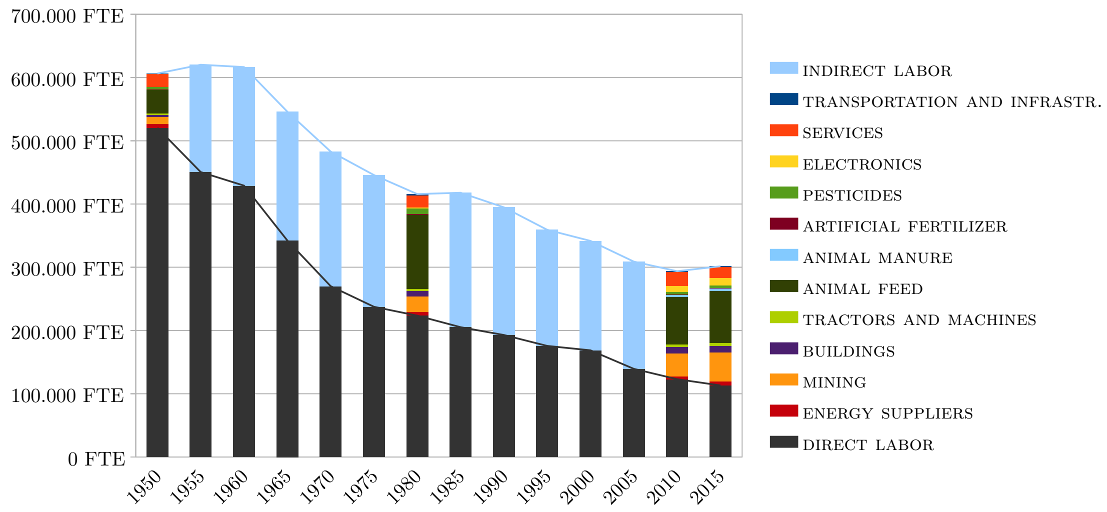


Figure 8.1: Total labor of the Dutch agriculture

Chapter 9
From a multitude to a single number?

9.1 There are a great many factors

In addition to the costs mentioned above, a multitude of potential impacts of agriculture can be identified from the studies.

Meino Smit, for example, cites a number of studies that have calculated the social costs of agriculture. These run from environmental damage (estimated at € 2.77 billion per year) over the social costs of livestock farming (more than € 2 billion per year) to social costs of the entire Dutch agricultural sector (between € 5 and € 20 billion per year).

These are sums that make you stop and think. Especially since Meino Smit calculates that the agricultural income (net added value at factor costs) for Dutch agriculture in 2015 will be € 6.9 billion. The social costs are therefore of the same order of magnitude as the income from agriculture. Or to put it another way, our way of doing agriculture is possibly socially economically unprofitable.

The study by Eosta ([Eos17]) adds factors such as accidents at work, illnesses caused by consumption of pesticides, erosion, biodiversity and the carbon content of the soil. From their calculations they conclude that for organic farming the economic balance is positive but for conventional farming it is negative.

However, there are still very many possible costs that need to be taken into account. Just think of noise pollution, odor nuisance, social exploitation or food scandals. These are shown schematically in figure 9.1.

9.2 Can this be converted into money?

Eosta is an organic wholesaler that has ordered a study to determine the „True Value" of their company and compare it with a similar non-organic wholesaler [Eos17].

For this purpose, a number of factors are examined and a cost in Euros is attached to them. In this way they combine all these factors and can make a comparison between themselves and their non-organic counterpart.

They themselves make a number of comments on this study:

- it is the first time such a study is done. Consequently, the number of factors taken into account is rather limited.

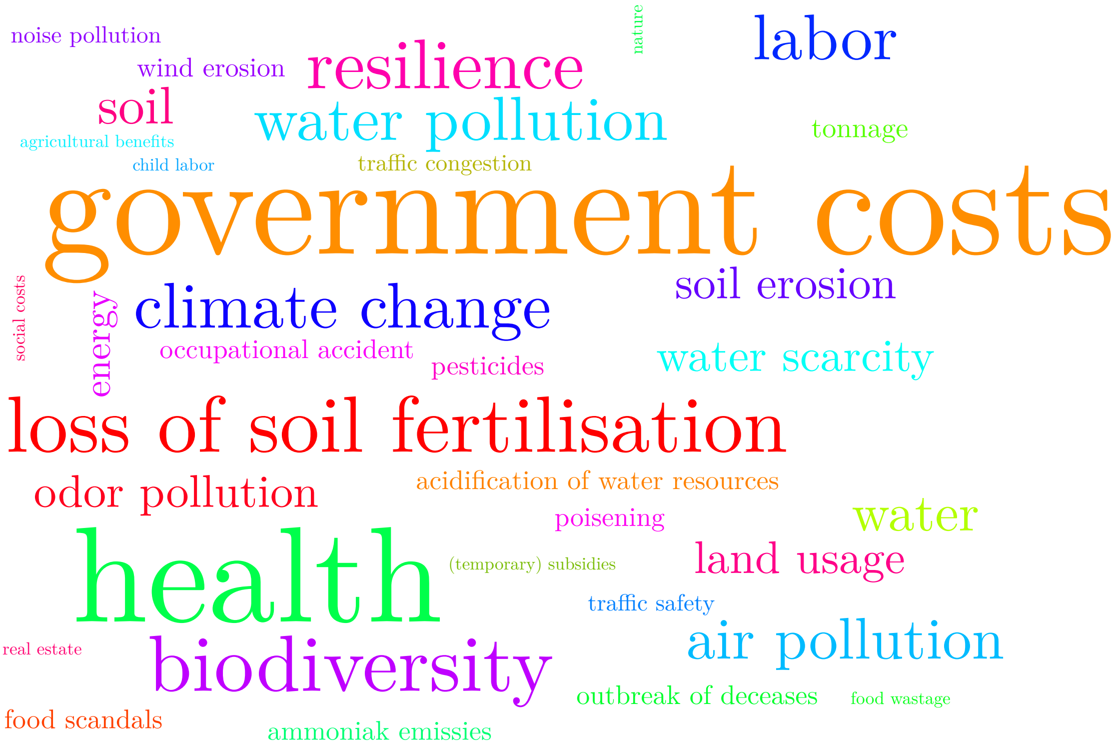


Figure 9.1: Overview of social costs

- they indicate that the „True Value" is an oversimplification of reality. For example, you can improve the „True Value" by paying your employees more. But can this offset the poor partial score of, say, CO_2 emissions[1]?

At first, I was very enthusiastic when I read this study. Such a way of working would give a possibility to indicate in a simple way that organic is not more expensive, but rather that non-organic causes many more costs that are not passed on.

The more I worked on it, the more reservations about this view of the world arose.

As they themselves point out, capturing value in a single number is a gross simplification of reality. This allows choices to be made that are actually unsustainable but improve this value. A similar comment was also made about the water footprint.

Although they caution against focusing too hard on the „True Value" value, the study's report emphasizes a link between the „True Value" and sustainability. In my view, it is dangerous to measure sustainability as a purely economic value.

Expressing sustainability in terms of money strikes me as odd. The monetary value of a product or service is subject to laws that have little to do with physical reality. What is the value of a ton CO_2? In the physical world, its impact is fixed, independent of any speculation. But the monetary value is not fixed. Meino Smit, for example, cites a value between € 5 and € 300 per ton. What value you take has an impact on the calculated „True Value" but not on the environmental impact. In this way, a negative „True Value" suddenly become positive or vice versa without making society better or worse off.

[1]Especially since higher wages usually cause higher consumption.

Finally, I find the entire study rather homocentric. Nowhere does it look at the impact on other organisms unless humans benefit. You get the feeling that a tree is only looked at as a source of fruit and coppice. The other values of a tree (place to have a family picnic under, source of life such as beneficial insects or birds, aesthetic value in the landscape, . . .) do not fit into the narrative being conducted.

9.3 The sustainability flower

It is my dream that there can be an indicator of sustainability. As is clear, this is not possible by bundling everything together in one parameter because there are so many factors that come into play. For example, how do you weigh a farmer's wages against water management?

Therefore, we need to work with an indicator that highlights the impact on different aspects in a visible way. In this way, the user is more fully informed and can himself weigh up which factor plays a greater or lesser role in the assessment. This consideration will depend on the context in which the user lives. This subjective assessment should not be imposed but each user should be able to make it for himself together with clear information about the aspects being measured.

Personally, I propose eleven facets to be included which are summarized in table 9.1.

This is a first step towards such an indicator. As can be seen, there are a number of facets that would systematically score negatively under the current system. Personally I don't mind because 1) it gives an impetus to improve and 2) there are several facets so the overall impression can still be positive.

To represent this visually, I dream of a flower where each petal represents a facet. The size and color of the petal indicates the value of the facet with a subtle line indicating the neutral value. Figure 9.2 represents a conceptual sketch of such a flower.

Table 9.1: Proposal of facets to include in a sustainability indicator

	Facet	Example of factors to include	What is a neutral value?
	Farmer	Does the farmer have autonomy (no strangleholds)? Is the income sufficiently high?	Farmer can easily switch contracts Farmer can make ends meet with farming income 50% of the sales price goes to the farmer
€$ ¥	Economy	Is the revenue in money more than what has to be put into it (e.g. subsidies)?	As much money flows in as is taken out
	Energy	What is the EROEI?	Neutral at EROEI of 4:1
	Raw material	How many external raw materials are needed? Are there raw materials that are already or are becoming scarce? Are there raw materials that are (geo)politically problematic?	
	Water	Water footprint of each type of water How much water is used according to the water reserve and replenishment of this reserve?	For blue water: as much is stored as is consumed. For green water: less is consumed than precipitation can replenish For gray water: no pollution
	Health	Impact of pesticides used Nutritional value of products Psychological pressure for the farmer	No substances are used that cause potential health risks

Greenhouse gases[2]	Effective CO_2 emissions Are greenhouse gases stored in the system?	No net emissions
Ground	Ratio of direct and indirect land use Accumulation or degradation of topsoil	
Biodiversity	Number of species simultaneously present on land Impact on species loss (e.g. through pesticides or effluents)	Equal species count compared to a similar natural biotope[3]
Welfare of cultivated organisms	Animal and plant welfare	
Cultural	Freedom to add your own touches Connection and integration with the local community	

[2]Possibly has a double accounting with energy.
[3]E.g. savanna for wheat field or young forest for orchard

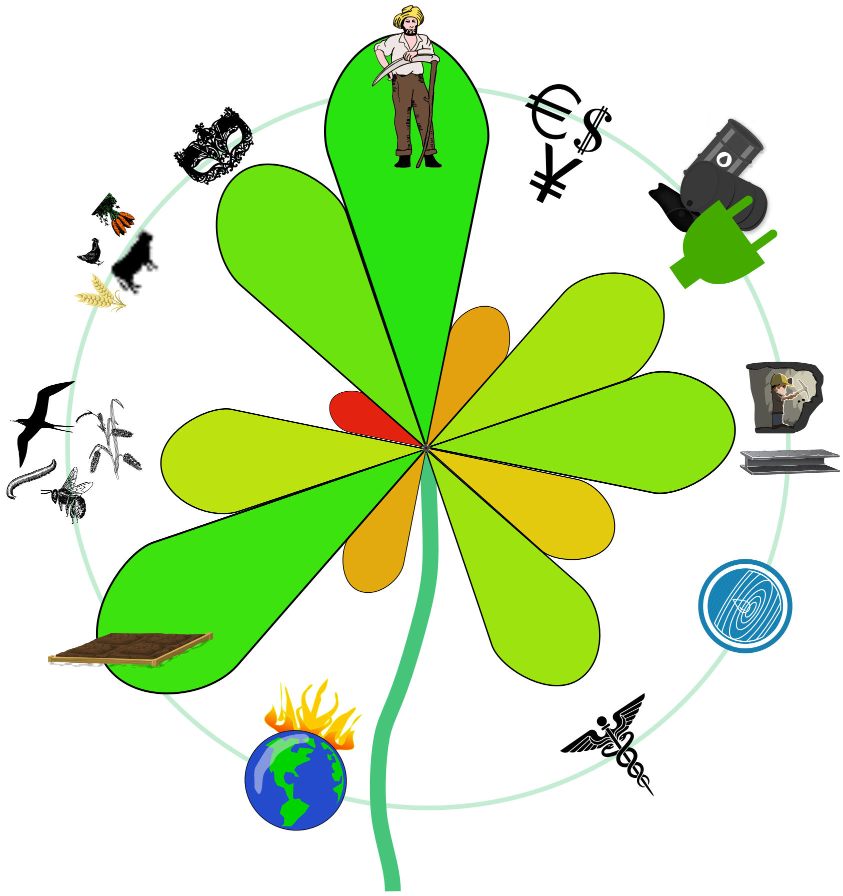


Figure 9.2: Sustainability Flower

Part IV

What do we learn from this?

Chapter 10
Impact of indirect costs

An important message from Meino Smit's thesis, is that if you only look at direct costs, you will get a distorted picture of the evolution of agriculture.

As a way of measuring the evolution of agriculture, two indicators are regularly used:

- how many hectares can a farmer cultivate annually
- how many tons of food can a farmer grow annually

For Meino Smit, however, these are not the best indicators. He prefers to work with energy-based indicators because they better capture the social costs of agriculture. Examples are energy efficiency (EROEI), energy output per full-time equivalent (FTE) or energy output per hectare.

Further on, it is also considers whether the increase in energetic costs is proportional to the output.

A word of warning: this is the chapter with the most numbers and graphs. If that's not your thing, here are the most striking numbers (note, if you want to stay in suspense you'll have to skip this).

First, let's summarize what has been found so far. These are conservative estimates so probably the ratios are worse:

- For every MJ directly attributed to western agriculture, there are still 1 to 2 MJ of indirect energy.
- To produce 1 calorie (or MJ) of food, mainstream agriculture needs between 2 and 3 calories of energy. This is separate from the rest of our food chain (all together, to produce 1 calorie to eat between 7 and 12 calories).
- For every Dutch farmer, there are 1.7 other individuals working.
- For every hectare of farmland worked in the Netherlands, another 1.7 hectares are needed abroad.

When we combine these numbers, new insights emerge:

- Between 1950 and 2015, the energetic input per hectare in the Netherlands increased by 620%. The energetic output per hectare used increased by only 10%.
- Between 1950 and 2015, the energetic input per Dutch farmer increased by 2 500% (!). Output per FTE increased by 320% during that period.
- between 1950 and 2015, yield in tons per hectare increased by 30%.

10.1 The classic indicators

10.1.1 Number of hectares cultivated per full-time equivalent

If only direct labor hours and land use are taken, then between 1950 and 2015 the number of hectares/FTE increased from about 4 hectares/FTE to 16 hectares/FTE, a factor of 3.6.

If you look at the total labor hours spent, so including mining, livestock, . . . , then between 1950 and 2015 the number of ha/FTE increased from about 4 ha/FTE to 6 ha/FTE, a factor of 1.6.

So much for what Meino Smit used. However, in my opinion, total land use should also be included because land is also used for indirect labor. If you do that, then the increase between 1950 and 2015 happens to be the same as in the first calculation: a factor of 3.6.

All this is also shown in figure 10.1.

So you notice two things:

- including indirect contributions does affect the efficiency increase in agriculture. In general, efficiency decreases when indirect contributions are included.

- it's important to think carefully about what you include and what you don't.

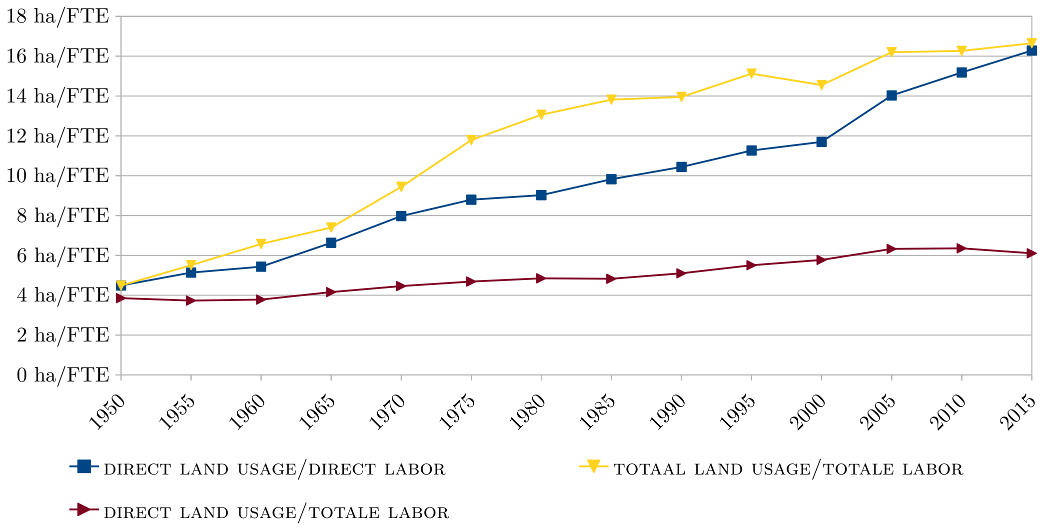


Figure 10.1: Movement of labor productivity in ha/FTE

10.1.2 Amount of tons produced per full-time equivalent

Here there is less discussion about which indirect contributions should be included.

Excluding indirect labor, tons/FTE increased by a factor of 11.2 between 1950 and 2015.

If you do take indirect labor into account, this increase is only 4.9.

So you notice a big difference in the improvement as shown in Figure 10.2.

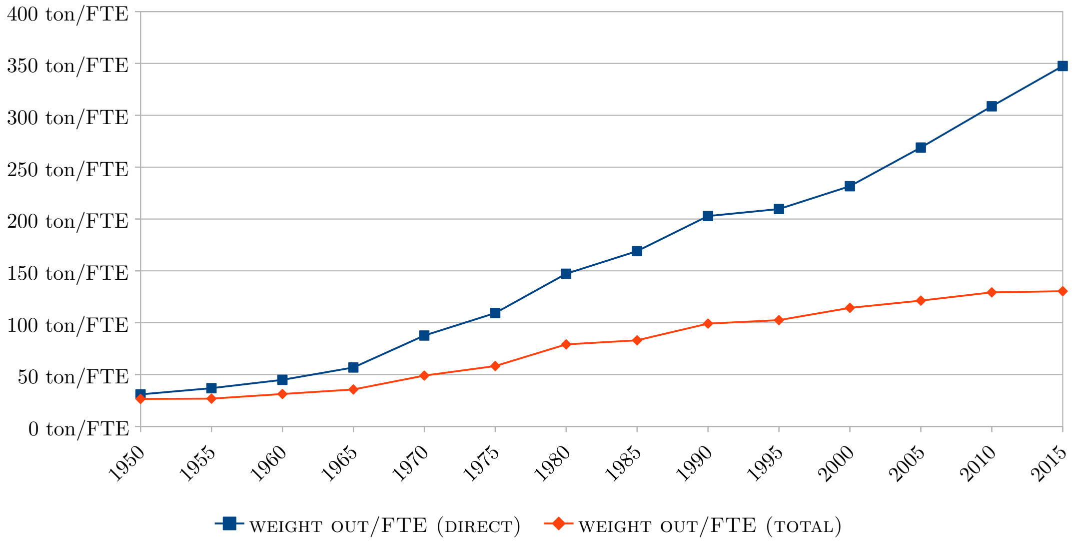


Figure 10.2: Movement of labor productivity in tons/FTE

10.2 Indicators based on energy

10.2.1 Energy efficiency

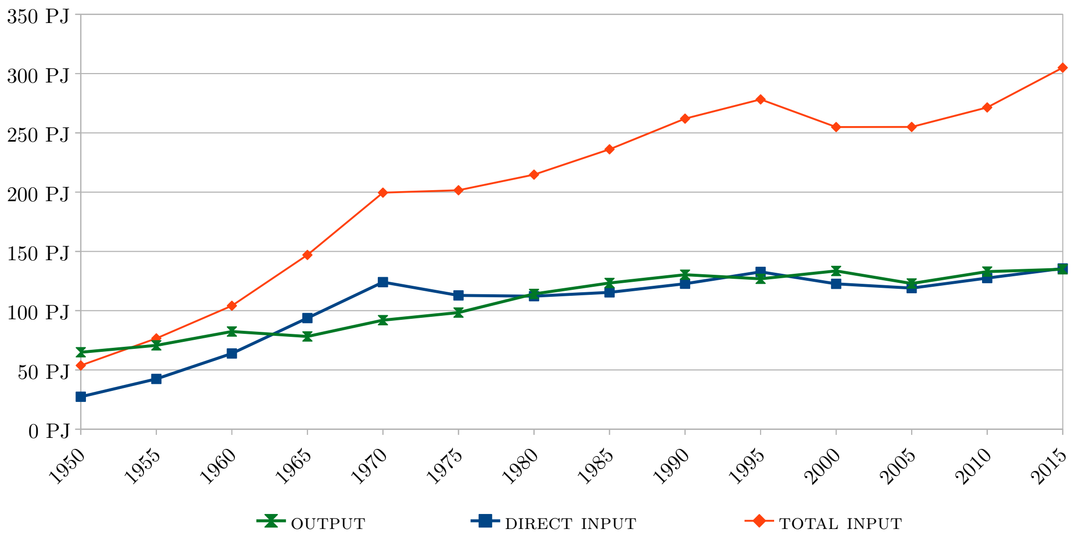


Figure 10.3: Comparison of energetic input and output

We have already seen that the energetic efficiency (EROEI) fell from 1:1 to 1:2 between 1950 and 2015.

This is also shown in Figure 10.3 where the total input in 2015 is double the output.

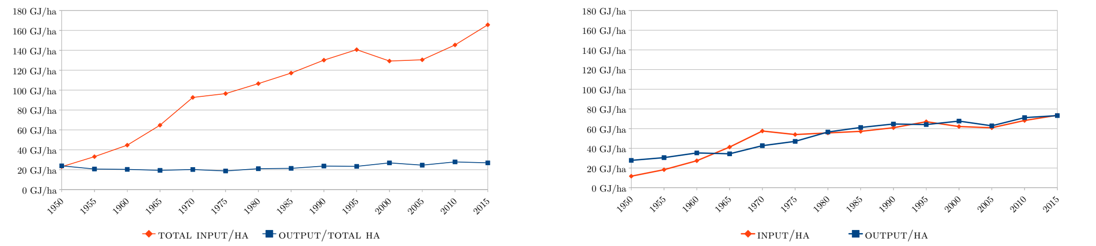
However, if indirect inputs are not taken into account, the EROEI in 2015 would be 1:1. This is a big difference because instead of appearing to be energy neutral, agriculture is demanding more energy than we are getting out of it.

10.2.2 Energy per hectare

Without taking into account indirect land use, output per hectare increased by a factor of 2.6 between 1950 and 2015. If indirect land use is included, this increase is only a factor of 1.1.

It is very enlightening to contrast this with the inputs needed per hectare.

Without taking into account the indirect contributions, the energy input per hectare has increased by a factor of 6.3. If we do take the indirect contributions into account, this increase increases to 7.2.



(a) Taking into account indirect contributions (b) Without taking indirect contributions into account

Figure 10.4: Course of energy per hectare

The evolution of these values is shown in Figure 10.4.

Note that currently 7 times more energy per hectare is invested in agriculture but only 0.1 times more output! If it is not clear yet, this makes the efficiency of the „Green Revolution" in questionable.

10.2.3 Energy per full-time equivalent

Similar to energy per hectare, you can also look at the evolution in both input and output in energy per labor hour worked.

Without taking into account the indirect factors, input per FTE increases by a factor of 23 and output by a factor of 9.6.

If we do take the indirect factors into account, input per FTE increases by a factor of 26 and output by a factor of 4.2.

It can be seen that output is now rising sharply because of mechanization. But this is offset by an enormous increase in the input needed per hour of work.

So the same conclusions as above can be drawn. The increase in energy input is not in proportion to the increase in energy output.

10.3 Yield in tons per hectare

In the yield in tons of products per hectare, there is an increase by a factor of 3.1 without taking into account the indirect contributions. With the indirect factors, this increase drops to 1.3.

Considering the strong increase in energetic inputs that happened per hectare, this increase in output is chicken feed.

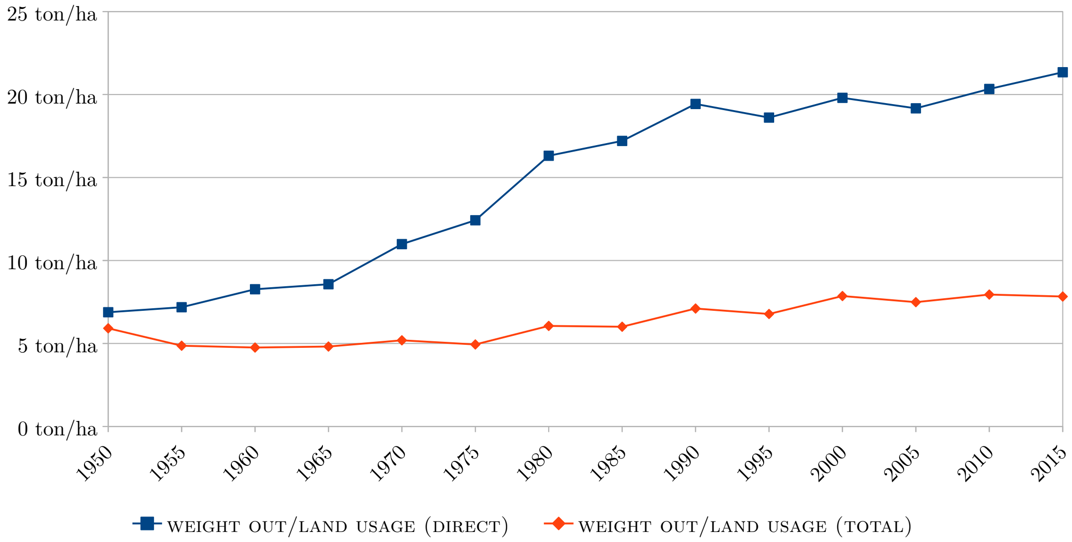


Figure 10.5: Development of yield in tons per hectare

10.4 Conclusion

It is clear that to get a good picture of the evolution of key figures for agriculture, you have to take into account indirect contributions.

As can be expected, the picture of agricultural evolution is much less flattering than it is currently portrayed. There is some positive evolution, but it is are much weaker than usually portrayed.

What is particularly striking is that the increase in input is much greater than that in output. If you compare these increases, you notice that this trend is getting worse. In other words, despite the stories around increasing efficiency in agriculture, more and more energy has to be put into it for a meager increase in output. This is generally not visible because of the limited inclusion of the increase in inputs.

Here only the energy factor was considered. The story around water, biodiversity, soil fertility or other factors identified above has not yet been included.

This is not a hopeful message. You get the feeling that the train of agriculture is derailing and heading towards a collapse.

Can we reverse this trend? We will look at that in the final chapter.

Chapter 11
What should agriculture look like?

To reverse the negative trend, there are a number of areas where change can happen. Meino Smit has identified possible adjustments that will be discussed in a moment.

I started the learning process of Landwijzer in order to be able to drop my own pebble in the water, starting from the system of Ferme du Bec Hellouin. Has the vision and dream I originally had changed as a result of this treatise?

11.1 The dream of Meino Smit

Meino Smit dreams of an agriculture in 2040 that does take indirect costs into account. This has major implications in all sorts of areas.

On the agricultural side, we need to move towards an integration of agriculture and nature management. There will be smaller farms which will be more resilient. There will also be less specialization and better closed cycles. The use of hot greenhouses and non-food greenhouse farming must be banned because it is energetically unsustainable (80% of direct energy in agriculture goes to heated greenhouses). Hand and animal power must be reinstated which also means more farmers.

Social changes are also needed.

- The harvest must go first and foremost to the local population.
- More plant products should be eaten and less animal products (Table 11.1). Note that this is a drastic shift in society's diet. Without this shift, we are eating our way toward starvation.
- Research must focus on technology that saves energy and resources.
- Taxes should shift from labor to capital.

These changes mean that many more people need to be employed in agriculture and indirect costs will fall sharply. The most important key figures also then become positive. It is striking that in this situation, more energy is produced by agriculture than is put into it. Energetically, we have a positive situation again.

A big exception is the total amount of agricultural land per inhabitant. Whereas this currently hovers around 30 ares/inhabits, in the proposed scenario it will drop to 12 ares/inhabits, below the minimum limit of 14 ares/inhabits. Is this enough?

This change in agriculture will require a new influx of farmers with new ideas.

Table 11.1: Shifts needed in food

	Value in 2015	Value in 2040	Difference
Number of inhabitants	16.900.726	17.000.000	
Vegetables	25,399 ha	44,321 ha	+ 70%
Fruit	19,770 ha	141,828 ha	+ 640%
Grains[1]	196,817 ha	516,481 ha	+ 160%
Potatoes[2]	71,736 ha	35,457 ha	- 50%
Nuts[3]	61 ha	78,200 ha	+1300%
Legumes[4]	15,506 ha	23,868 ha	+ 50%
Sunflowers[5]	660 ha	310,250 ha	
Rapeseed[5]		124,100 ha	
Sugar beet[6]	58,436 ha		- 100%
Flower bulbs[7]	28,842 ha		- 100%
Area for horses		40,000 ha	
Horses[8]	30.000	100.000	+ 300%
Cattle	4.133.854	845.302	-80%
Pigs	12.602.888	401.194	-97%
Sheep	523.103	250.000	-50%
Poultry	103.038.539	21.017.938	-80%

One possible consequence of this change is that the price of agricultural products increases. But this is only the case if the social costs are not taken into account. If these were to fall significantly, wouldn't society be better off? However, getting this message across is very difficult as we have seen in France with the Yellow Vests.

Meino Smit makes the case that if there had been a policy in 1950 that took all costs into account, we would be better off now. Breeding has caused an output increase of 20 to 25%. Partly because of this and through innovation that would have focused more on better working conditions with less use of energy and raw materials, for example through improved hand tools, agriculture could have achieved an output increase that was greater than today without the hallucinatory increase in input. Agriculture would have been more resilient and there would be more farmers and greater social support.

11.2 Has my dream changed?

My goal in starting the training is to bring the system of Ferme du Bec Hellouin to Flanders.

[1] Currently, many grains are imported. The intention is to grow all needed grains in the Netherlands.

[2] No more seed and starch potatoes would be grown. This would free up 83,000 ha of agricultural land.

[3] According to the advice of the „Disk of Five"

[4] Replacing animal proteins with plant proteins

[5] Mainly scrap

[6] Less sugar and no longer used as cattle feed

[7] Focus on nutrition

[8] The hobby horses that are currently kept, will be replaced by work horses.

Through the study work around this paper, it has become clear that there is a real need for agriculture that repairs the damage done. We have seen that kitchen gardens and especially the Chinese agriculture of 1930 can be great sources of inspiration here. The system of Ferme du Bec Hellouin uses the same principles of combined cultivation, intense follow-up, high input of organic fertilizers combined with not disturbing the soil, permanent cover crops and many other factors to optimize the natural processes.

Within the Chinese agriculture of 1930, cattle breeding was done in an extensive way, which is still missing at Ferme du Bec Hellouin. Also arable farming is missing, but we have seen that for cereals the current way of arable farming already gives good figures.

From the experience I already had with the combination crops of Ferme du Bec Hellouin, I could reflect during the drafting of this paper what this system does around the different identified costs such as water, ecology, ... My conclusion is that the system of Ferme du Bec Hellouin offers a strong base to start from.

So my dream has only grown stronger.

Chapter 12
Summary

This search for the true cost of food started with a search for the origin of the meme „it takes 10 calories of oil to consume 1 calorie of food”. There was also the suspicion that it is not so much that organic food is expensive, but that, compared to organic food, conventional food has more indirect costs that are less reflected in the final price.

Only the Eosta study distinguishes between organic and non-organic and shows that organic indeed has lower social costs. All other studies look at the totality of the food chain without making a distinction between organic and non-bio.

We found that agriculture bears very high indirect energy costs. These range from feed and fertilizer over the cost of buildings and machinery to things like mining, electronics and services. There are also costs in many other areas such as labor, water, land use and you name it.

Direct costs are still a significant portion of the total costs, but indirect costs have increased dramatically over the last 50 years until they outpaced direct costs. In indirect costs, livestock feed takes up a particularly important share. What I have also noticed are the contributions of mining, grain and grass drying, and irrigation in the energy balance.

Further down the food chain, packaging and household use particularly stood out, with an energetic share equivalent to that of agriculture itself.

The share of agriculture in the energy consumption of the total food chain is a quarter or less.

That you need 10 times more energy than you consume turns out to be true. This is not sustainable in the long run because the supply of energy is finite. The same problem applies to other costs as well. „Business as usual” is going to lead to „Starvation by gorging”. So the status-quo has to change.

To measure necessary progress, it is necessary to maintain the nuances of life. Summarizing the progress in one number loses much needed nuance. Hence the proposal to start from a sustainability flower.

If we compare the energy efficiency of different farming systems, we can see major differences. With the available information, it is possible to determine which systems fall by the wayside and which can be good sources of inspiration for future agriculture.

Among the industrial farming systems, animal production or heated greenhouse systems consume a disproportionate amount of energy. Arable systems come out better.

Pre- and semi-industrial farming systems often turn out to be energetically advantageous but many of these are not possible in our area due to high population density.

The best candidates for a future agriculture is horticulture as practiced in China until the beginning of the last century. This was possible because of the intensive attention of the farmer together with a large supply of nutrients, combination crops and an intensive follow-up of crops.

The principles that make the old horticulture from China so strong can also be found in the system of Ferme du Bec Hellouin. However, this system still needs to be developed further. In its present form, the emphasis is very much on the cultivation of fine vegetables. Therefore, it cannot offer a complete answer. But its further development can provide inspiration for other branches of agriculture to embrace „Small is beautiful".

Important to realize, is that the necessary changes are not only needed in agriculture. The rest of the food chain must join in. The diet must also change, with a particular need to reduce the consumption of meat.

Thanks to working on this paper, I have gained many more insights into the impacts of agriculture on our society. It has also strengthened my conviction that we must actively seek a different way of doing agriculture. The system of Ferme du Bec Hellouin seems to be a very good basis for this.

Time to get our hands dirty.

Part V

Appendices

Appendix A
Some technical terms

A.1 Brief summary of some scientific concepts

A.1.1 Joule or calorie?

In this work, a lot of work is done with energy. The SI unit of joules (J) is taken for this purpose.

There are different units for energy. In food, the calorie is the best known but also the most confusing. This is because a kilocalorie is actually used for food, but written down as a calorie. In joules, fortunately, this is not done.

How can you convert one to the other? 1 (real) calorie equals 4.184 joule.

A.1.2 But still acres and tons?

But, but, but, says a fellow physicist, you still use hectare (ha) instead of 10 000 square meters and tons instead of Mg (megagram)?

Well, what can I say. As a farmer in training, hectares and tons are simply more telling units.

A.1.3 Kilo, mega, giga, oh no

A number of prefixes are used to write things down more concisely. Kilo is well known, as in for example kilogram (1 000 grams) or kilometer (1 000 meters). Hecto is known from hectare (100 are, a hecto-are).

We use other prefixes in this work that are probably less well known. So a small overview:

pronunciation	symbol	multiply by		English numeral	example
kilo	k	1 000	(10^3)	thousand	5 kJ
mega	M	1 000 000	(10^6)	million	10 MJ
giga	G	1 000 000 000	(10^9)	billion	4,3 GJ
tera	T	1 000 000 000 000	(10^{12})	trillion	9 TJ
peta	P	1 000 000 000 000 000	(10^{15})	quadrillion	32 PJ
exa	E	1 000 000 000 000 000 000	(10^{18})	quintillion	7 EJ

And why couldn't I leave this? Well, after a degree in physics, that's probably an occupational disorder.

A.2 Greenhouse gases

Of course, we all know about the greenhouse effect and know that CO_2 is a greenhouse gas. But did you also know the following?

- Greenhouse gases are not only released by combustion. Livestock farming and the use of fertilizers also contribute to the greenhouse effect.
- Not only CO_2 is a greenhouse gas. There are others such as [kli19]:
  - methane (NH_4). This is 25 times more powerful than CO_2 and causes 20% of the greenhouse effect. Methane, among other things, is emitted in animal husbandry and composting.
  - Nitrous oxide (N_2O). This is 289 times more potent than CO_2 and causes 6% of the greenhouse effect. Nitrous oxide is produced in agriculture from excessive use of liquid manure and fertilizer.
  - Other natural greenhouse gases are water (H_2O) and ozone (O_3).
  - „industrial" greenhouse gases are usually much more potent than those above (1 300 to 23 900 times more potent than CO_2).

A.3 EROEI

EROEI (Energy Return On Energy Invested) is the ratio of the amount of useful energy obtained to the amount of energy that was needed to produce it. If the EROEI is less than 1, then more energy has been consumed than has been gained.

Since energy is required not only in extracting a fuel, but also in refining, transportation, . . . there are different places in the process where you can determine the required energy. These give a different value of the EROEI which can vary considerably.

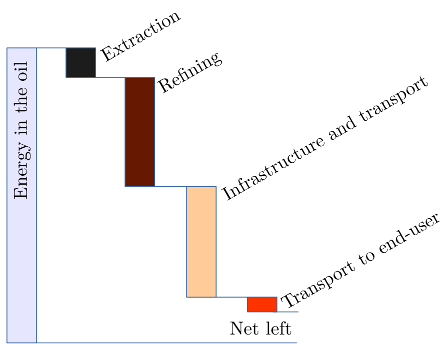


Figure A.1: Diagram of energy loss in the oil chain

In figure A.1 the EROEI drops from 10:1 when only the energy for oil extraction is considered, to 1.3:1 when all energy is considered.

Usually only the energy needed for extraction is taken to determine the EROEI. In that case, at least an EROEI greater than 3:1 to 5:1 is needed to still have useful energy left at the end.

Appendix B
Ferme du Bec Hellouin

As is clear, I'm a big fan of Ferme du Bec Hellouin. For those not familiar with it, here a little description as I see it. You can also watch the documentary film „Tomorrow" to get acquainted.

Ferme du Bec Hellouin is located in Normandy, about 20 km southwest of Rouen.

What appeals to me most about this system is the combination of their vision and the published economic results.

B.1 Their vision

The start of Ferme du Bec Hellouin was the desire of Charles and Perrine Hervé-Gruyer to produce all the food for their family themselves in a way that does not burden the earth. This means: a minimum input of fossil fuels, producing as much as possible themselves, an agriculture that nourishes the earth.

The first goal is minimizing fossil fuels. They do have a small tractor but only use it for larger infrastructure works or turning the compost pile. There is also an indirect use of fossil fuels from the plastic of the greenhouses, the supply of materials (such as horse manure), deliveries, ... So they are not completely independent of fossil fuels, but try to minimize the use.

They want to produce as much as possible themselves. Not only vegetables, but also commodities such as firewood. They have their own blacksmith shop, Charles does his own woodwork and they make their own biochar.

Their agriculture feeds the earth. There is an enormous amount of biodiversity in their fields. Not only because of the variety of vegetables, but also because of the opportunities they offer to nature. Bees and birds are seen that are barely seen elsewhere in France. Year after year, they build up carbon in the soil.

Beyond these aspects, I find their sense of beauty hugely inspiring. The whole estate is worthy of a painting. An artistic sense is also clearly present in their own publications.

In their book „Miraculous Abundance" they have a vision on micro-farming that strongly appeals to me. Especially in a Flemish context, it is important to be able to work on small plots. And this while the prevailing trend is still towards an increase in scale.

Furthermore, they are very grounded in their approach. It is no-nonsense and they are very clear: farming is work, hard work and even harder work.

B.2 Economic results

As one of the few permaculture companies, their numbers have been scientifically mapped.

A study by INRA (comparable to ILVO in Flanders) looked at the yield of 0.1 ha net cultivation area. This yield increased over the course of the study from 30 to 55 000 Euros per year. Obviously there are many discussions around this but it gives a direction. Especially since there are already several farms in France that have successfully adopted their system.

How many similar projects have failed and why is unfortunately less clear.

B.3 Relevance to this work

As mentioned elsewhere, the system of the Chinese agriculture from the 1930s appears to be a very good basis from which to start an agriculture that produces more energy than it takes to feed Flanders.

The strengths of the Chinese agriculture from the 1930s can also be found at Ferme du Bec Hellouin:

- combination crops
- pre- and post-harvests
- intensive monitoring by the farmer („The best manure is the footstep of the farmer")
- intensive usage of manure

Through various paths, these principles came to Ferme du Bec Hellouin. Most remarkably, these principles were also used in 19th century Parisian urban agriculture.

With additional principles such as not turning the soil, leaving as much plant residues as possible in situ, making paths part of the system, ... additional steps were taken.

Although there are no figures available about energetic input and output, it is to be assumed that their system will approach the figures of the Chinese agriculture of the 1930s. Hence, it's a good start for agriculture that both yields more energy than you put into it and is productive enough to feed many people on a small area.

B.4 A few figures

Ferme du Bec Hellouin consists of about 20 ha. This seems large from a microfarm, but 12 ha of this is forest used for firewood. Furthermore, there is 3 ha „edible landscape", 2,4 ha of terraces that are barely used and a house and eco-center building. The actual fields are 1.8 ha including a few small meadows, 2 food forests plus a greenhouse of 6 are.

An estimated 4 people work here full time. There is also an administrative assistant and a cook, but it is unclear from which part of the company these are paid (there is also a research center and an educational branch).

Sales are as follows:

- packages
- restaurants
- stores
- wholesale

There used to be a farm store, but it has recently been discontinued due to lack of time as they want to focus more on research around their system.

Appendix C
Will technology save the world?

Throughout his dissertation, you notice that Meino Smit questions the sustainability of electronics and a switch to renewable energy in a „business-as-usual" scenario. For me, coming from the IT sector, that was a bitter pill to swallow. Although what is discussed here is not directly related to the real subject of this in-depth piece of work, due to my background, I would like share it with you.

C.1 External costs of electronics

Electronics is a strange thing. We can't imagine life without them, and this dependence has crept into our lives awfully fast. Electronics has also become prominent in agriculture in a short period of time. Drones to plant crops, vertical farming, sensors galore, ... You can't think of anything or electronics has a foot in the door or even more.

More capital is required for the production of electronics than during their use. Production is also where most of the waste is generated, not the disposal of the electronic devices. This indicates that recycling of electronic equipment is useful but will not greatly reduce the footprint.

During usable lifetime of electronics, a variety of other electronics is also needed to transport (data communication networks such as 4G, WiFi, fiber optics, . . .), process (computing centers) and store (storage centers) the data that is generated.

Looking at costs, the following can be noted:

- the large energy consumption in production,
- the raw materials used:
  - the mining and extraction of various crucial raw materials is burdensome, both in energy and social costs:
    - use of fracking
    - toxic and radioactive waste
    - blood metals
  - some needed metals are only obtained as byproduct of other raw materials, which does not allow for a rapid response to fluctuations in demand,
  - the high dependence on rare earths with exotic names like neodymium, dysprosium or europium also has geopolitical consequences. 85% of rare earths today come from China! That gives one country enormous control over its global supply,

- production of the chips themselves is a toxic process requiring ultra pure water,
- processing the waste,
- the use of an electronic device, as mentioned above, requires a plethora of other electronic devices.

The costs and benefits of electronics are disproportionately distributed. Those who take pleasure in electronics are totally unaffected by its costs in terms of social exploitation, toxic waste, land loss, ...

There are continuous improvements in the efficiency of production and of the equipment itself. But this is mostly offset by the ever-increasing consumption of electronic equipment.

It is not the intention to condemn electronics. But it is important to be conscious of its impact. So what does this entail ?

1. First think carefully whether you really need the electronics. Marketing is very good at talking you into buying a new or more complex appliance because of features you don't really need. Is it so important that your refrigerator automatically orders milk?
2. When you buy, first look for a valid appliance on the secondhand market. This avoids the burdensome manufacturing process and it's waste.
3. Make your electronics last as long as possible. Electronic equipment has a very short life cycle. Since much of the cost is in manufacturing, a longer life cycle is a good way to reduce its footprint. This also means that it is best not to purchase a more energy friendly appliance because in most cases this is more taxing than continuing to use the old one.
4. Whenever possible, make use of wires. Wifi, GSM and other wireless communications have a higher footprint than „good old" network cables or landline phones.
5. Buy electronic devices that you can repair. Usually electronic devices are repaired by replacing entire circuit boards. The smaller the circuit boards that are replaced, the less impact the repair will have.

C.2 Renewable energy

Meino Smit is not convinced that the current evolution of energy use allows for the phasing out of fossil fuels in favor of renewable energy. This has not so much to do with the technology itself, but rather from an assessment of the amount of raw materials needed to complete the transformation and how quickly they need to be available. This is going to have an impact on „Business as usual" scenarios.

Rare earths also play an important role in renewable energy. Not only because of the electronics used, but also because these metals, for example, greatly increase the efficiency of magnets or are needed in solar cells.

Most forms of renewable energy are less efficient than fossil fuels. In figure C.1 you can find the minimum and maximum EROEI of a number of energy sources.

The EROEI of renewable fuels is linked to that of fossil fuels because even today the latter are consumed to make the infrastructure of the former[1]. Therefore, if the EROEI of fossil fuels decreases, the EROEI of renewable fuels will also decrease. Since the easier to extract fossil fuels are consumed first, more energy must be used in the future to extract the same amount of energy. In the beginning, the EROEI for natural gas was 100:1. Now, however, it has dropped to 10:1.

It is assumed that an EROEI of 3:1 to 5:1 is needed for an energy source to have a positive energy balance. This is because the storage, conversion, transportation and distribution also require a great deal of energy.

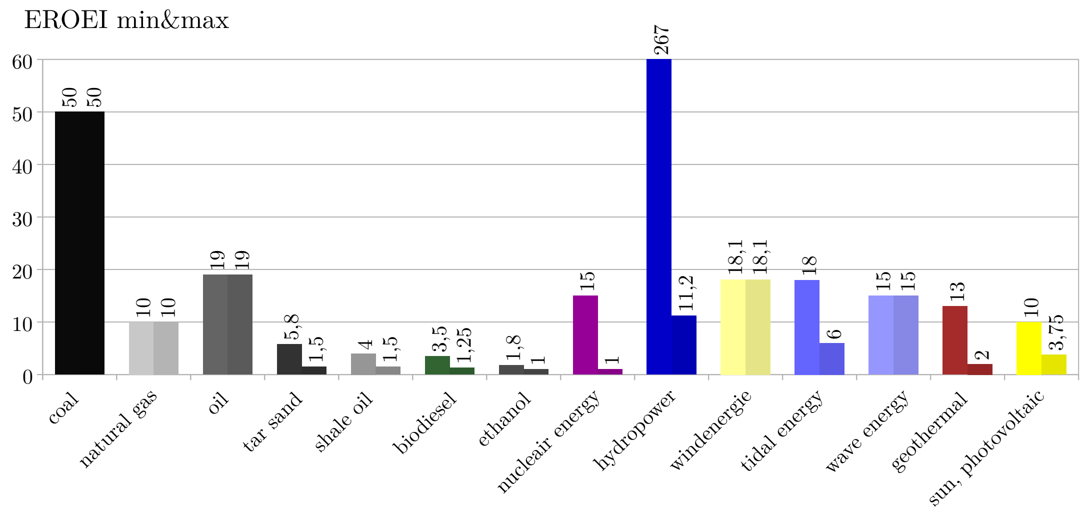


Figure C.1: The EROEI of a number of energy sources. [Smi18, p. 32 naar Hall, 2008]

Furthermore, a lot of storage, transport and other infrastructure needs to be created for renewable energy. This requires not only energy but also raw materials. Meino Smit indicates that there is not enough capacity to mine these raw materials of, for example, earth metals in a considerable time. [Smi18, par. 6.4]. Scaling up of this capacity goes very slow because, on the one hand, the creation of a new raw material flow takes years, but on the other hand, because many earth metals are byproducts when another raw material is mined. Therefore, an increase in need of the byproduct might not be feasible if there is no similar increase in the other raw material.

The only way to shift to a sustainable future is to curb energy use. The most sustainable mega joule is the one that is not needed.

This can be done by using less energy per person on the one hand, but also by reducing the population[2].

The fear of returning to the Middle Ages is very understandable. Fortunately, studies show that there is a link between well-being and the amount of energy used [Smi18, p. 35]. From an energy consumption of 50 to 70 GJ per person per year, there is a feeling of sufficient well-being. From a value of 100 GJ per person and per year, well-being no longer increases!

[1]Currently, 85% of our energy needs are met by burning fuels.

[2]How to ethically and sustainably reduce population seems to me to be a very difficult question.

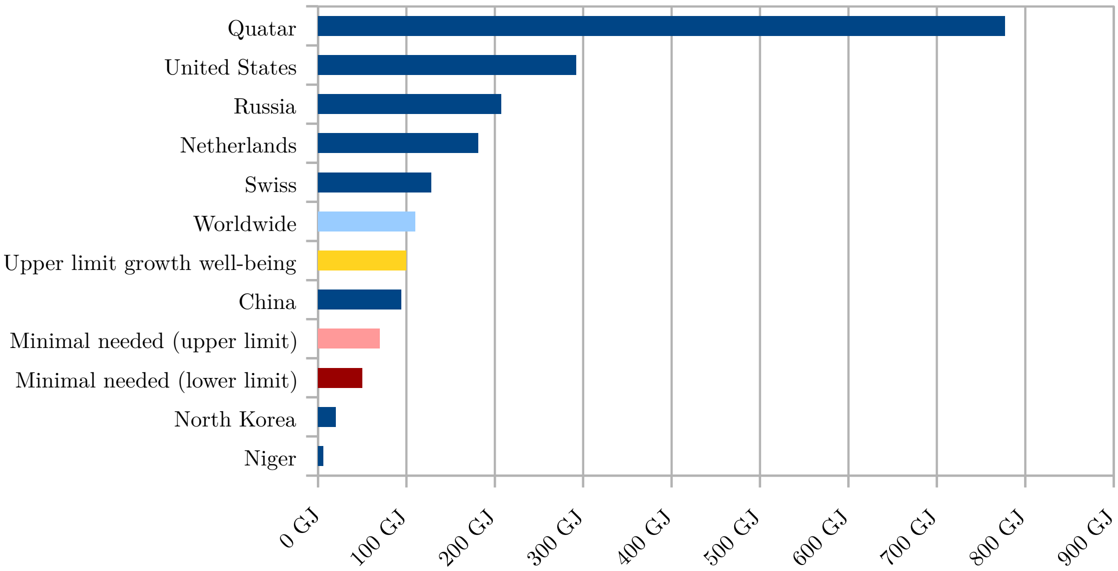


Figure C.2: Energy consumption per person and per year

Figure C.2 shows the situation for a number of countries together with the mentioned boundaries and the global average. We see that halving the energy consumption per Dutch person will not have much impact on well-being.

It is also true that this reduction should not be borne equally by everyone. After all, the richer you are, the more energy you consume [Uni20]. So it is only natural that the most consuming people would make the greatest effort.

Bibliography

[Cha+06] A.K. Chapagain et al. “The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries.” In: *Ecological Economics* 60.1 (2006), pp. 186–203.

[Eos17] Eosta. *True Cost Accounting for Food, Farming & Finance (TCA-FFF).* `https://www.natureandmore.com/files/documenten/tca-fff-report.pdf`. 2017.

[Fal95] Malin Falkenmark. “Land-water linkages: A synopsis.” In: *Land and Water Integration and River Basin Management.* Land and Water Bulletin 1. Rome, 1995, pp. 15–16.

[FAO14] FAO. *Food wastage foodprint: Full-cost accounting.* Tech. rep. Research In- stitute for Organic Farming (FiBL), 2014.

[GMH13] P.W. Gerbens-Leenes, Mesfin M. Mekonnen, and Arjen Y. Hoekstra. “The water footprint of poultry, pork and beef: A comparative study in different countries and production systems.” In: *Water Resources and Industry* 1–2 (2013), pp. 25–36.

[HFP18] N. Haie, M.R. Freitas, and J.C. Pereira. “Integrating Water Footprint and Sefficiency: Overcoming Water Footprint Criticisms and Improving Decision Making.” In: *Water Alternatives* 11.3 (2018), pp. 933–956.

[HG18] Charles Hervé and Perrine Gruyer. *Zaaien met toekomst. La ferme du Bec Hellouin.* Jan van Arkel, 2018. ISBN: 9789062240418.

[HH02] Arjen Y. Hoekstra and P.Q. Hung. *Virtual water trade : A quantification of virtual water flows between nations in relation to international crop trade.* Tech. rep. Delft: IHE, 2002.

[Hoe+11] Arjen Y. Hoekstra et al. *The Water Footprint Assessment Manual.* Earthscan, 2011.

[Hos09] Rebecca Hosking. *A Farm for the Future.* `https://vimeo.com/136857929`. 2009.

[Kin11] F. H. King. *Farmers of Forty Centuries. Organic Farming In China, Korea, And Japan.* 1911.

[kli19] klimaat.be. *De verschillende broeikasgassen.* `https://klimaat.be/klimaatverandering/oorzaken/broeikasgassen`. 2019.

[Lea76] Gerald Leach. *Energy and food production.* Guildford: IPC science and technology press, 1976. ISBN: 0902852558.

[LLB84] Amory B. Lovins, L. Hunter Lovins, and Marty Bender. “Energy and Agriculture.” In: *Meeting the expectations of the land*. Ed. by Wes Jackson, Wendell Berry, and Bruce Colman. San Francisco: North Point Press, 1984, pp. 68–86.

[Mor06] Faith Morgan. *The Power of Community: How Cuba Survived Peak Oil*. `https://en.wikipedia.org/wiki/The_Power_of_Community:_How_Cuba_Survived_Peak_Oil`. 2006.

[Sey22] Eric Seynaeve. *The true cost of food – Technical deep-dive*. `https://github.com/EricSeynaeve/landwijzer_werkstuk/raw/master/text/manuscript-tech-en-us_print.pdf`. 2022.

[Smi18] Meino Smit. “De duurzaamheid van de Nederlandse landbouw: 1950 – 2015 – 2040.” PhD thesis. Wageningen University, Sept. 2018.

[SS74] J. S. Steinhart and C. E. Steinhart. “Energy use in the U.S. food system.” In: *Science* 184.4134 (Apr. 1974), pp. 307–316. DOI: `10.1126/science.184.4134.307`.

[Uni20] University of Leeds. *Shining a light on international energy inequality*. `https://www.leeds.ac.uk/news/article/4562/shining_a_light_on_international_energy_inequality`. Mar. 2020.