The Embodied Land indicator

Background and substantiation

March 2013

Zuyd Research

Executive summary: **MAXergy and Embodied Land:** A combined approach to energy and material

The impetus for the development of the MAXergy calculation method was a discussion about 0 energy homes. If all a building's energy needs are generated on or by the building itself, utilising renewable resources, then materials (including the materials needed to generate energy) are the only actual environmental burden., outside the buidlsings system borders. So how can energy and materials be evaluated together?

Weighting factors are subjective and negotiable, and therefore unusable. As such, they should be avoided. What is called for is an absolute evaluation of energy and material together.

Exergetic analyses of the built environment made it clear that ultimately, solar radiation (and the knowledge needed to convert it to a form which humans can use) is the only thing which adds value to a system and which therefore indicates the joint impact of energy and materials.

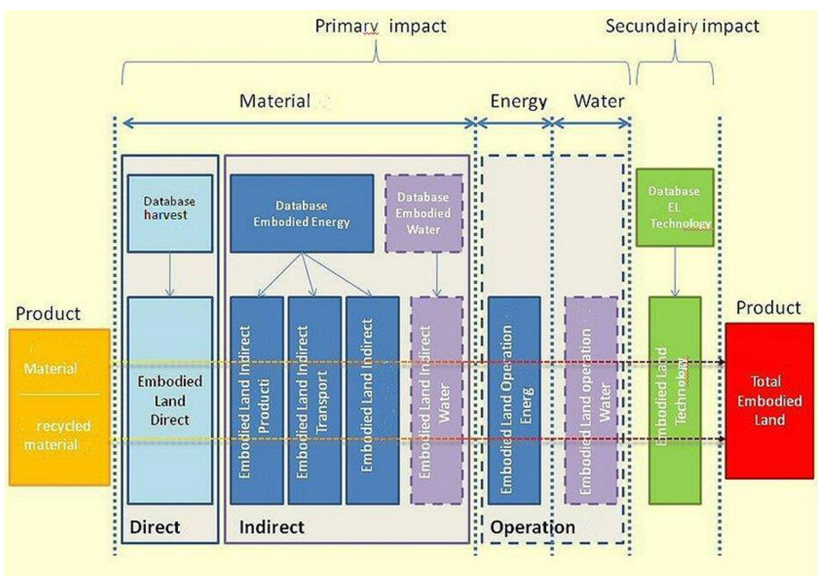
We have developed a calculation method and a model on this basis. The basic assumption behind this model is the idea that within a few decades, society will be exclusively based on renewable resources for both energy and materials (and ultimately for food and water as well) - in other words, society will be exclusively based on solar energy. Converting solar radiation into a usable form requires space and time. One square metre of land is needed for a solar panel, the cultivation of vegetables, or forest management; and in all these cases, the square metre of land generates a particular annual harvest.

This indicates the effectiveness with which solar radiation can be converted. Our method is derived from this concept, which we have called Embodied Land. Embodied Land is defined as the number of square metres per year which a product or building needs in order to meet its needs in terms of energy and materials - in other words, in order to fulfil its intended function over the course of that year.

The Embodied Land is reconverted back to solar radiation in space and time, as follows:

- The agricultural production for materials, in tonnes per hectare per year (we are developing a database to this end). This figure is necessary in order to calculate the total number of hectares needed for construction materials (for instance) in terms of hectare-years.
- The next figure is the energy needed for harvesting, processing and transport in terms of final use ('embodied energy'). This is converted into the amount of solar energy needed in hectare-years. We examine an average yield for our region for the technology selected (at present, photovoltaic cells only) and at this stage we use the ICE database.
- We also look at the operational energy for the building in terms of kWh of end use and convert this into m^2-years of solar radiation needed.

This results in the total hectare-years that the land linked to the building is occupied by the needs of that building (Embodied Land). This is the amount of land that must be reserved to meet the demands for production or compensation. This can potentially be distributed over the useful lifespan of the building - 50 years, for instance. In that case, the Embodied Land can be divided by 50, which reduces the amount of land used, but increases the length of time it is occupied.This is the basic calculation. However, certain aspects still need to be factored in.



There are secondary effects such as the need to store energy when using solar panels, so that the energy is available throughout a 24-hour period. This storage results in conversion losses (such as with hydrogen) and therefore demands more production and Embodied Land (up to four times as much). Other conversion routes are possible (such as biomass, which includes storage but requires a much greater production area), but they will need to be worked out in a second version. An additional factor is the fact that at present, energy is largely generated by fossil fuels and non-renewable materials. An additional important issue is how recycling should be dealt with.

Fossil fuels are technically renewable energy sources, but they are renewed over a very long geological cycle. It is possible to calculate this cycle as it is transformed from biomass at the surface by 60 million years of sedimentation, heating and pressure, into oil. This cycle results in a space-time relationship. The calculations show an effective production of 0.0006 kWh of electricity per year per hectare, or an average of 0.0014 kWh of electricity per hectare-year for all fossil fuels.

Non-renewable materials also have an 'embodied energy' factor, but in most cases they are also subject to exhaustion. This means that the system loses energy (energy potential or energy quality), and this energy needs to be refilled or renewed in order to avoid entropy. There is also a renewable route available to most minerals. For instance, limestone can be extracted from built-up seashells, and plaster can be extracted from evaporated seawater (both of which have a space-time relationship).

For metals, the process is somewhat more complicated. Metals ultimately end up as ions dissolved in seawater as a result of oxidation and being carried to the ocean by rivers. The extraction of concentrated metal from seawater through electrolysis gives an idea of the amount of energy required to replenish the supply. This is the 'Return Energy' which can be converted to an Embodied Land factor for the input of solar radiation.

Recycling can reduce the Embodied Land, but studies show that this is not a free ride. If the first use is not compensated (as described above), reuse or recycling is not free of burden - it is equal to the use of new materials. If compensation has taken place, a correction factor can be applied in terms of space-time.

E1 energy demand in per year for all operating end uses (HVL)	kWh/m^2 ua	21
E2 the fraction of total annual operating energy provided by on-site renewable energy production	kWh RE/m^2 ua	21
E3 embodied energy from the total of off-site materials used in construction ICE database	kWh/m^2 ua	785
M1 total weight per area of materials	kg/m^2 ua	454
M2 Total weight of renewable materials	kg/m^2 ua and %	372 (82%)
M3 Total weight of reused/recycled materials	kg/m^2 ua	0

Calculation for the fourth building of The District of Tomorrow - Table above: KPI according to iiSBE; table below: MAXergy calculation

WEIGHT	floor-net	renewable	normalised weight	design	EL total	per m2 floor	Emb Energy	EE m2/m2 floor	Operational O-Energy	
ton	m2	%	kg/m2		ha	ha/m2 fl	m2		m2-tot/year	m2/m2floor-year
121	266	82	454	group 12	2508,00	9,43	2470,00	9,29	142	0,53

Note: the Embodied Land is in hectare-years and the embodied energy and operational energy figures are in m^2-years! The total Embodied Land is 2508 hectare-years. For only the 82% renewable material its just 21 hectare-years (or 0.08 hectare-years/m^2 of floor space). This results in approximately one football pitch of growth area for fifty years as compensation (Embodied Land) for 266 square metres of floor space. (including and supposing the remaining 18 % of materials have a renewable alternative). The factor between OE and EE in kWh KPI is 37 (-years to equal). In EL its only 17 (-years to equal) Diffrerence is that in EL we include extra energygeneration due to conversion losses for storage) increasing OE m2 pannels.

Dutch Executive summary

MAXergy, en Embodied Land, een gecombineerde energie en materiaal benadering.

Het begon met nadenken over een 0-energiewoning: als alle energie op of aan het gebouw zelf gegenereerd wordt, uit hernieuwbare bron, dan zijn materialen de enige en feitelijke milieubelasting (ook die voor energiewinning) Dus hoe zijn die energie en materialen samen te evalueren?

Weegfactoren zijn subjectief en onderhandelbaar, en daardoor onbruikbaar. Ze moeten vermeden worden, en een absolute evaluatie van energie en materiaal samen is hard nodig.

Ten derde, betrokkenheid in exergetische analyses van de gebouwde omgeving gaven het inzicht dat het uiteindelijk zonnestraling is (en de kennis om die te converteren in - voor mensen -bruikbare vorm) , dat de enige waarde toevoeging aan ons systeem levert, en dus de gezamenlijke impact voor energie en materiaal meet .

Op basis hiervan is een model en berekeningsmethode ontwikkeld, met als onderliggende aanname dat het binnen enkele tientallen jaren weer uitsluitend hernieuwbare bronnen zullen zijn waarop de samenleving zich dient te baseren , zowel voor energie als materialen, op basis dus van zonne-energie (en feitelijk ook voor voedsel en water) . Om zonnestraling te converteren, is ruimte en tijd nodig: : een m2 land voor de installatie van een zonnepaneel, om groente te kweken of een bos te beheren, alles met een bepaalde oogst per jaar.

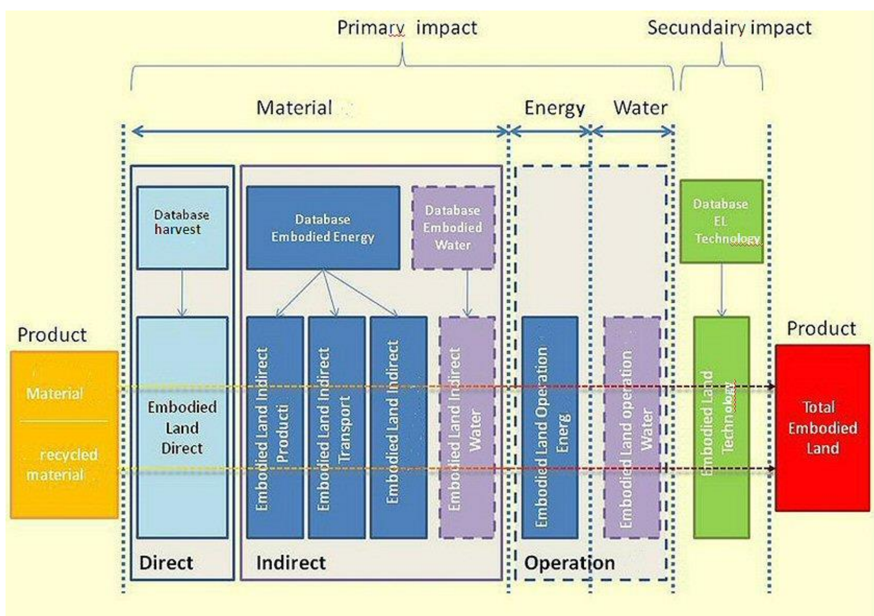
Dit leidt tot een methode, gebaseerd op de effectiviteit waarmee zonnestraling omgezet kan worden, met als indicator Embodied Land: de m2 per jaar geïncorporeerd in een product of gebouw nodig om de aan de vraag te voldoen, of beter: om in de functie te voorzien in de tijd.

Alles teruggerekend naar zonnestraling conversie in ruimte en tijd , als volgt:

- Landbouwproductie voor materialen, in ton per hectare per jaar. (Eigen database ontwikkeling) Dit is nodig om het totaal aantal hectare te berekenen voor bijv bouwmaterialen, in hayear .

- Vervolgens de energy nodig voor oogsten verwerken, transport in eindgebruik, ("embodied energy") die is omgezet in de hoeveelheid zonne-energie benodigd in ha-jaar. We nemen een gemiddelde opbrengst voor onze regio voor de gekozen technologie (nu nog alleen PV) en gebruiken voorlopig de ICE database.

- En we nemen de operationele energy voor het gebouw, in kWh eindgebruik, en omgezet naar m2jaar zonnestraling behoefte.



Dit levert een totaal aan ha-jaar landbeslag, gekoppeld aan het gebouw (embodied Land). Land dat gereserveerd moet worden om aan productie of compensatie van de vraag te voldoen. Dit kan evt over de levensduur verdeeld worden bijv 50 jaar .In dat geval kan de EL gedeeld worden door 50, wat het landbeslag reduceert maar de bezette tijd verlengd. .Dit is de basis . Er zijn echter nog een aantal aanvullingen nodig.

Er zijn secondaire effecten zoals de behoefte aan opslag bij gebruik van zonnepanelen, om 24 uur beschikbaar te zijn . Dit levert omzettingsverliezen (bijv via waterstof) en vergt dus meer productie en embodied Land . (dat kan tot een factor 4 oplopen). Andere conversie routes zijn mogelijk, maar zullen in tweede instantie worden uitgewerkt (zoals biomassa, dat inclusief opslag is, maar veel groter productiegebied vergt.).Daarnaast is een gegeven dat voor het moment nog steeds een groot deel fossiel energie gebruikt wordt, en vele niet –hernieuwbare materialen. En niet te vergeten: hoe om te gaan met recycling?

Fossiele brandstoffen zij in feite hernieuwbare energie , via een lange geologische cyclus Dit kan berekend worden: van biomassa (oppervlak) via 60 miljoen jaar sedimenteren, koken en persen, naar olie, levert een tijd-ruimte relatie op. Dit leidt tot een effectieve productie van 0,0006 kWh-electrisch per year per hectare. (of 0,0017 kWh-e /ha-year , gemiddeld voor alle fossiele brandstoffen)

Niet hernieuwbare materialen hebben ook een “embodied energy” factor, maar kennen in de meeste gevallen ook “uitputting”. Daarmee gaat exergie(potentie cq kwaliteit) verloren in het systeem, dat aangevuld cq hernieuwd moet worden om equilibrium te vermijden. Voor de meeste mineralen is een ‘hernieuwbare route beschikbaar: zo kan kalksteen ook uit (aangroeide) zeeschelpen worden gehaald, en kan gips worden gewonnen door verdamping van zeewater (wat allebei een ruimte tijd relatie heeft) .

Voor metalen is iets meer vereist. De uiteindelijke staat van metalen zijn ionen opgelost in zeewater. (oxidatie, uitspoeling naar rivieren, eindigend in zee) . De reproductie van geconcentreerd metaal uit zeewater door elektrolyse geeft een maat voor de energie benodigd, voor de hernieuwing van de voorraad : retour of “ Return Energy” die weer omgezet kan worden in een embodied land factor voor zonnestraling input.

Recycling kan de embodied Land verlagen. Studie laat zien dat dit geen free ride is: Als het eerste gebruik niet is gecompenseerd (zoals hiervoor beschreven) , is hergebruik of recycling ook niet vrij van belasting , ofwel gelijk aan nieuw. Al er wel compensatie heeft plaats gevonden, kan een correctiefactor worden toegepast, in ruimte tijd.

Berekening voor het 4e gebouw van de wijk van morgen Tabel boven: kpi volgens iiSBE, onder de MAXergy berekening

E1 energy demand in per year for all operating end uses (HVL)	kWh /m2 ua	21
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let op: EL is in ha-jaar en Embodied energie en operationele energie cijfers in m2-jaar!. El totaal is 2508 ha-year. De fractie van 82 % hernieuwbaar materiaal telt slechts voor 21 ha-year. (0,08 hayear/m2floor) op een 50 jaar basis levert dit ongeveer 1 voetbalveld aan groeigebied voor 50 jaar lang op als compensatie (embodied Land) voor 266 m2 vloer. Het factorverschil tussen OE en Ee i kWh ind eppi is 37 (is aantal jaren tot gelijke impact) . In Emb Land is dta slechts 17 . Verschil is dat in EL opslag is meegenomen, waardoor meer PV nodig is om conversieverliezen te compenseren.

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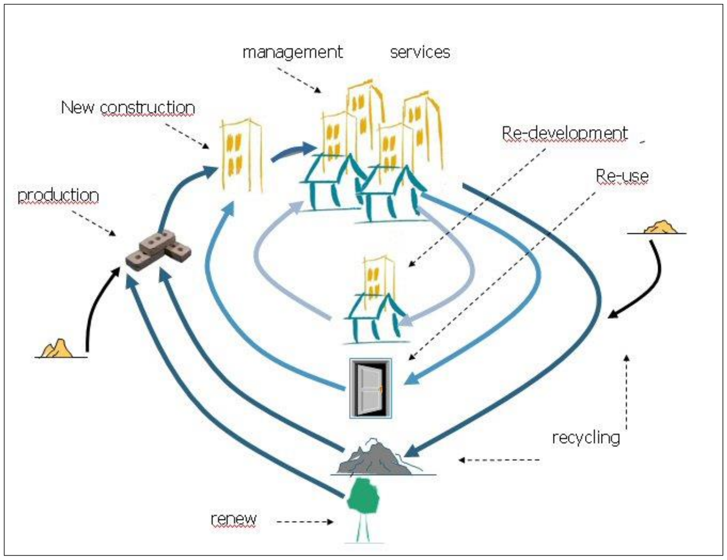
1 Considerations

1.1: 0 Energy

By now, it is common knowledge that the trend in construction is towards 0-energy buildings. The first new construction projects and the first renovation projects have been completed and knowledge is growing. There is also a political tendency in this direction: The EU has already formally established policy stating that from 2018 on, buildings must be '(near-) 0 energy'. And the developments in solar cell technology and other areas are making this goal financially more realistic. But this raises the question of what '0 energy' actually means and what the consequences are. Primarily, 0 energy means that there is a balance between the demand for energy and the supply of renewable energy that is either locally generated or generated by the building itself. So it doesn't necessarily mean that the demand for energy has to be reduced. A second consequence is that if a building is 0-energy, its energy use no longer puts any burden on the environment, because the energy is renewable and generated locally. Any remaining environmental burden comes from the materials used to achieve that 0 balance, including materials for reducing energy use, such as insulation, and materials for solar cells. How can the optimum balance between energy and materials be determined? Leading as well to a optimised level of demand and supply ? Until now there has not been a useful method for finding the right balance between materials and energy without using a kind of 'weighing ratio' [1].

1.1 Closing cycles

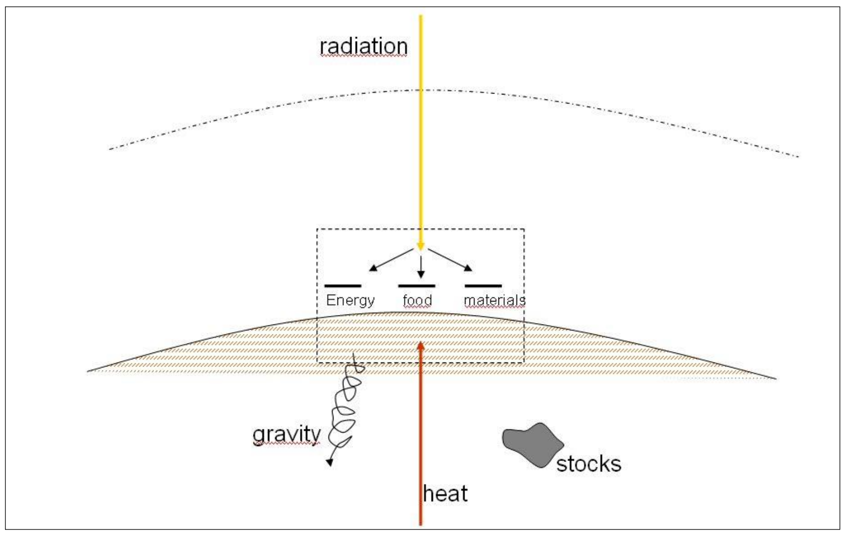
Ultimately, here on earth we need to work to close cycles, in balance between the different resources.. Nature itsself is constantly balancing cycles, and a society that intends to function sustainable (maintanable) needs to aim for this as well. Closing cycles means more than just reusing energy and materials. As long as the demand is greater than the natural supply, the supply will diminish, particularly once fossil fuels have been exhausted in an attempt to use the stock even faster. Ultimately, stocks and natural supplies will be completely used up. In a world with a population of 7 billion and counting, all of whom are striving to achieve greater prosperity and purchase more consumables, additional measures are necessary. It is not enough to merely close the cycle and ensure that all materials used are also re-used and returned to the cycle. It is also essential that the volume of the materials in the cycle, the speed with which those materials go through the cycle, and the amount of energy needed to power the cycle are all kept as low as possible. Balance is achieved when



everything entering the cycle from outside comes from renewable sources. The cycle is powered by renewable energy and the materials themselves are renewable, and what is added to the cycle is no more than can be accounted for by annual growth or inflow. In other words, both renewable materials and renewable energy are dependent on the effectiveness with which we use solar energy, with land area as the common denominator [2].

1.2 Exergy

A recent four-year project researched the relationship between exergy and spatial planning [3]. Exergy[1] considers not only the amount of energy - the kWh or joules - but also the quality of that energy, whether from oil, gas, heat, or biomass. For instance, it is difficult to make electricity using warm water without great losses in power. This is a difference in quality. This idea can be taken even further: Once you have defined a system (a building, for instance), how can you obtain the maximum work from energy within that system? For example, solar cells provide 12 volts of direct current, which is converted into the 220 volts that come out of the electrical outlet in your wall, and your laptop converts it back into 12 volts (approximately). You could get more out of your electricity by connecting your laptop directly to the 12-volt solar cells rather than converting it twice and losing energy in the process. In this way you would need a smaller surface area of solar cells (in theory; this does not count any solar cells used for storing energy). This idea can also be incorporated into spatial planning, in that the demand for energy can be placed in the same location as the supply of energy. But an even better solution would be to limit the demand for energy, or activities requiring energy, to the supply of renewable energy available within the location system (a building, a neighbourhood) - in other words,limit to the heat and electricity which can be generated on the basis of renewable resources within that system. This could, and perhaps should, be a principle of spatial planning. (and is the 0-energy quest)



This research generated a number of insights, most particularly that energy and materials actually have the same origin, namely solar energy. Ultimately, this is the only source which adds something to a system, whether the system is a building, a city, or the world as a whole. Everything used within the system places a burden on the system itself, and its potential is reduced. In other words, solar energy is the only energy source that can increase the power of the system without placing a burden on neighbouring systems. And solar energy

[1] Exergy is more or less a factor of how concentrated the molecules are. If they are highly concentrated, the energy or material can be easily made use of. If the molecules are more diffuse, more energy must be invested in order to make the molecules available in a concentrated form - i.e., in a form suitable for human use.

can be used for producing food, energy or materials - primarily extraction and process energy; but as we will see later, also the growth of and/or supplements to compensation. The use of solar energy requires land on which to collect the solar energy in order to convert it, so land has the potential to generate quality. And the use of land is an interesting indicator for exploring how we can maintain the quality within a system, or at least ensure that it degrades as little as possible. In principle, we need to avoid degrading the quality, because that will gradually lead to exhaustion of the system, and in the long term to a dead area in which nothing can survive. Focusing only on energy and not on materials may appear to be a smart approach (as in the case of the 0-energy home), but really, we are digging our own grave by doing so.

The conclusion of the research mentioned earlier is that activities should not be brought to those places where energy is available, but rather that every piece of land or location can deliver a certain maximum amount of power (from solar energy), and that all activities (within the defined system) must remain within that limit, no matter where they are or what they consist of.

2. MAXergy and the Embodied Land tool

2.1 Sun and land

Solar energy therefor is responsible for everything that we are able to do on earth. Solar energy is responsible for life itself. It causes food and materials to grow. We can also collect solar energy and convert it into heat or electricity. It is possible to use solar energy to make things; but doing this requires land. Land can generally only be used for one thing at a time: growing food, for instance, or collecting solar energy. Usually, it is not possible to do both at the same time on the same piece of land. Yet it is essential to ensure that there is enough land to perform the necessary functions on, so that we have enough of the things we need. So land is the most important factor in terms of the use of resources.

(even if it seems currently overdone, in the end this will be the siuation, as many cultures already experienced (like Easter Islands) . And In Maxergy we take this as a starting point to evaluate our resoruce consumption, and measure how far of we are from that closed cycle situation.)

In order to determine how much land is needed, it is necessary to look at the amount of land being used for the components mentioned above. The MAXergy method was developed to accomplish this. The name 'MAXergy' means 'maximising exergy,' for material and energy together. The Embodied Land calculation tool is based on this method. In this method, the various components which are grown or generated by the sun can be compared to one another. The method as it is here described examines the components of energy and materials from what we call the Concept of Zero: the startegic approach to not only achive 0-energy system, but also 0-materials, 0-water, 0-food.) stands fort he closed cycle situation, zero degradation or 0-impact .

2.2 Space-time

In order to compare energy and materials with one another, they must first be comparable to one another. Ordinarily, materials are measured in terms of kilograms and energy is measured in terms of kilowatts. These two units cannot ordinarily be compared to one another. It is thus necessary to find a unit which can measure all the various components which grow or are generated by the sun, so that they can be compared to one another. The common basis for comparison became all components to be calculated in terms of square metres of land use. The method looks at the surface area of land used to grow materials or to generate energy. Looking at land use automatically creates a link between energy and materials. Its the

But merely looking at surface area does not give us much to compare: How much energy can be generated by the sun on how many square metres of land? It is necessary to look at a particular length of time in order to determine this. Time is therefore also a factor. In the case of energy this is relatively simple, but for materials it is much more complex.

Nature is the basis for all the materials we use. This is easy to picture in the case of wood. The sun makes trees grow, which are cut down, sawn into beams or planks, and used in construction. The trees need a certain amount of time to grow, So a particular number of trees must grow for a particular length of time in order to produce the particular amount of wood needed for the construction of a building. And those trees need a particular amount of land area. This is logical and simple to follow. But it also works for other materials - metal, for instance - though more difficult to visualise. Steel or aluminium does not grow out of the ground, like trees. It was necessary to find a different method of analysis for these materials. That method is as follows.

Given enough time, metals are eventually washed away out of a system and transported by rivers into the oceans. After even more time, these metals coalesce together. This results in nodules of metals being formed on the bottom of the ocean. In theory, it is possible to harvest metal nodules from the ocean (in the future this may be possible in practice as well). This proces makes it possible to ascribe a certain land area to metals (amount of iron content in nodules per seabed m2) . As a result, it is also necessary to ascribe a certain length of time to the renewability of metals (the concentration of molecules). However, very little is known about how many manganese nodules can be found on the ocean floor and the time necessary for them to be formed.

Another possibility is not to wait until the nodules have formed, but to interfere in the iron cycle at an earlier moment: to filter the metals out of the ocean directly (before becoming nodules) using an electrolytic process. This method will require the use of serious amounts of energy. This energy, in turn, can be calculated as the amount of land needed for solar cells to generate that energy. This is used as a preliminary reference method in MAXergy.(later other interceptive moments could be calculated, like rocks)

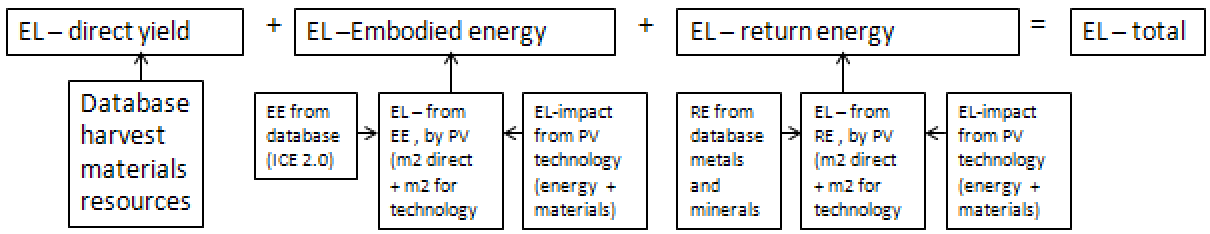
The MAXergy tool compares energy and materials to each other in terms of land surface area and time. This automatically results in the unit 'space-time in m^2-years'. The time is examined in terms of years because this is the unit which is best suited to growing materials and generating energy. The connection between space and time is as follows. Growing a particular amount of material or generating a particular amount of energy in one year's time requires a particular surface area. If the growth of the material or the generation of energy is spread out over several years, the amount of land required to do so automatically shrinks, because it can is spread out over more years. This is only feasable, when the function os also spread over more years, otherwise a heritage in resource claim remains after the functional period.

2.3 Embodied Land

The term 'Embodied Land' is derived from the concept of space-time. The word 'embodied' may be familiar as part of the term 'embodied energy,' the amount of energy needed to make a product. Embodied Land follows the same principle. It is the amount of land needed for a particular length of time to make a product or form of energy. The MAXergy tool calculates the Embodied Land. The smaller the Embodied Land, the fewer m^2-years are needed to generate the energy or produce the materials for a building, for instance. The Embodied Land can be divided up into components in order to look at the materials and products used in a building. First of all, as explained above, Embodied Land is necessary to grow a material. But another component which must be taken into account for Embodied Land is the energy needed to harvest, process and transport this material (the embodied energy). And to generate this energy, more land is needed. In the case of metals, for instance, energy is needed to recover from the exhaustion of the resource, in the form of extracting the metals from ocean water (called the 'Return Energy'). And a certain number of m^2-years are needed in order to produce that energy.

So the total Embodied Land consists of primary Embodied Land and secondary Embodied Land. If we take this further, for instance at the space-time necessary to grow the tools used in the harvest process, such as a saw, a tertiary Embodied Land can be added. However, the fractions become increasingly smaller (the saw is used for several tasks) and for this reason, we chose to include only the primary and secondary Embodied Land in the MAXergy calculations.

The results of MAXergy calculations usually show that it is better to use as little material as possible in a structure such as a building. The less material that is used, the smaller the space-time will be and the more m^2-years can be used for other purposes. The number of m^2-years arrived at with the MAXergy tool is actually the space-time needed to 'regrow' a building (to regenerate the resources) . In this way, each building can include its own garden the size of a certain number of m^2, in which the same 'building' can grow over a certain number of years. In fact, this is a 0-material building!



Simplified model calculating Embodied Land –for each resource. For energy generation based on multi-crystalline PV, including storage. (but could be replaced by for instance biomass energy) . Operational energy is to be added similarly , as EL for OE, direct PV surface plus technology related EL.

2.4 Other tools

Relation to existing tools

There are many tools in existence for analysing the sustainability of buildings and areas, but they only very rarely measure the actual improvements to the impact on resources and climate Nearly all of them use subjective scoring methods, apply weighting factors which arbitrarily count various elements together, and/or compare the new situation to an old, 'bad' reference situation from the past. In addition, some tools combine source and process measures and weight them together. Studies indicate that tools are very vulnerable when a variety of indicators are counted together in order to achieve a single score [4, 5]. Many tools are so complicated that their calculations are no longer transparent [4].

Tools Characteristics: differences

Cause	-	effect/impact
Absolute	-	relative
Historic benchmark	-	future target
Weighted results	-	un-weighted results
Performance	-	process evaluation
Unit-less	-	Mass/ CO2/ physical/money unit
Climate adapted	-	non-adapted
Socioculturally adapt.	-	non-adapted
Whole chain ass.	-	construction assessment

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Ultimately, we want to measure whether we are truly heading towards a balanced use of resources at a fundamental level so that future generations are guaranteed that they will also be able to use these resources - in other words, whether our use of resources is sustainable or can be continued over time. This means that we are not interested so much in the absolute use of resources, but in whether we can continue this use within a particular space and for an infinite length of time. In other words, we are not trying to optimise the life cycle, we are trying to achieve a closed cycle, which can continue to flow.

A good instrument which monitors the progress towards a closed cycle must fulfil the following requirements:

- Performance-oriented: Only measure the actual use of the resources. Looking at social, economic and organisational aspects (such as noise, accessibility, social safety, costs) can mean that the actual improvements to sustainability in the sense of burdens on resource use (whether the use can be continued over time) may be neglected. The other aspects are useful, but if there are no more resources with which to build, there is not much point to evaluating the soundproofing or accessibility of a building. Everything starts with resource management.

- Realistic units: The scoring represents a physical unit. Scoring by means of a made-up value is relative and subjective.

- Unweighted: Weighting factors are subjective and should be avoided.

- Distance to target : Look at the situation from the perspective of the future and measure the progress towards a sustainable end situation instead of measuring relative improvements compared to an old, non-sustainable starting situation, such as a benchmark building. In MAXergy this means that a particular function has a particular land impact. If that land is not reserved for that function, there is a difference compared to the ideal situation, or distance to target.

- Cause/effect: Focus on the cause of effects, not the effects themselves or end-of-pipe measures, so that the problem is truly solved and not merely shifted to a different location or point in time.

- Quantitative: The scoring makes use of absolute results. Relative/qualitative scores create subjectivity and mask degradation of the system.

- Not corrected for climate: Some calculation methods apply a correction for the climate zone, such as degree days for a building. We do not do that in MAXergy. The location has an influence on the Embodied Land, so the climate circumstances is part of the calculation.

- Not corrected for behaviour: Of course the ultimate use of a function determines what the burden will be. For instance, leaving a window open in the winter increases a residence's energy use. Use is not a component of the evaluation of function. The designer/producer cannot be held responsible for the fact that a resident leaves a window open. Maintaining the balance between the reserved Embodied Land versus the actual use of it will need to be part of policy, not part of the initial evaluation or calculation of a building.

- Clear delineation:

We have tested a number of tools against these criteria and the currently available tools do not fulfil them (see Appendix). The MAXergy method is an attempt to fulfil these criteria.

Comparison to existing databases

The set-up of the MAXergy database is particularly reminiscent of two other approaches: LCA and Ecological Footprint. Therefore, we will briefly compare these two methods to the MAXergy tool.

Embodied Land vs LCA

Many of the tools mentioned above use databases for LCA calculations, such as those from ecoinvent, SimaPro, MRPI and the ICE, as input for their analysis. In the LCA method, the environmental impact of all processes in the chain of a product are shown for a range of different themes. A weighting factor bundles these effects into a single score for the total impact of a product. Land use is also included as an impact in the assessment, in particular for agricultural and forestry products (in m^2-years). Objections to the use of the LCA database include the fact that every phase in the life cycle has a margin of error, which builds up with each new process (this is also a risk in the MAXergy approach). In addition, in the LCA method, the weighting factors are a subjective and artificial way to arrive at a single final number. On the other hand, the MAXergy tool does not directly take environmental effects into account (for an explanation, see 'Embodied impact').

Many environmental effects are a consequence of particular primary resource use and not a cause (this can result in double counts - see 'Embodied energy' for more information). The biggest difference, however, is that MAXergy does not evaluate an entire spectrum of effects but assumes cause and input: It will need to fit within a cyclical use of resources. In this case, the effects are less relevant. Of course, CO_2 is released when burning biomass, for instance. But the amount of CO_2 has already been established by the growth in that same biomass. So the CO_2 itself is less relevant than whether the biomass is regrown - in other words, whether land is reserved for it, so that the supply is not exhausted.

Embodied Land vs Ecological Footprint

The MAXergy tool and the tools for Ecological Footprint have some similarities. Both methods give a final result in terms of the number of hectares needed, but MAXergy gives the result in hectares needed for a product or service while Ecological Footprint gives the result in hectares needed per person/city/region/country (including for food). So the Ecological Footprint method links actual burden to user behaviour, which are actually two entirely different units, as explained above. Although it does give practical insight into the burden we create, it is not feasible as a way to value the actual function, such as in the case of a building. Furthermore, both methods divide the unit to be investigated into primary materials and use the terms 'embodied energy,' 'embodied footprint' and 'embodied land': '...the embodied Footprint is measured as the number of global hectares required to make a tonne per year of a given product.' One difference between the MAXergy tool and the Ecological Footprint tool is that the Ecological Footprint tool compares the consumption in hectares to the land available in the world, making it clear whether we are using more land than there exists or not. This also takes the productivity of the land into account. In contrast, the MAXergy method looks at the returns of solar energy when converted into a usable resource per location, not an average. In addition, the Ecological Footprint method looks not only at the production and consumption of resources, but also at the production of waste and the ability of the ecosystem to process that waste so that it does not accumulate (here, 'waste' includes greenhouse gases and their absorption by the ocean and vegetation). But that is combining end-of-pipe effects with causes, and it is precisely this that MAXergy tries to avoid.

The MAXergy tool offers a new approach, with other possibilities for application.

1. The Ecological Footprint tool only looks at renewable resources which can regenerate or reorganise themselves within a human time scale. Non-renewable resources and resource exhaustion are not taken into account. The MAXergy tool does take these aspects into account.

2. The Ecological Footprint tool does admit that its results cannot be seen as an indicator of how sustainable a country or individual is (here, 'sustainable' means the prevention of resource exhaustion), in part because CO_2 emission is included as 'production' in addition to the actual use of resources. That causes the balance to shift. Nor does it examine the results per product, but primarily per spatial system, meaning that import and export could distort the image.

3. And that brings us to the most significant difference between the two methods. The Ecological Footprint tool looks at end-of-pipe effects such as compensation land for CO_2 emissions, whereas MAXergy assumes a closed cycle and for this reason looks at the primary burden. For this reason, CO_2 emissions are irrelevant in the MAXergy tool.

4. The outcome of an Ecological Footprint calculation is not given in absolute hectares, but in 'global hectares,' representing the average production of a single hectare in the world. This means that the embodied footprint is based on averages and not on hard facts.

As such, MAXergy's use of hectare-years in order to establish the sustainability of a product, service or building is fundamentally different from the Ecological Footprint method, although the two methods are comparable at the basic level. MAXergy is also useful for evaluating products or functions, including non-renewable materials.

3 Details and background information

3.1 Function and system

In principle, MAXergy looks at the impact of *performing a function* within a delineated system. It is important to define the function, because that determines what is asked or what must be provided. For instance, the function could be 'providing shelter for a certain number of m^2'. Another example is the function 'washing clothes'(in contrary to laundy machine performance: ist not laundry machines we want, but our laundy cleaned) . Using this as the starting point generates various possible solutions at different levels of scale, for which the Embodied Land can be determined. For instance, you can look at 'washing clothes' at the level of a single washing machine or at the level of a laundromat for an entire neighbourhood with pick-up and delivery services: In both cases the result is that clothes get washed. But which of the two has the lowest Embodied Land? Or another question, for which MAXergy is specifically suited, is the consideration of whether to use more insulation (materials) or to produce more energy in a home, whereby energy and materials must be considered together. The function in this case is providing heat (within standard comfort zones); whether that occurs by means of more insulating material or more solar cells is in principle irrelevant - what matters is the optimum balance, with the fewest m^2-years.

In a second phase, the actual implementation in society of the results, this MAXergy evaluation system is overruled by a second valuation system - the monetary valuation system, with euros as the unit of measurement. It may be that a different consideration is made on this basis. If money considerations result in a choice other than that of the lowest Embodied Land, this likely means that the monetary system does not match up with the physical valuation system. Which iss not unexpected, since the monetary system is not based on the physical valuation system in any way and often leads to counterproductive or non-optimum choices. There's a good reason why we're in so much trouble environmentally speaking.

MAXergy can be applied to systems of any size - in fact, MAXergy itself determines the size of the system. When a residence is evaluated, the construction site may have a particular surface area, but the outcome of the MAXergy calculation may demonstrate that the surface area needs to be much larger. The impact of the building system is thus calculated, but in fact as well the exergetically burdened space, or how large the actual system can be and needs to be. MAXergy can also calculate how many functions will fit inside a particular space, such as how many homes and their Embodied Land will fit in a hectare. The initial results of calculations show that this is approximately two single-family homes. In the Dutch province of Limburg, each hectare has an average population of 5.2 people, or approximately two families. However, this includes the land needed for energy, materials and water, but not the land needed for food and any cultural and social services (buildings). And this calculation assumes that the residence has a lifespan and 'payback period' of 50 years. If that period is extended to 100 years (for use of the residence), the demand for space is reduced by half and space is created for food. This example clearly shows how Embodied Land can be used to gain a clear picture of what is needed so that good decisions can be made. It also shows how the cycle can be closed by including time and volume: The speed at which something travels through the cycle can be slowed down, creating 'space,' or space-time).

MAXergy can also be used on a larger scale, such as a neighbourhood or a city, to gain a broader perspective. The Urban Harvest+ method was developed to this end. It makes an integrated consideration in combination with other requirements, particularly those arising from an existing burden (the existing neighbourhood, for instance), in order to determine how the burden can be reduced within the limits of the system being examined. For more information, see the relevant documents.

3.2 Harvests

The basis for the Embodied Land calculation lies in determining the harvest per hectare of land. This is not always easy. For comparisons of wood to bamboo (both in processed form), for instance, it was very difficult to find good, reliable figures. Forestry companies prefer to keep their figures secret, or else they provide incomplete information. The figures are also presented differently each time: dried or wet, sawn or raw; and it is unclear whether a reforestation policy is implemented in cases of clear felling. For bamboo, there are simply too few figures available as yet. This was the impetus for investigating the forests in China on our own (see the relevant research). For cork as well, the situation only became clear once we asked the growers themselves. This revealed that for the first eight years, a cork oak does not produce any cork, and that afterwards only a certain part of the bark can be used. Ultimately, when production is averaged out over the entire lifespan of a cork oak, it only produces 125 kg per hectare-year. That is a ridiculously small amount, and while it may be enough for a few wine bottles, it is not enough to be used as a construction insulation material in bulk. The situation is even worse for sheep's wool: If sheep were only kept for their wool, and that wool was only used as insulation material, that would result in approximately 25 kg of wool per hectare-year.

flax fibres (vlas) for insulation material	2.000	kg/ha-year
flax shives for partile board / flax board	3.000	
flax linseed for linoleum	1.500	
straw	4.000	
roof reed (dry)	6.500	
sheep wool	29	
hemp	3.500	
wood	10.800	
bamboo	36.000	
cork	125	
shells	245	
loam	1.000	
sand	1.000	

However, most figures can be found from available sources, particularly for forestry and agriculture. These figures are still locally determined, because the yield from the land is highly dependent on the climate and the cultivation methods. In other words, the same building located in two different countries can result in two different Embodied Lands. It is also likely that in different locations, different choices are made regarding energy and materials. This also demonstrates the fact that the MAXergy approach bases its assumptions on the energy and materials that are available locally and compensated locally. MAXergy works with the immediate exergetic quality which is present and on which choices are based; moreover, MAXergy is based on the inherent quality of the individual energy and materials and the data is not transferred in advance to a different, unregulated system. In principle, each square metre must be used productively.

To return to the example of sheep's wool, the question is whether a sheep is kept solely for its wool, or whether the wool is a by-product of an animal that is actually kept for meat or milk. That brings us to the issue of allocation - that part of the hectare that is allocated to the raw material used for the actual application.

3.3 System limits and allocation

Sensitive aspects of the calculation are, on the one hand, the yields per hectare (the published figures disagree to some extent - for more information, see the explanation of the database); and on the other hand, the calculations made with the yield, which is only rarely used for just a single product.

A crop consists of various parts which can be used in various products. Sometimes, only a portion of the crop is used for the product being calculated. This phenomenon is called allocation: how much of a product is assigned to how much hectares of land.

In principle, there are four possibilities for allocation:

1. The non-used portion remains on the land. The entire hectare is allocated to the product, despite the fact that only part of the harvest is used, because the hectare is not available for other production.

2. We allocate everything to one product, even if part of the harvest is not used, as in possibility 1 above, unless it is clearly demonstrated that the remaining part of the harvest is used, perhaps by third parties. In this case a reduction factor is applied.

3. We make the assumption (even though we cannot verify it) that all of the harvest is used, in part for our desired product, the remaining part by other uses. In this case, the figure is calculated as x% of the land when x% of the yield is used directly.

4. We assume that the remainder of the crop is used to produce energy, which is calculated separately. In the study *Duurzaamheid van Biobased produkten* ('Sustainability of biobased products') [6], for instance, allocation is avoided by assuming that the coproducts are also harvested and used for energy, in principle to benefit the same process. In other words, this is a combination of material and energy benefiting the material.

The first variant is clear, but it is probably not ideal. One issue is that it creates a problem with optimisation. It no longer pays attention to whether, for instance, one type of bamboo is used at 50% (for a particular amount of product for a particular function) and another type is used at 75%. Both types of bamboo are allocated the same amount of hectares, even though with one type, fewer hectares are available for a different function.

If more of a resource can be used for the same amount of product, this does make a difference, as it does when the same amount of resource results in more product per hectare allocated. However, the gross and net calculations on the basis of the portion of hectare used will still be lower, as is the case with variant 3.

The second variant is an improvement on the first, and can be implemented up to a possible maximum limited by the minimum essential amounts of organic material which must remain in the soil. So far, however, this amount is unknown, or in any case uncalculated (see below).

The third option is a net land use method. The crop remains are assumed to be used (and to be suitable for use), but no account of this is required.

Regarding option four, although it is a very neat way to solve the problem of allocation, it is exergetically irresponsible: The difficult-to-generate quality is immediately sacrificed through burning or other means. The mass could have spent longer serving as mass before being burnt, which would put much more exergy into the system and slow the speed at which the cycle travels. The basic principle is 'once mass, always mass,' because:

1. Its energy production is ineffective. Solar energy is used to produce mass, and then the mass is expected to produce energy in turn. It would be better to produce energy more directly.

2. Mass is needed more earnestly, and sooner in the cycle, than 'external energy'.

3. Mass can always be converted into energy in the long term. After functioning as a plank for 100 years, a wooden plank can still be burned for energy. In this case, the material has a double exergetic effect. It first fulfils a particular function for a number of years, and then as a bonus, it also has the energy which will be released by burning. So this system severely underuses the potential exergetic value.

4. Biomass stores CO_2, which is released through burning, giving it a net result of zero.

In principle, all biomass generated can be used for products, in degrees of quality varying from low to high (depending on the level of energy input). One criterion could be the fraction of the biomass that is given a high-quality use: bamboo as wooden beams as opposed to bamboo fibres or sawdust being used as filling material or fuel. This would need to be calculated in terms of space-time.

Moreover, it may be that the Embodied Land of biomass energy is better than that of other energy routes. This is unlikely, but not impossible. However, this has not yet been calculated, and it is one of the proposed follow-up studies.

Nutrient balance and remaining organic soil material

In addition, none of the options offer a clear answer to the issue of how the nutrient balance of the soil is to be maintained if no remains of the crop are left on the land. In principle, in 'standard' agriculture the nutrients are supplemented by the natural annual influx via water and dust-materials. This is the case for extensive agriculture and varied crop cultivation. In the case of intensive monocultures, the nutrients must be supplemented further, by means of artificial fertiliser, for instance. This process is too complex to be discussed here in detail, as this is an entirely different discipline. In the MAXergy system, we have chosen to assume that a form of agriculture is used in which the nutrient balance is 'maintained'. Additional research into the database may change this view, and in the long term it may be possible to distinguish between yields from intensive and extensive cultivation and the corresponding Embodied Land effects.

As for allocation, within MAXergy it can be approached in one of two ways:

A. From the point of view of the achievement or product/function. A particular number of hectares of land are needed to provide the required amount of material, regardless of how much of the yield is used. This amount of land is needed in any case, regardless of whether any portion of the yield is available for other users. The entire hectare is needed for that portion of the yield that is used, and using just a portion of the hectare would not have yielded the required amount.

B. From the point of view of land yield. What is the ideal product combination in order for 100% of the yield to be useful and usable, not counting the portion which needs to remain behind for the sake of soil balance? The second approach could result in a different product choice, such as having slightly less of one product in order to make the remainder more useful for a second product.

This is an ideal approach, but also a very complex one. In actual fact, an integrated system approach is called for, in which the land determines the range of materials, but this is outside the scope of the approach chosen here. This is why the MAXergy system uses the function approach in combination with supply. In other words, the entire hectare is allocated to the product (A) and to the Embodied Land calculation. This has been done in the form of variant 2 in order to ensure the possibility of implementing a reduction factor in the future on the basis of more research.

The Urban Harvest+ study (focusing on existing areas) [7] established that there is also an order of priority in resource use: Food comes before materials. If land use becomes critical, food will be given priority over materials. This means that even now, it is worthwhile to produce building materials from the remains of food production, such as using the straw remaining from grain production. In that case, it will be necessary to look at allocation in more detail, because the hectare would in principle be allocated to food, and the materials would be a 'bonus' (B).

What is true of materials is also essentially true of energy: A hectare of solar panels produces electricity, but in the process heat is lost, so only some of the potential is utilised. In this case we allocate the entire hectare to the production of electricity by solar panels. But this does not preclude the possibility of increasing the energy productivity of a hectare - just as is the case with agriculture.

What this comes down to is that MAXergy 1.0 works with the direct approach of 'one hectare for one hectare,' in which the optimisation of the productive use of land is left to other research for the time being. As they become available, new results could update the database or lead to a different way of dealing with allocation. This would then be 'MAXergy 2.0'.

3.4 Energy in MAXergy

As established above, the earth is a system slowly gaining in entropy (the loss of energy and/or quality), which can only be compensated by the constant addition of solar energy. And this is also true of systems on a smaller scale, such as a country or an individual neighbourhood. Ultimately, the efficiency with which solar energy is utilised for energy, food and materials determines whether a system exhausts itself (and how quickly), maintains its balance, or even improves in quality. (in a natural or organic system, this process occurs automatically). In MAXergy, we calculate the effectiveness of the application of solar energy, taken from the moment the energy reaches the earth's surface and measured for the amount of time needed to achieve its function.

For the requirement of quality in the form of energy, we initially decided to assume that energy is delivered as electricity via solar cells, specifically via polycrystalline photovoltaic cells. This is primarily a practical choice, but also a rather arbitrary one. Energy can enter the system through a multitude of other ways (wind, hydropower, biomass), but as we continue to develop the system this will need to be investigated as an option and calculated (or set up as a preference if research indicates that the Embodied Land can be reduced in this way).

When calculating a building, the operational energy is of major significance. First of all, it is necessary to directly calculate the number of solar panels needed to meet the final demand (possibly including energy exchange with the grid). This is the 'demand impact,' or DI.
Additionally, there is the impact of the materials used for the production of one square metre of photovoltaic cells: That is the Embodied Land (EL) calculated from land use for primary material production, embodied energy and perhaps return energy for the panel itself (return energy will be discussed in more detail below). This is called the 'panel impact,' or PI.

On top of this there is the 'system impact,' or SI. The energy from solar panels cannot always be used immediately and some of it must be stored. For short-term storage (from day to night) this can be done with batteries; for long-term storage (from summer to winter) this can be done with hydrogen, for instance. This is the option we have chosen for the time being. Research may be able to calculate other options with a more effective use of land.

The impact of energy is an issue not just when calculating the Embodied Land for the operational energy but also in terms of materials as a source of embodied energy (and any return energy). This applies to both photovoltaic materials and to construction or product materials.

Operational energy

The starting point for the operational energy is the straightforward number of square metres of solar panel times the impact of the panels themselves. The operational energy requires a continuous supply - in other words, the timeliness of the supply of energy is important. This is why the SI is calculated in addition to the DI and the PI. The SI is the primary surface area of photovoltaic cells plus additional surface area to compensate storage losses, times the impact of the physical panel.

There are two good reasons to include storage (SI) and not to assume connection to the grid. One reason is that in the future, everything will be based on solar energy and storage will be essential. The other reason is that it enables an honest comparison with biomass or other energy routes for which storage is inherent.

Of course the installations implemented also have an impact (in terms of storage, for instance), such as fuel cells and storage tanks. They can probably be shared with other projects, such as for hydrogen production at a neighbourhood level. These 'third-order effects' have not been taken into consideration in the calculations.

The installations for direct use, such as for heating and lighting, do need to be evaluated. In this case it is the cables and equipment that are of importance. Because of a lack of reliable figures, these elements have not been included in the examples, but this will be necessary in the future..

Material-based energy:

Material-based energy refers to the embodied energy and the return energy. In this case, a timely supply (in real time) is not essential, but the amount of energy supplied is. As a result, material-based energy is calculated together with the demand impact and the panel impact, but not with the System Impact. For the PI, one twenty-fifth is calculated - in other words, the PI is divided by 25 years, the lifespan of the panel (PI25), because this is not supplied each year, but only once. If the panel supply balances its impact within one year, it still has 24 years of productivity for other demands.

Fossil fuels

Of course fossil fuels will continue to be used for the time being, probably until they are all but exhausted. This means that it is necessary to find a mode in which fossil fuels can be incorporated in the Embodied Land calculations. This is simple in and of itself, because fossil fuels originated as biomass which became trapped between layers of rock through erosion and sedimentation, underwent extreme heat and pressure for millions of years, and was ultimately transformed into petrified carbon, bubbles of gas or pools of oil. It is therefore possible to approximately calculate how much oil a hectare of land can generate per year. This amount is very low. A rough calculation provides the following results:
Given a rough estimate of the total used and known supply of fossil fuels, divided by a process time of 65 million years, approximately 14,000 litres of oil per day are added around the world.
If we distribute that over the surface of the earth (the production area: 510,066,000 km^2), we arrive at approximately 0.01 litre of oil per km^2-year. In terms of energy, this is approximately 0.0012 kWh per hectare-year. With central returns of 50%, that is equivalent to 0.0006 kWh per hectare-year. If gas and coal are included, the overall total is 0.0017 kWh per hectare-year.
Compare that to one hectare of solar panels, which generate 1,000,000 kWh per hectare-year! [2]

Here, too, the figures refer back to the original solar energy, the source of both forms of energy. The returns for solar cells amount to 14% and the returns for fossil fuels are 1×10^{-9}%, or 0.000000001%. These are only rough figures; the margin of error may be an order of magnitude or two. This does not really make any difference to the conclusion. The fossil fuel supply can be seen to be infinitely inefficient, regardless of the actual values [8].[3]

In MAXergy, we do not take fossil energy into account in principle, but it is possible to make a comparison on the basis of land use by fossil fuels. Chapter 4 includes an example of this.
MAXergy assumes that eventually, we will only be able to work with solar energy. By calculating in this way, it is possible to see how far we are from achieving that goal, assuming that certain fuels and materials will be phased out or will become exhausted.

3.5 Materials in MAXergy

So far we have been speaking in terms of renewable and non-renewable materials.

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[2] These figures do not include the impact of energy and materials for the panels or energy and materials for the power stations and electricity grids. The panel effects are included in the MAXergy calculations (see above).

[3] This also makes it clear that the term 'primary energy' is out-of-date. For years, this term has been used by the fossil fuel sector as a unit of measurement, but this disguises the actual impact: Primary energy assumes that fossil fuels have the highest exergy, and this standpoint is the basis for calculating effectiveness and the entire prior history is ignored. The yields from solar panels converting solar energy into electricity is also compared to the returns from converting fossil fuels to electricity. In fact, this ignores a portion of the conversion route. By doing so, the fossil energy sector creates the possibility of further increasing the system's entropy - in other words, of destroying quality. The only proper approach is to utterly disregard the concept of primary energy and replace it with something like 'primary solar energy' (PSE) and relate all energy sources, including fossil fuels, to that.

Non-renewable materials include metals, materials with an inorganic origin, or minerals, assumed to have a very long replacement cycle.[4]

Renewable materials usually have a natural/organic origin and have a short replacement period. Some minerals are considered renewable; this distinction is not always clear. At present, the term 'biobased' is in wide use, but it has several definitions as well.

In our research, we discovered that in fact, all materials are renewable, but the time span and the route vary. For instance, metals are renewable, in the sense that they leach or weather away, are dissolved in water and wind up in the ocean. By pumping seawater and filtering out the metals, it may be possible to supplement and replace the original supply of metals. Similar routes are conceivable for all metals and minerals. We have named this concept 'Return Energy'. And the Return Energy can be used to calculate the Embodied Land.

The ocean route appears to be the most logical on the basis of initial considerations, with the least impact for the environment. But it could be that research investigates or discovers other routes for regeneration which are more effective.

2. It seems excessive to include this high factor of return energy in the calculations. However, in an exergy-based approach, it is necessary to gain an understanding of the exhaustion and entropy, because otherwise the system will evolve to a dead state, without quality potential. Moreover, we do include this factor for renewable materials, in that the land needed for potential growth is part of the calculations. This is logical when one thinks about it. Either the regeneration of both renewable and non-renewable materials should be calculated, or neither should be; but this would mean that only embodied energy and the Embodied Land derived from it are included in calculations. And we are not only exhausting our fossil fuels, we are also exhausting renewable resources (forests are no longer being regenerated).

In fact, the major difference between metals and minerals on the one hand and organic materials on the other hand is that the one can be renewed through human intervention by adding energy, and the other can renew itself in a natural process. The only difference is the route taken.

For this reason, we have chosen to use the following distinctions:

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[4] *Note: In general it is assumed that these objects cannot be renewed, hence the name. That is not entirely true: even for metals there are natural recover routes, but they take place over millions of years. In that sense they can be compared to fossil fuels. One known route, which has not been calculated, is that of the manganese nodules. It appears that metal ions are dissolved in seawater, are lumped together by means of algae and land on the ocean floor in high concentrations of fist-sized nodules. It is not known how long this process takes. Initial attempts have been made to harvest manganese nodules, most notably by Japan. Ultimately, most materials, including metals, will wind up in nature as highly dilute ions, and from there they will end up in the oceans. Compare this to energy which transforms into heat of decreasing density or delta T and as such becomes unsuitable for direct use and escapes into outer space. In other words, its entropy increases. In order to maintain the exergy in this system, the concentration of materials must also be maintained. The use and loss of metals must be compensated.*

Renewable materials: Materials which can be renewed *through human intervention*;
and
Regrowable materials: Materials with a built-in mechanism for reproducing in nature - organic materials. (within a generations lifetime).

Both types of materials can be renewed through the addition of solar energy, either directly (for organic materials) or indirectly (for inorganic materials). As such, there is no real difference between the two, and therefore we do not make this distinction either. They are characterised strictly by the amount of solar energy and the surface area of land needed to close the cycle and prevent exhaustion.

NOTE! These are not standard terms, but they are used in MAXergy-related works.

However, regrowable materials do not always regrow automatically. This is an area where human intervention is counterproductive in that it can obstruct regrowth. If a forest is cut down and a new housing estate is built where the forest used to be, the wood has been used, but it has not regrown naturally. The fact that it has not been renewed is a direct result of human intervention. This is a form of exhaustion, and any advantage has been lost.

It is worth pointing out that the Cradle to Cradle approach [9] assumes two cycles: an organic cycle and a technological cycle. The organic cycle renews itself and the technological cycle is about recycling. In MAXergy, we have come to the conclusion that there is only one cycle, which must constantly renew itself, and that the difference lies only the route and time span over which that renewal takes place. In contrast to the C2C philosophy, the MAXergy approach makes it clear that there are still limits to the availability of materials, and that despite recycling efforts there are also still limits to the amount of materials available. The basic idea is that without renewal or regrowth, exhaustion sets in and exergy is lost. This is discussed further under 'Recycling'.

It is important to be aware that the definition of renewable materials does not in any way include materials which can be used in a new way at the end of their life cycle, such as by recycling. This is something which is often heard in the field: 'Don't worry, it's renewable. Everything we're using can be used in a different way after being demolished.' That is recycling or reuse, but not renewal! This is a worthless argument for other reasons too, because it merely delays dealing with the problem, as explained in the following paragraphs.

3.6 Recycling

In principle, recycling (or reuse) is nothing more than an extension of the useful lifespan of a material by adding extra energy, so it can be calculated in terms of Embodied Land. Recycling reduces the Embodied Land by extending the timespan over which the material is used. However, this applies to newly produced buildings or products, a portion of which will be recycled or reused at some point in the future whereby it is known what the previous function and timespan of use was.

The situation is different for old material that is used in new projects. For these materials, the origin, burden and timespan are not known. The material may have been in use for one day or for fifty years. It may have been produced using fossil fuels or renewable energy. In MAXergy, this material is also counted as new material, unless it can be proved how long the material has been in use and whether it has been compensated during that period with Embodied Land or whether it still needs to be compensated. In this sense, recycling does have an impact and places a burden on the system!

For instance, if the steel industry were to produce 50% of its steel from old iron, this would always be more beneficial than dumping. However, the degree to which this recycling reduces the burden created by steel production is unknown. Theoretically, it may even increase the burden, such as when a batch of new, unused steel is reused (perhaps because it had been produced to incorrect specifications, maybe even in a different factory) and the factory assumes that it is recycling. Then this batch of steel will have been molten twice without fulfilling any functionality, giving it a higher energy content than primary steel! In other words, the exhaustion or return energy remains the same. In order to ensure that recycling reduces the impact on the system, it is necessary to know the prior history of the steel or iron. Of course, in reality it is all but impossible to label and track the origin of every piece of waste. Practically speaking, a government could decide to implement a general cancellation of the 'waste debt,' to reduce the 'official' amount of waste by 100% (this would only count for the material itself, not for the recycling process). Then the government could impose a labelling requirement on all newly created products and materials. MAXergy is simply a model, and Embodied Land is only a calculation method. It does include the condition that the origin of a material must be known in order to ascribe an advantage to it. This is simply a technological and scientific approach. Were a government to use Embodied Land, they could impose similar conditions in terms of regulations and ambition levels.

In the cases calculated so far, recycling has not been included.

3.7 Embodied energy[5]

'Embodied energy' is a relatively familiar concept. It is the energy which accumulates through the process of transforming a raw material into a product or application. However, a consideration of the concept's practical applications is in its infancy, so far the focus has primarily been on operational energy. MAXergy consistently uses the database put together by the University of Bath and called the Inventory of Carbon and Energy (ICE) 2.0 [10]. For ICE 2.0, the developers analysed the data known to science, which is quite divergent, and calculated the average. In the cases where ICE 2.0 did not give a clear answer, other sources were consulted or we carried out our own research. For wood and bamboo in particular, supplementary research was carried out (see chapter 4).
However, there are some issues with the way embodied energy is currently calculated. ICE 2.0 assumes cradle-to-gate calculations, from the extraction of raw materials to the gates of the factory. A positive aspect is that the transport from the factory to the construction site, for instance, can be calculated separately, whether it refers to bricks from the brickyard down the street or a profile from Taiwan. But the cradle-to-gate figures are averages, so the transport distance from extraction to the factory are averages as well. It is possible for these figures to be calculated more accurately.

[5] There is another approach, called 'emergy,' which was introduced in the latter half of the twentieth century by Howard T. Odum. The emergy approach is very interesting and bears similarities to the MAXergy approach. Discussing the emergy approach in detail is beyond the scope of this paper, but it will almost certainly be included in a more extensive analysis.

In addition, embodied energy figures are often expressed in terms of primary energy, which includes the energy mix utilised by a country or region (nuclear energy, gas, wind, etc.). It would make more sense to take the final use, which then can be calculated in terms of solar radiation conversion in the Embodied Land model. This is not only because this is how MAXergy works, but also because the mix changes, and in the long term it could consist entirely of renewable energy. Because of that, there is value in determining the optimum on the basis of the desired energy mix in advance, in order to prevent the encouragement of detrimental developments.
In addition, if end-use energy is the standard, the same figures would apply all over the world (assuming best-available technology) and the only difference would be the energy mix and transport. This simplifies the database and makes it more manageable. In incidental cases, it is always possible to enter a particular mix in MAXergy.
In cases where figures for the end-use embodied energy are lacking (and there was insufficient capacity to determine them), the calculations assume the primary energy for embodied energy, and the Embodied Land was calculated on this basis. If these calculations were to use end-use energy, the results in Embodied Land would be improved. This is an important task for further development.

3.8 Operational energy

Residences use energy on a daily basis. Of course energy is used for heating and ventilation, but it is also used for lighting, warm water and luxury energy (all the appliances which we can no longer live without in our society). Operational energy by definition usually applies to the components of heating, ventilation, lighting and warm water. These elements are the basis for the function of 'living'. But if we evaluate the building as performance, then of course warm water is not an item, because the building has no influence on it. Our aim in MAXergy is to evaluate the performance delivered in m^2 of building ('shelter'), separate from user influence. This means the performance at a particular basic level of use, in the sense of temperature and ventilation. Whether the resident opens the window has nothing to do with the quality of the building itself.
In MAXergy, operational energy in relation to buildings is limited to the energy for heating, ventilation and lighting.

3.9 The 50-year criterion

In principle, MAXergy calculates on the basis of the physical impact of a function, such as a square metre of building expressed in hectare-years, or Embodied Land. That is the performance of an inert object such as a building. A certain amount of Embodied Land is needed to achieve a certain number of square metres of building and make the building operational. The amount of Embodied Land needed is for all intents and purposes independent of the number of people using that building. Whether a residence is home to two people or four makes little difference. There are, of course, marginal differences: For instance, a home with four residents will need to be heated marginally less in a cold winter than a home with two residents, but these differences are not significant. Nor does the amount of people in the building make much difference to construction and maintenance. This means that buildings, and their construction and design performance, can be easily compared physically. In addition, the Embodied Land can be compensated over a particular period of time, such as one year, 10 years, 50 years or 100 years. The calculation is only one aspect, but the builder or owner needs to make choices and, in principle, to guarantee that compensation will take place, or else we will outstrip our supplies faster than they can be replenished. This is something that needs to happen on a global scale in order to gain a clear picture of the space-time available for buildings and other functions, Of course, the main issue is that the people who use these buildings need food in order to survive. The space-time for food is taken from the worldwide 'budget'. In essence, from the moment of birth every human being carries with them a certain amount of space-time necessary for growing food, their personal exergetic space. And each new member of the global population causes the potential available space per person to shrink. [6]

The exergetic space for the person's residence comes on top of this, and of course this decreases per person in proportion to how many people live in the residence. The physical exergetic space of the building remains the same, but the personal exergetic space varies. This figure depends on how the analysis is carried out and which approach is taken. For the building performance in and of itself, the physical space-time is the standard. For general purposes of organising our sources, the per capita exergetic space is the standard.

However, it doesn't matter how small the Embodied Land is for a new construction project - if the system does not have any space-time (land) available, the project should in fact not be built.

It is also clear that when goods last longer, their space can shrink. The space-time remains the same, but the annual allocation decreases in proportion to how long it lasts, leaving more space for other functions. However, these functions will also need to last longer.

The situation becomes interesting when we consider what the optimum figures are in terms of compensation for space over time. The length of time given can be 100 years or even a thousand, with a much smaller annual space allocated. At that point, the personal space becomes the standard. The use of space or land cannot be spread out over an eternity, as the human lifespan is finite, meaning that our use of personal space is merely temporary. If someone's personal space is spread out over a longer time than their lifespan, they are annexing space-time from their children, who will inherit an environmental burden in the form of a space-time remainder from their parents. This affects not only the residence, but in fact all goods and food. And then the system will continue to degrade slowly until nothing is left: All the space is being used to compensate the burden created by everyone's ancestors, and adult children will have no choice but to wait until 'land' becomes available - in other words, until the system reaches equilibrium again.

The question that follows from this is: How long is a human life? What is the maximum time that can be allocated?

This can be reasoned as follows. People live independently (occupy a home) approximately from the age of 20 (leaving the parental home) to the age of 70 (moving into a nursing home). That works out to fifty years.

[6] At the time of writing, the worldwide average available land per person amounts to 1.2 hectare-years. That can be distributed over vegetarian or meat-eating diets, larger or smaller buildings, etc. The hectare-year is merely a measurement and not a recommended amount. Furthermore, the amount of hectare-years varies. In the Dutch province of Limburg, for instance, each person has 0.2 hectare-year available.

People also occupy workspace approximately from the age of 16 to 66 (at present), which is also fifty years. This means that a home should be allocated for a maximum of 50 years in order not to eat into the space-time inheritance of the grandchildren and speed exhaustion.

Of course these figures are rough estimates. A nursing home costs space, as does a day-care centre. But this is a reasonable rough assumption. It should be pointed out that there are countries where these figures are completely different. If people die at a younger age on average, the figure of fifty years may be reduced to 40 years, for instance. But there is also a trend towards living and working longer, which causes these figures to increase. This immediately demonstrates that the space per person in the world drastically decreases if people take up space for longer. It may be that the space is being allocated over a longer time period, but the burden is growing and the personal space-time is increasing. This is particularly due to food and operational energy. The effects for buildings and infrastructure will be less severe.[7]

This means that if a building has been allocated over 50 years (so the land compensation has been calculated for 50 years) and the building is used for even longer, this brings about returns. Functionality (square metres of building) is achieved without needing to compensate exergetic space for it (for the building itself, that is; the exergetic space for the operational energy remains present, as does a small bit of exergetic energy for maintenance).

This is the basis for the reasoning that a building can only be allocated for a maximum of 50 years, for physical space as well as personal space. This falls within the time limits that a person needs to compensate the impact of their presence, without having inherited a burden from past generations. And it means potential returns for a society if the building continues to be used, because by that point it will be free of environmental burdens. And if that building is shared, the per capita burdens can be even smaller, because only fractions of the building are added to its exergetic space-time.

This is why we have decided to work with figures for total Embodied Land and an Embodied Land of 50.

[7] *The text uses the example of a building throughout, but the same would apply for television sets or any other product. Suppose a consumer 'allocates' television sets to himself for fifty years, either alone or shared with someone else. In that time he may go through five or perhaps even ten televisions. In this way the burden can be calculated per functional unit of television hour.*

4 Cases

4.1 Simple beam comparison

So as to clarify the method and reasoning, we have made a simple comparison between two beams, one of wood and the other of steel, each of which can carry a comparable portion of floor. This is purely a comparison of material, without an building operational energy component.

met versie 1.0							
steel and wood beam adapted for comparable load (carry floor section)							
						without return	
m2 (-year)		Emb Land, Ren. Energy based				or prim. harvest EL	Embodied energy
	kg	EL-harvest	EL -emb.energy	EL-return energy	TOTAL EL-RE	is only EL from EE	in MJ
steel beam	18	0,002	255	19130681,00	19130936,0	255	630
wood beam	11,3	23,8	33,4	0	57,2	33,4	83,25

Here we can see the three aspects which make up a MAXergy calculation (for material): the amount of land directly taken up by raw materials ('EL harvest'), the land use to generate the embodied energy ('EL emb. energy') and the land use to achieve compensation ('EL return energy'). For the last two, the surface areas directly needed for PV energy production have been calculated, as well as the impact of the panel production prior to that. There is a massive difference in the total Embodied Land for steel (19 million m^2-years) and wood (57 m^2-years).

Even if we ignore the Embodied Land of return energy, the difference is still significant - 255 for steel and 57 for wood.

If we ignore the 'renewable route' for both materials - the return energy for steel and the primary land use for wood - the only thing remaining is the Embodied Land for embodied energy. Even then, steel has seven or eight times more impact than wood. This is not entirely illogical, because it is the same ratio as that of the 'standard' comparison of embodied energy in MJ, without the conversion to EL (630 MJ for steel and 83.25 MJ for wood). This chart does not take into the fact that other resources are of influence: In order to produce steel or wood, air and water are also needed (the rucksack approach). These resources could be built in to the Embodied Land calculations in future versions of MAXergy. However, even if air and water are taken into account, steel is still at a disadvantage.

What this demonstrates is not that steel is a 'bad' material by definition, but that its use is only acceptable if its Embodied Land is smaller than that of an alternative; and that is usually the case when the characteristics are fully utilised and the function cannot be fulfilled by another material. Even then, the impact is very large, and it will be necessary to reserve the needed space for it.

4.2 MAXergy house

The MAXergy house is study case for the embodied land approach. Requirements for the designThe are '0 energy or better' for operational energy and it must be made of 100% renewable material. In other words, it is a '100% biobased residence'. These are factually determined practical indicators developed from the methodology and calculations using MAXergy. The requirement '0 energy or better' says nothing about insulation or energy production, only that there must be a balance between the demand and the energy generated renewable on location. The requirement for 100% renewable energy is a step in the direction towards the lowest Embodied Land and challenges for instance students to find alternatives.

algemene gegevens					Embodied Land Totaal			EL energie componenten (EE en OE) (m2!)			
gewicht	vloer opp	hernieuw baar	spec. gew.		EL totaal	per m2	per m2 en 50 jaar	EL van Emb energy	per m2 vloer	EL van operat. Energie	per m2 vloer
ton	m2	%	kg/m2		hajaar	hajaar	ha	m2jaar	m2jaar	m2jaar	m2jaar
122	111	7	1099	NL-ref	1028,00	9,3	0,18	1497,00	13,49	257	2,32
121	266	80	454	winnaar totaal	**1494,00**	**5,62**	**0,11**	2470,00	9,29	142	0,53
				alleen 80% hern.	**21,60**	**0,08**	**0,0016**				

The project case has also been compared with other cases, such as the Dutch reference home as standarised by Senternovem/Netherlands Enterprise Agency [11].

The comparison above is based on version 0.9. Since then, version 1.0 has been released, the most significant change in which is that the Panel Impact has been added, which results in higher figures. A separate publication about the MAXergy house“ based on this, is in preparation. For illustration purposes, here the comparison has been made using the old version.

The most important figures are the total EL and the EL per m^2. The first is important for the sake of the building's impact and the second is important for making comparisons with other buildings, standardised for floor area. The results are described in more detail in the paper for the 2012 PLEA conference [xx].

The initial design had a total EL of 1,494 hectare-years, or 5.62 hectare-years per square metre of floor space. The line shows data for only the portion of materials that are renewable (approximately 80%, in this case). This impact, without metals and minerals, is significantly lower (0.08 hectare-years per square metre of floor space). In this case the figures from various projects can no longer be compared because different percentages of renewable materials have been achieved.

The data are compared to the Dutch reference home for new construction by the Netherlands Enterprise Agency. The total is not interesting because of differing amounts of square metres of floor space. The reference home works out to about 9.3 hectare-years per square metre of floor space, as compared to the winning design's 5.62 hectare-years per square metre.

Energy: The EL of the embodied energy of materials has been considered separately, as has the EL of the operational energy. These figures are discussed in square metres instead of in hectares, and the case-design has an EL for embodied energy of 9.29 m^2-years per square metre of floor and the EL for operational energy is 0.53 m^2-years per square metre of floor. It is remarkable that the EL for embodied energy is so much higher than that for operational energy. However, the direct m^2 for extracting the EL for operational energy cannot be spread over many years, but is permanent (needed each year). This means that the differences become smaller as measured over longer time periods and after 17.5 years the figures would be more or less equal. It is important *to note that the panel impact has not been included in this, as in version 1.0. The details of this need to be addressed by further research, as laid out in section 4.4 below.*

To clarify, here square metres are net square metres, without traffic areas, balconies, garages, etc. This is also called 'net rentable m^2'.

For purposes of comparison, the Key Performance Indicators for the case design can be found to the right, as they were used by iiSBE in the Sustainable Building Challenge (an exhibit of projects during the global conferences on sustainable construction).

E1 energy demand in per year for all operating end uses(HVL)	*kWh/m^2 ua*	*21*
E2 the fraction of total annual operating energy provided by on-site renewable energy production.	*kWh RE/m^2 ua*	*21*
E3 embodied energy from the total of off-site materials used in construction ICE database	*kWh/m^2 ua*	*785*
M1 total weight per area of materials	*kg/m^2 ua*	*454*
M2 Total weight of renewable materials	*kg/m^2 ua and %*	*372 (82%)*
M3 Total weight of reused/recycled materials	*kg/m^2 ua*	*0*

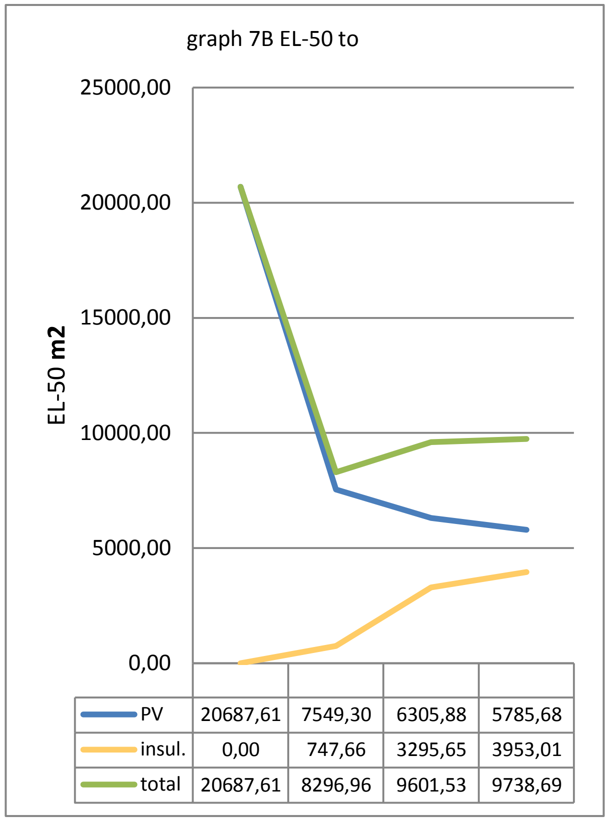
4.3 Bamboo versus wood

Bamboo was studied in the context of a multi-year research programme as a potential option for the Dutch market of the future. The research included comparative studies of bamboo versus wood. During these studies, which went into even greater detail and investigated bandwidths, certain critical points came to light, including the range of differences between embodied energy figures and the lack of data on production per hectare for both wood and bamboo. The research was carried out twice and was then given final corrections as a result of our own research into the facts of details such as yields from bamboo in China. The results will soon be available in a report [13].

4.4 Insulation versus production

In March 2013, a study was completed researching the optimum balance between energy and materials. In the Netherlands, and throughout the world, much is made of the necessity to use energy economically. It is essential that sustainable sources of energy become available and it is necessary to ensure that as little energy as possible is lost. For this reason, the walls of buildings are being given increasingly thick layers of insulation, windows now can use triple glazing (HR+++), and more and more climate installations are being hooked up per location. What no one has taken into account before now is the high volume of materials that are used for this and the enormous land surface area needed to grow and/or produce these materials. It may very well become clear in the future that materials require more m^2 than energy, and that this may become a problem earlier than expected. Somewhere there is a balance to be found between the thickness of the insulation in the walls of buildings and the energy lost, measured on the basis of the combined effect of energy and material use. At present we have no idea where that optimum lies.

We used the maxergy approach provide a first exploration of this quaestion, realted to a similar quastion form local cooperative housing associations: Do we need to use more insulation, or do we need to install or produce more? This study was carried out because MAXergy is the first method capable of making an integrated comparison of materials and energy [10]. To this end, an existing home was taken as the basis (Netherlands Enterprise Agency Dutch reference home for existing homes) and four different levels of insulation were calculated.(none, basic-cavity, extended-1layer outside, and passive level) This resulted in four levels of energy demand or generation by PV panels (polycrystalline photovoltaic cells). The installations were assumed to be the same in all four variants, even though some marginal improvement would be possible (somewhat smaller Heat pump in the better insulated variants). The calculations, using the MAXergy method, were drawn up on a separate spreadsheet for this study.



PV	20687,61	7549,30	6305,88	5785,68
insul.	0,00	747,66	3295,65	3953,01
total	20687,61	8296,96	9601,53	9738,69

The results show that an optimisation curve does indeed arise: The total Embodied Land, calculated over fifty years of operation (during which the solar panels have been replaced once), indicates that a first basic insulation package (cavity walls and cavities between the beams of the floor and the roof, etc.) immediately results in a significant improvement in the total performance. After that, however, the effects of insulation disappear entirely and the curve rises again(the combined impact in EL over time) . The impact of extra insulation is greater than the savings generated by reducing the amount of solar panels by a few square metres. These calculations use the 0-energy option - in other words, that the entire demand for electricity is met by solar panels, including correction for storage. A report is available, together with the calculations spreadsheet [14].

5 Scope for improvement

At this point the methodology is relatively clear, and the method of calculation has advanced enough that it is usable. However, there are still a great many variants which need to be researched, for instance in terms of the energy conversion technique used and in terms of the cases calculated. The following is a brief overview of all aspects requiring adaptation, improvements, or further detail:

- Add more energy conversion routes, including routes for conversion of renewable energy. The currently available options for converting solar radiation are polycrystalline photovoltaic cells, amorphous thin film and generic fossil fuel. In-depth research in other variants, such as biomass, wind and hydropower, are necessary.

- The definitions of 'renewable' and 'regrowable' need to be refined further.

- There is scope for significant improvement in the figures for embodied energy, an area in which RiBuilT itself does not carry out research. If in the near future research carried out elsewhere results in better figures, these will be used in calculations. Another area in which further research is needed is in the division between transport and process energy and the calculation in terms of end-use energy [x].

- The database of primary land use for materials is not yet complete and could be filled in and improved further.

- Various routes are possible for the calculations of return energy. The amounts will most likely remain extremely high, and therefore the conclusions will remain the same; but it is a good idea to investigate this further.

- Recycling has been incorporated in the methodology, but it has not yet been tested or included in the calculations.

- Many minor items have not been considered, such as the amount of screws and nails. Would it be a good idea to maintain flat-rate values for items such as this?

- The installations in the buildings have not yet been included, as there are not yet any figures available relating to material use. An initial test will be carried out utilising the installations in a pilot building. The aim will be to chart the use of materials in these installations in detail.

5.1 Future developments and supplements to MAXergy

MAXergy was initially developed with the intention of comparing buildings, and more specifically the building performance achieved, without combining it with resident behaviour, which is unpredictable. Resident behaviour is an essential component, but it is not part of the building performance achieved. The choices made with regard to installations, for instance, do influence resident behaviour, as the typical resident will not be an expert in machine maintenance. The costs will also have an influence, even though they fall under a different evaluation system than the exergetic approach. Both resident behaviour and financial considerations, as well as any legislation, must be examined separately and parallel to each other; and the Embodied Land calculations could serve as a foundation for decision-making.

However, MAXergy should never be incorporated into another combined comparison instrument, as this would compromise the entire approach. The MAXergy approach focuses on determining impact and compoensation, clearly and without weighting factors, assuming a society based on solar radiation. Of course, the political field, for instance, can decide to base regulations or policy ambitions on part of the data. But the calculation method should not be combined with another secondary comparison system.

As regards operational energy, those elements have been assumed which are largely determined by the building, within acceptable variations: heating (including heating of the individual residence), lighting and ventilation. The resident's equipment has not been included.

But this methodology can also be used for other functionalities in society. For instance, it can be used to calculate an integrated material-energy impact.

Land use is the denominator on the basis of which everything is calculated in MAXergy. However, there are more factors that influence land use than just energy and material, the resources that are directly involved in the building. It would also be possible to develop and calculate the Embodied Land for water. The goal is to add this resource in a later version of MAXergy. In the long term, it would even be possible to include food in the MAXergy calculations, as it can also be related to land use. However, both water and food are strongly connected to behaviour. It will need to be investigated whether a base case is possible.

The impact of resource use is usually larger than has been included here. In particular, this refers to the rucksack approach, in which the wuppertal institute [11] has determined which indirect resources are involved in the extraction of raw materials. This, too, is an element that should be researched in order to include it in MAXergy.

MAXergy is an excellent approach for new construction projects or new functionalities which are to be added to existing buildings. However, research into insulation versus production has demonstrated that it can also be used on existing buildings, at least at the level of individual buildings. The next step is to apply it at the level of neighbourhoods as a tool for evaluating regions. The Urban Harvest+ approach has been developed to this end. However, this is truly a different approach [box image], as it starts with an existing burden, which often vastly outstrips the available land in an area or region. This approach works the other way around: How can the impact be brought back within the exergetic ability of the neighbourhood or region? A number of studies in this area have already been carried out, and parts of MAXergy are incorporated in these studies [12].
A case study has been made for Kerkrade, the west district. Certain aspects will need to be worked out in detail in a tool or calculation method.

EPC

We have already mentioned that primary energy is no longer useful as a calculation when, on the one hand, materials are included in the comparison and on the other hand, construction tends towards 0 energy impact. By the same token, the energy performance calculation, or EPC, is no longer useful in the way in which it is generally used in the Netherlands. EPC primarily focuses on the energy aspect, and in principle it stimulates reduction in demand in particular. The material impact is not included, even though an environmental impact calculation has been required in the Netherlands as of 1 January 2013. But EPC as a guidance instrument must be replaced by a 0-energy demand calculation, indicating how the lowest material impact can be achieved.

3D/4D

In principle, MAXergy and Embodied Land are based on space and use. But it is clear that as 0-energy construction comes closer to reality, the third dimension of space will gain in importance, as there is little point in installing solar cells if the building is not directly illuminated by the sun. High buildings cast shadows on the shorter buildings behind them, and the land in terms of surface area heads towards 0 instead of the energy balance. It will be necessary to take a 3D approach in order to incorporate this in performance considerations. Further study in this regard is in preparation.

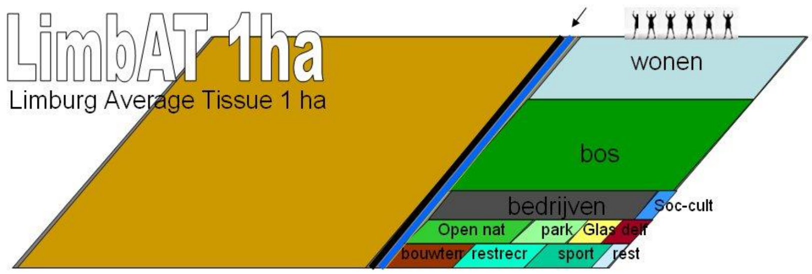
RiBuilT, March 2013

Appendix:

1.

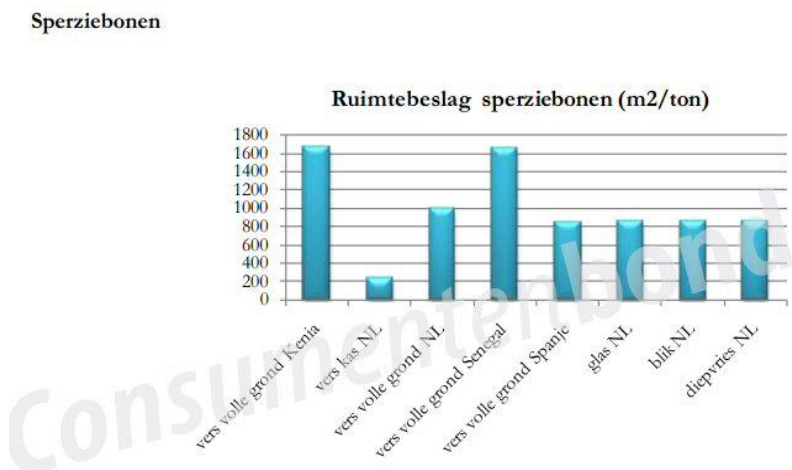
Food

Food and the provision of food is of great importance in an Embodied Land approach. This has not yet been incorporated in the method, but an estimate shows that it is of the same order of magnitude as materials. An 'Urbat' (an average hectare with land use) has been calculated for Limburg.



An average of approximately 5.2 persons, or roughly 2 families, live on each hectare in Limburg. Assuming approximately 3000 m^2 of land use for food production per person (for the current average diet), this works out to 1.5 hectares for the five persons living in one hectare. In order to arrive at the share of agriculture in a single Urbat (approximately 6000 m^2) the residents will need to switch to a vegetarian diet, which requires approximately 1000 m^2 per person.

Incidentally, these are not hard figures, as different sources give different figures. As an example of how this could be integrated into further research, the figures for various production methods for beans [x] are given below. This is actual use of space, without the Embodied Land for energy and materials, as is the case with greenhouses.



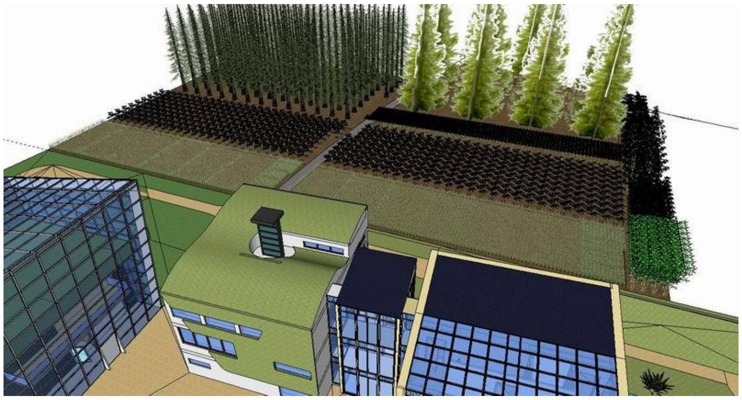
*Figuur 4: Ruimtebeslag van verschillende bereidingen van sperziebonen, in m²*jaar/ton.*

2.

MAXergy House: The case study, MAXergy House, has been optimised in terms of the Embodied Land calculation. However, this is an example in which Maxergy has been translated into manageable indicators. The guidelines are: a 0 energy balance, linked to a requirement for a minimisation of installations (in order to reduce the material burden - still to be calculated) and the requirement that all materials used must be 100% renewable or biobased. For the sake of simplicity, recycling has not been included here; it will be included in follow-up projects. As a result of the requirement that materials be 100% biobased, an entire chain movement has arisen, because the bulk of a single building can be supplied by biobased materials (wooden construction, insulation using flax and hemp, etc.) but not the entire amount of finishing materials.

0 Materials house

The aim for case study is to construct it entirely using renewable materials. If we manage to built a pilot project , then the materials should be regrown in the garden behind the house in addition to the house project itself. (to include the EL within plot size) This means that the house will produce its own materials over time. This is similar to a 0 energy house, which produces its own energy during its operation. As such, it could be the first 0 materials house in the Netherlands, and possibly in Europe.



100% biobased house

Using renewable materials, even if they are sometimes produced using industrial processes (such as in the biobased industry), also achieves a 100% biobased house. The aim is to produce biobased alternatives for every element used in the home, including light switches, sanitary fixtures, etc. If these elements are not available on the market, there is the option to use 3D printing to produce them using biobased materials. A pilot projetc is currently set uo, to produce door handels. As such it could be a real 100% biobased house and serve as a showcase for the biobased economy.

0 Exergy house

The home could also be a 0 exergy building (one which does not increase entropy within its borders) if, in addition to the materials garden, the house were to include enough solar photovoltaic panels to compensate for all the energy production capacity involved in materials fabrication and metal and mineral restoration.

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