# Space-time of solar radiation as guiding principle for energy and materials choices

## Embodied Land instead of primary energy as universal performance indicator

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**Abstract:** Renewable energy is based on using a direct route from solar radiation to consumption, as an efficiency improvement from a long term route via fossils. However, both routes put a claim on space/land and the time of use of that land/space to intercept and convert it to useful forms. However, the same solar radiation is needed, to produce materials in a similar change from fossil materials to renewable materials, and materials are needed as well to produce the conversion devices for renewable energy. Similar processes take place in the realizing sustainable buildings, especially 0-energy buildings: : there is space time involved to generate the renewable energy, but also to generate for instance the renewable material based insulation materials, or the wooden construction.
These insights lead to the notion that looking to production of renewable energy only is sub- optimization of systems, and could in fact be counterproductive. This has defined our research to explore new ways of evaluation of activities, and in our case buildings. We have developed a indicator called Embodied Land, to evaluate the time and space occupied by generating both renewable energy and renewable materials. This has been tested in two cases, and runs out to be a interesting approach, showing clearly how the optimization of land and space use over a certain time period relates to choices in materials and energy together, and makes it possible to optimise from both resources together, using an minimum of land occupation.

*Keywords:* *Exergy , Exergetic space, Embodied land, Primary energy, Maxergy, Space time evaulation, Building assessment,*

## 1. Introduction and research questions

In reducing the impact of Buildings and built environments, what we want in the end is to measure whether we are really moving towards a more balanced use of materials and energy at a fundamental level and to see whether this can provide a approach and strategy that will transform the activities in a way to be maintained for many generations to come. It is however not the absolute use or burden we are interested in but whether the use within a certain space (system) and time (frame) can be continuous , with regeneration of quality instead of net depletion of systems potentials over the time of use. Studying the different possibilities of such a approach creates an inconvenient feeling with current calculation methods, performance indicators and assessment Tools . These exist in many forms however seldom measure real improvement of the global impact or resource situation. Nearly all tools use relative or subjective weighting, historic benchmarks and more, including even LCA (Life Cycle Assessment) tools . Other studies have provided similar conclusions: “Many research studies show the vulnerability of tools when accumulating indicators are used to reach a sole value”. [1] [2] Lowe has attempted to see if we could define absolute environmental limits for the built environment. Lowe concluded that there are also many uncertainties and problems when applying. [3] Another issue is that, for practical use, most tools and assessment methods are not very convenient, and provide too much detail according to the influences of the specific stakeholders’ position as has also been experienced in practice and concluded in research: “the non-transparency of tools for use in practice”. [1,2]
We will have to see if we can find new ways of calculating and accompanying tools and approaches that overcome these disadvantages..

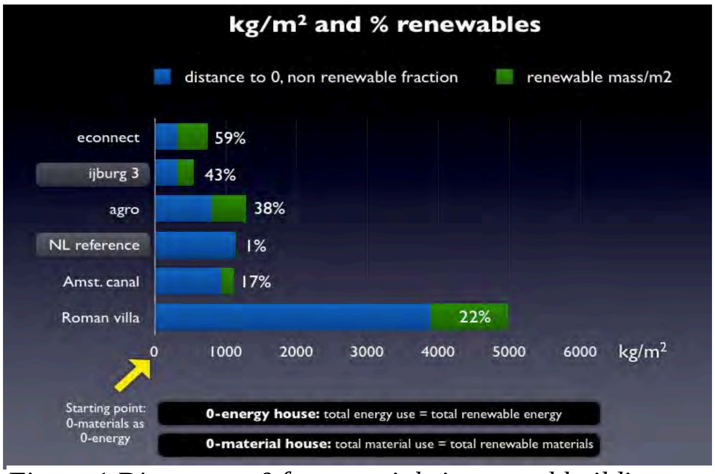


*Figure 1 Distance to 0 for materials in several buildings*

A first step to improve from looking at energy alone has been made in research on how to define a closing cycles approach, firstly focussing at materials. [4,5,6] . Materials are under threats of scarcity as well, and are a m ain cause of CO2 emissions in production. Materials should therefore , similar to energy, after centuries of growing depletion, start to fit in to a closed cycle approach. The logic step is to define a material neutral building as one that is been made of renewable materials. There are still resources involved, but only ones that ca be regenerated over the time of their use. It's a similar approach as for E nergy, when applying solar radiation . The difference is that the renewable energy is instantaneously regenerated, for renewable materials the time span is much longer. ( but so is their application)

At that point a few questions were phrased:

A) If a 0-energy building is created, (fossil-) energy for operations and CO2 emissions are no issue anymore ( besides in production of devices)[ 7 ] However, the embodied (fossil) energy of construction materials have become the major cause of the resource depletion and CO2 emissions related to erect and construct a building…! This poses questions like: Should we add more insulation ( with still energy and CO2 impacts) or remain a higher heating load ( requiring more –renewable-energy), what is best? [8] In other w ords: looking only into operational energy has become obsolete and is sub-optimisation, . But and how to combine both energy and materials in a evaluation? [1]

B) renewable materials are only renewable if they are renewed, and how would that work out in defining a 0-materials building, one that regenerates the resources on site?

C ) both energy approach and materials approach , before described, is still a quantitative approach. How would this change if we look at specific qualities needed? ( heat, structural materials etc).

This paper further explores answers to these questions, introduces a approach and a exploration of two cases to test the approach.

## 2. MAXergy

One of the main question to address, in order to get answers, is to explore how energy and materials can be combined in a closed cycle approach , what would be a common denominator, one that automatically requires that different qualities are integrative addressed[2].

This forces us to look more in-depth at an overarching approach, that of exergy, which explores the quality potentials in a system. Energy can not be depleted, however its exergy ,

[1] The production of materials requires enormous amounts of energy, ( cement production alone is responsible for 7 pct of all worldwide CO2 emissions, and growing [9] the total burden on fossil fuels is due to materials use! [10]

[2] This link between materials and energy has been explored in research on exergy, among others in The SREX programme in The Netherlands {http://www.exergieplanning.nl/} [11]

the qualities of energy ( to provide work) that can get lost . The approach is mainly to see how decrease of the quality can be reduced. The usual approach is that a system is trying to be optimised from the inside: re-use of waste heat for instance ( get more out of the same energy flow). More important however, the analyses is usually based on a "fossil" notion of exergy: that of oil and gas of high exergetic quality , available in a system. These however have only a high exergy/quality, since they are 'available'. It is seldom asked how they *became* available… These notions require a redefinition of quality in a system and how to maintain it. The following observations and arguing help redefine this.

### 2.1. Ecosystems, quality and humans

Natural ecosystems generate the highest quality. However one can argue if the word quality is the right word to use. Nature in fact has no q uality, nature just is. Physically its about thermodynamic stored potential, however only quality in terms of human use if made available *to do "work*". Its humans that value qualities since they make use of it. To explore the *human valued* quality, in different forms, we will explore in how far humans can make a potential available , and to have maximum use of it, maximum in the sense of lowest exergy loss ( or better: to balance exergy *consumption* with exergy *growth* in time and space in a human managed system. )

### 2.2. Systems

the system addressed is usually limited ie a part of the earth. If quality is a main evaluating criterion for mankind's inhabiting of the earth, then its no use looking at a limited system: the largest system that is bordering human influence is the earth. There is no neighbouring system that can provide resources[3]. There is only one connection outside that system: that of solar radiation, the driver of our whole system, and the only source capable of preventing equilibrium( total decrease of quality). ( besides a little gravity)

### 2.3. Redefining the oil route: solar radiation

Following this argument, the origin of Oil in fact is solar radiation ( from outside the largest human addressed system) , converted to biomass, ending up as sediments and under heat and pressure changed in Oil ( or gas or coal) This reveals that oil is in fact not the ultimate source for (100%) exergy calculations but just a specific state into a process of using/decreasing quality in the system as a w hole. . If we calculate this, (total known oil stocks, 65 m illion years process, over total earth surface) , w e can find that oil is renewably generated at a speed of approximately 14000 liter per day globally!. One step further we can derive the relation of oil gas and coal with space and time: the speed of generation and the earth surface use over time ( for the biomass involved) . In fact electricity via the fossil fuel route (average of oil gas and coal) comes out at ~0,0017 kWh per ha per year. As comparison : el ectricity from solar panels provides ~1.000.000 kWh per ha per year . Its two different routes from solar radiation to electricity, with different impacts in land use and time. This creates a direct link to the use of a source and the space- time involved. And directly from that, the space time occupied by the use of it. Or in other words: if we do not use more oil as regenerated it's a lasting process, a sustainable operation. Based on the input of land and time to convert solar radiation. Via a different route Tran and Vale come to the same question of involving land in measuring sustainability and renewable energy production.. [12]

[3] Many of our system analyses are based on looking at a limited system, with imported resources un quantified, however having a burden on a neighbouring system loosing quality. This is only acceptable is the neighbouring system is also a well managed system. In the end its at the scale of the earth it all comes together, and no neighbouring system is available anymore.

### 2.4. And what about mass?

Energy and mass are two of the same, as Einstein already concluded and both share thermodynamic laws. In modern ecosystem approach its even mainly mass recognised as the main potential and process for capturing quality ( as was biomass for oil…) [13, 14] Connect this to the fact that a shift to a *renewable* materials approach is based on solar energy as well, for materials to be (re-)generated on land, in a certain time period, and we have our first direct relation to evaluate energy and materials in one assessment. : the land use over time to produce the ( human valued) quality. For food and water similar approaches apply.

Ultimately it is the solar radiation that decides on the quality in a system that directly translates into forming of mass and energy out of solar radiation, and both have direct effect on the land-use to make these conversions take place. In a change for a renewable sources based society-(closed cycles) there is in fact 1 principle basic to both, which is the ability to convert solar radiation into useful forms of exergy: quality in the form of mass and/or energy. (and food and water, however is not the scope of this paper)

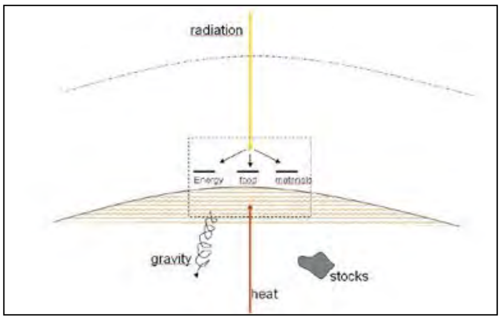


*Figure 2 solar radiation access as the main structuring value*

Important aspect of this approach is the relation with space needed to produce these resources and the time aspect in which they will regrow.

The questions we posed before can now be answered .
Ad A1 how can energy and materials be evaluated in a common system, is to explore the time space use that is involved in maintaining a closed cycle management, based on renewable resources. the question on energy and materials sub optimisation can be answered by using a common nominator for their impact: m2 solar radiation access over time to (re-)generate the demand ( and the different qualities).:( or restore quality)

Ad B What is a 0-materials building, can be answered as one that re-generates the resources *on site*: it has to include space over a certain time to be able to regrow the resources used to construct the building, and the time relates to do so before their end of use.: In other words: the land to be appointed for their regrow should be included in the building site ( similar to roof surface for PV for example)

Ad C The issue of qualities in stead of quantities has become obsolete in this approach: Its not an issue, it’s the production potential to fulfil a function, with least time space occupation that is decisive for our possibilities , staying within closed cycle limits. Its all a matter of m2 solar access, which helps makes choices, also in qualities.

## 3. The Exergetic Space approach

Mass and energy , in a closed cycle operated society, have become one and the same, and can be only optimised in a combined way, in relation to their claim on solar radiation access via land/space over time. This can be phrased as The Exergetic Space , required for some function: The space-time needed to produces certain qualities over the time of use of a function fulfilled.

And the only real value to address this quality, or better the prevention of decrease in potential quality, is the m2, and our capability to create quality ( convert solar radiation into human valued resources) in ( at least) the same pace as it is consumed.

Or to turn it around: any system, no matter what size defined, has a maximum capacity to generate quality. If activities inside the system uses more quality then generated, it depletes resources and will face collapse in the end. Or in other words: one can determine the maximum activities in a system, to be maintained for ever by incoming potential and converted to useful forms.
Optimising for space-time, on the basis of converting energy/mass into useful carriers for human used value, leads to a complete different approach as so far. It requires reserving areas of space for generating a meaningful volume of the the most wanted quality.
And preserving the highest quality in a system, is not established by starting from cascading inside sources, but by starting from the system entering solar radiation and capture and convert in the highest valued mix of needed qualities

### 3.1. New indicator: Embodied land

Going back to our fist exploration into kg's of material involved in construction - the distance to 0 where all materials required were provided on a renewable basis - we can now quantify the impacts of the need to regrow these resources, without depleting a system: it's the land over a certain time involved : or the Embodied Land (EL).

## 4. Pilot cases

The approach developed can be used in two different ways. One is to evaluate the performance of different buildings ( "the exergetic space need" or Embodied Land, for providing the building m2's) .

The other way is to explore in how far an existing and consuming urban environment can be re-developed into a 0-impact area, using the time space need as structuring element. This has been explored in a parallel case in which we develop the Urban Harvest + approach, and tested in a pilot Kerkrade West, a district in the south of The Netherlands. Its described in detail in other papers { 15}

### 4.1. The methodology

The methodology is structured as in the illustration (fig 3): first to explore the space need involved with generating the renewable materials. A database has to be developed to record yields for different resources. The results will be part of another publication, the illustration shows some basic findings ( these are climate related of course). Next step is to include the embodied energy of the materials, and translate this into Embodied land.

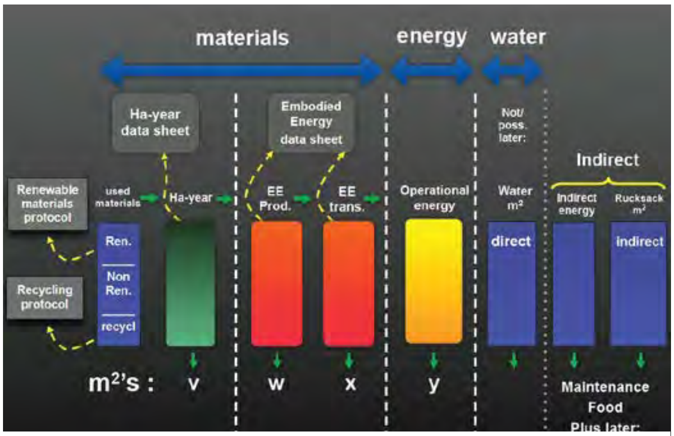



*Figure 3 the methodology*

For Embodied Energy figures, this research bases itself on the Inventory of Carbon & Energy (ICE) from the University of Bath version 1.6a .
As an example we both re-calculated the land use for fossil energy as well as with renewable energy. The third step is to add the operational energy to the calculation, giving a total land

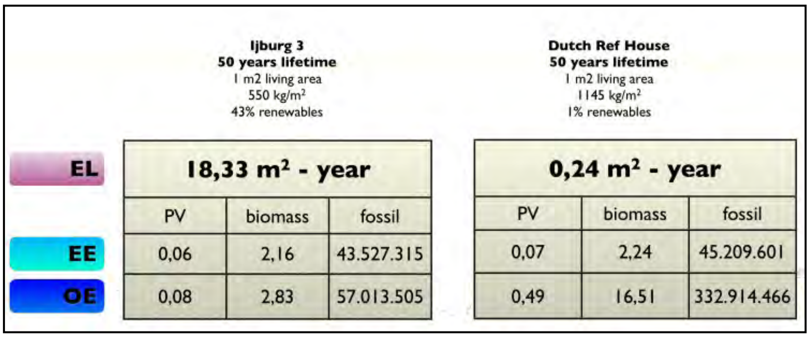
need over a certain period of time to compensate for the exergy load/ quality loss in the system. In a further research also water will be added as well as secondary resource use and maybe food.

### *4.2. The cases and results*

One case was a 5 level prefab Timber frame and straw bale house, designed for Amsterdam's new canal house district Ijburg.. Its based on 43 % of renewable materials
The materials use and energy related data were brought together and the embodied land was calculated for the above mentioned fractions.

*Materials embodied land*
In the case of Ijburg , the production of (43% renewable) materials require 916 m 2-year to produce , per m2 of living area. This can be produced in 1 year on 916 m2, or , if we take the lifecycle of a house as 50 years, on 18.3 m2 for the continuous period of 50 years. The space time occupation of embodied land significantly drops when lifetime of the house increases.

*Energy embodied land*
This has been recalculated for both fossil based energy and renewable based energy. To produce the energy for materials production by fossils, a land use of 43 million m2 per m2 of living area is involved ( on a 50 year regeneration basis…!) . A huge amount, of course. To do so with modern biomass energy generation 2,16 m2 is needed, and via PV panels 0,06 m2.( both in 50 years) ( only direct energy, not including yet indirect energy, for storage for instance) But it shows already the immense difference in effectivity whether fossils or renewables are used. For operational energy similar calculations are made: for Ijburg-3 0,08 m2 per m2 living area is needed. (solar generated, or 57 million m2 when fossils are used)



| | Ijburg 3<br>50 years lifetime<br>1 m2 living area<br>550 kg/m²<br>43% renewables | | | Dutch Ref House<br>50 years lifetime<br>1 m2 living area<br>1145 kg/m²<br>1% renewables | | |
|---|---|---|---|---|---|---|
| EL | 18,33 m² - year | | | 0,24 m² - year | | |
| | PV | biomass | fossil | PV | biomass | fossil |
| EE | 0,06 | 2,16 | 43.527.315 | 0,07 | 2,24 | 45.209.601 |
| OE | 0,08 | 2,83 | 57.013.505 | 0,49 | 16,51 | 332.914.466 |

*Figuur 4: Embodied land for reference house and house from Straw and wood: for materials generation(EL) and for three energy sources providing Operational energy (OE) and embodied energy (EE)*

From this point on its already clear that in the case of a ch ange to renewable materials , with still using fossil fuels as energy source, the last one is by far the most devastating to our land use : A 100 m illion m2 for EE and OE per m2 living area, compared to 18.33 m2 for materials ( t he 43%, maybe twice as much for a 100 pct renewable materials house). However, if we include the fact that we have to change for 100% renewable energy, the picture is completely turned upside down: 0,14 m2 for EE and OE compared to 18,33 m2 for the materials fraction ( on a 50 year calculation, but the relation remains the same) This already shows that decisions regarding materials have far more impact then those related to energy, in a renewable resources based world. As we will see later more in detail. In a second case study we started at the other side: that of an existing district which consumes more energy and mass as is produced in the area, or in other words, has huge embodied land occupied outside its own "jurisdiction", providing its own water and materials as well. This will require strong reduction of demand, and maximise production. This has been done following a 5 step model ( the Urban Harvest plus approach [Rovers 2010] .For example: The energy plan assumes all houses are renovated towards passive house standards, requiring large amounts of insulation materials and a new structural façade. However from materials point of view these are not available, and require a large extra amount of land. A calculation shows that there is need for 135 ha of extra land to supply all materials for the whole district over a period of 20 years. On the other side it only requires 17 ha of Solar collector "land" to supply the heat for un-insulated houses. The choice is clear: no insulation and extra heating is the most effective choice. The finding were surprising even for the researchers, and even when expecting that materials might be more important then energy in a closed cycle and renewable source based society. It should be noted that only direct energy and mass has been calculated: materials for collectors, or process energy for materials have not been included yet. A follow up study should detail this issue, and probably find an optimum between insulation and heating. Both examples show that it is possible to combine energy and mass in one objective approach and relate directly to the sole sources for both qualities in the earthen system: m2 access to solar radiation, or "Embodied Land" . The model developed proved useful, and shows no un beatable barriers. Nevertheless some issues still have to be specified: The land relation for non renewable materials, as far as they are still used, the valuing of recycled materials ( 16), the detailing of choices, using indirect energy and materials, and other issues.

## 5. Conclusions and Consequences:

First of all the attempt to combine both energy and materials in one objective calculation has been proven possible though details still have to be settled. It turns out that direct solar access and the space time involved is the real value to relate decisions of environmental effectively and operation within a closed cycle process. Even food can be included in this evaluation ( though not explored here) since it is in the same way depending on solar access. A second conclusion is that materials are as expected more influential in the environmental performance as (renewable) energy , though even far more as expected by the researchers.
Further findings and conclusions are:

- Quality is not a direct issue anymore: Since the evaluation starts from the potential available( in a given district) or the potential needed and the land to be included, in case of a new development qualities are to a certain extent given facts, and not directly structuring.
- Embodied Land seems a very good and understandable indicator to judge the impact of any activity .
- Optimising space and time in capturing the needed qualities, is what has to be valued , in order to establish a highest level of materialised welfare . How high is depending on our pattern of consumption of qualities, and the amount of individuals striving for that level of welfare, ie acquiring the useful functionalities.
- Optimising for space time, on the basis of converting energy/mass into useful carriers for human use, leads to a complete different approach as so far. It requires reserving areas of space for generating a meaningful volume of the most wanted quality.
- Preserving the highest quality in a system, is not established by starting from cascading inside sources, but by starting from the system entering energy and capture and convert in the highest valued mix of needed qualities

There is a few consequences to this approach. First of all: The notion " primary Energy " has become a historic artefact and thrown in the rubbish bin, since a historic relic from a fossil fuel driven society. When real values and impacts are calculated, the reference has become the sun, and the time space involved to generate quality from its radiation, and the capability to convert that in useful forms for humanity[4]. It also shows that trying to optimise the energy cycle, looking at ( renewable) energy alone, , is sub optimising. The role of materials is far more important . So far the exploration has only involved a 2 D approach, in m2 land available for a specific amount in time. However in fact we face a 3D problem: How to deal with shading, how to deal with excavations, quarries in this approach? Think of a troglodyte house: The underground houses found in dry climates, like Tunisia, and including some underground villas by the Romans. They in fact produce materials, in stead of consuming by way of excavating soil to create living space. Or to include height in the form of hydropower potential . A more general approach for this has to be explored, in relation to the study of the use of non renewable materials .

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