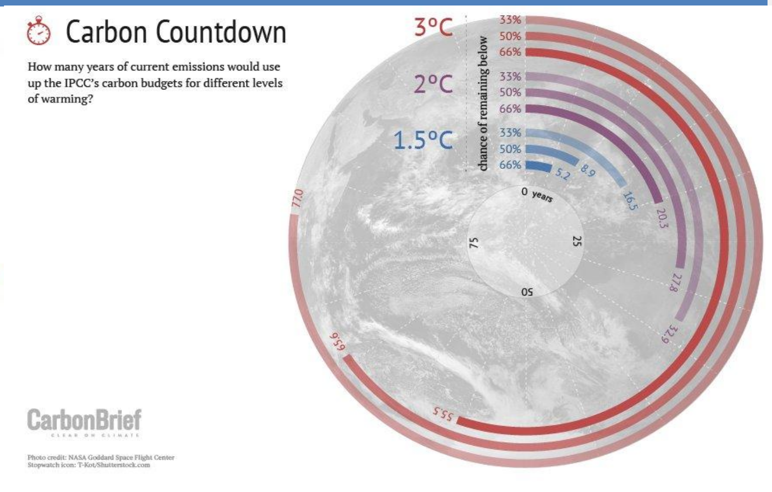
Staying below 2 (1,5) degrees of Global warming :

a (near) 0-CO_2 built environment

expert explorations of CO2 consequences for the built environment



iiSBE report

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Launched at :COP22 Marrakesh, November 2016
Version 1.1 September 2017

Preface/reading guidance: CO_2, buildings and people

There are many strategies, policies, and technical approaches about how to limit climate change to 2 or even 1.5 degrees of global warming in order to prevent major disruption and disasters.

The major issue is to drastically reduce CO_2 emissions (a major component of GHG emissions), and to explore the implications for energy and materials that we use for our daily activities.

Increased CO_2 levels in the atmosphere cause more heat to be trapped into the atmosphere, leading to global warming. It is estimated that to have chance to limit global warming to a maximum of 2 degrees, the remaining CO_2 budget that can be emitted is currently a total of about 800 Gt (and decreasing by the day of course).

This report is intended to provide a collection of expert-based explorations of the consequences for the built environment of staying within that budget, focusing on building construction, housing, and the people inhabiting that built environment. It focuses purely on CO_2 emissions related to energy and material used in the built environment, regardless of financial, political, or regulatory consequences.

This report is also not about the construction sector directly, or the industry or mining, but takes the living environment as the core topic. The explorations will reveal consequences for the construction and related sectors.

The questions identified are such as: how much of the budget can be attributed to the building sector, per country, per inhabitant? How much CO2 emissions will be involved in retrofitting the built environment for renewable energy-based operation? Or: How much CO2 can be attributed for new construction for additional housing demand?

We hope to give tangible insight in the directions to develop the built environment, the possibilities as well as the limitations, so that we can plan the most effective route while remaining an acceptable living standard.

Part A of the 1stversion of this report provides the background and starting points for such analyses, and a matrix of topics and sectors to explore.

Part B provides the first three explorations by three iiSBE academic members, and draws some general conclusions from that.

Part C will in time contain the overall conclusions and a backcasting exercise.

This bundle of explorations is meant to interest others and to mobilize a wider range of intellectual capacity to explore this challenge in additional essays, within the same starting assumptions. The whole should act as background and reference document to make the necessary choices in what to do and what not, to limit the emissions to stay the maximum of global warming bellow 2 degrees.

A maximum of 800Gt is the limiting factor, and the total of explorations provides input for defining strategies within this limit, using thebackcastingapproach, to detail the route to follow.

PART A: Background and Scope

The Paris Agreement target of <2 ºC:Consequences for the Built environment.

Countries participating in the Paris COP21 meeting agreed that climate change should in any case stay below 2 degrees of global warming, and attempted to stay below 1.5 degrees. These commitments were ratified in Marrakesh during COP22.

What does this actually imply for the construction, operation and maintenance of houses,buildings and built environment in general?

This is the central question of this document, developed as strategic paper to guide discussion on transitions in the built environment.

The report briefly introduces the global CO_2 targets related to climate change, and the role that the built environment plays in this transition, and to which level the built environment should comply with climate change targets.

This report attempts to explore these consequences apart from existing and sometimes conflicting goals in society, with people's needs and wants as well as within the UN Sustainable development goals. The report takes CO_2 reduction as the core issue, and explores the consequences from different overarching angles.

After an introduction and explaining basic background of the exploration, starting points and boundary conditions are defined to structure the reports explorations.

Part B will contain the first three analyses, from three different points of view/ three different angles of perception. Each explored as to maintain a scientific defensible level, in relation to the other 2 issues.

These first three explorations are then summarized and general conclusions drawn.

The report is intended as a kickoff document, and to invite other members of the academic community within iiSBE, to develop additional explorations, under the same assumptions and conditions. Our intent is to present this to the global community as strategic paper. The first three explorations were introduced at COP22 Marrakesh as a draft, to get feedback in the developing stage. Experiences from these discussions are incorporated.

Follow the projects Website: http://www.buildingscarbonbudget.org/

The CO_2 budget

The anthropogenic driver of climate change is the increasing concentration of greenhouse gases (GHG) in the atmosphere, chiefly CO2, but also including Methane, Sox and Nox gases, of which a large part is emitted due to human related activities. The cause is mainly burning fossil fuels, and related effects, like the industrial capacity to produce artificial fertilizers, to grow increased yields to feed cattle, that emits NOx. Eliminating fossil fuels would be a direct improvement, which is the main issue for the built environment.

Within the building sector, the most practical strategy is to focus on CO2 emissions.

Scientific research has been able to calculate that there is a kind of maximum emissions budget, which cannot be exceeded without having global temperatures exceed2ºC, which is considered by IPCC and other researchers to constitute the maximum rise without causing drastic consequences for human life on the planet.[1,2,3] There is also a consensus that 1.5ºC is a safer limit, and attempts should be made to limit global warming close to the 1,5 degree.

The current situation is that we have only 5 years left before the 66% chance to stay below 1.5 degrees is blown. That budget is204 Gtonnes$CO_{2\text{-eq}}$.

For 2 degrees the budget left is 800 Gtonnes$CO_{2\text{-eq}}$ (2016)Without any (additional) action, and with current emissions of 40 billion tonnes a year, that budget will be spent in 20 years . See the graph for additional calculations with other chances and with 1.5 , 2 or 3 degrees target [4]

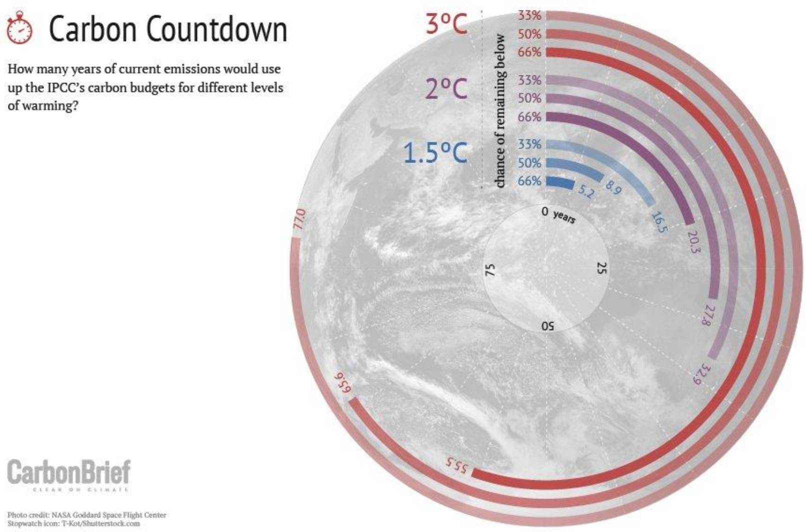


Figure 1: Carbon Countdown for different scenario (1.5 to 3degrees) and for different risk consideration (35% to 66% chance to achieve this scenario)(Sce: carbonbrief [4]).

The actual amount of remaining emissions, is real time documented on a website maintained by the scientific editors from the Guardian Newspaper, and can be found here: https://www.theguardian.com/environment/datablog/2017/jan/19/carbon-countdown-clock-how-much-of-the-worlds-carbon-budget-have-we-spent

After having used this budget, the man caused emissions mustremain at zero in the following years. And this situation should be prolonged for as long as the nature has resettled and absorbed CO_2, which can take up 50-100 years or more. In this situation, zero does not mean an absolute zero in emissions, but that the emissions needs to be compensated by the naturally captured CO_2, this extra budget being related to productive biomass and bio-based materials use, with renewable energy as the driver.

With 0-CO_2 being the target for human activities, any new activity or materials investment not complying with 0-CO_2 from this moment on, will consume part of the budget, and increasing demand, without being used to be invested for contributing to lowering demand thereafter.

Studies show that building a renewable energy supply system, might even need more materials and related CO_2 input as is available in material stocks and GHG budget. [5,6,7]. In other words,the remaining budget should only be used to bringing all our CO2 emitting activities to (near-) 0.

Recently new papers have been published highlighting the urgency of the situation, and the very small time window remaining to bring us on track to the 2 degrees.

Hanssen and 17 colleagues published in a spring 2016 paper further scientific analyses on the GHG consequences, and state:

"We conclude that the message our climate science delivers to society, policymakers, and the public alike is this: "we have a global emergency". [8]

Rogelj and colleagues announced in their Nature paper in may 2016 that the Paris Agreement climate proposals need a boost to keep warming well below 2 °C. The paper argues that we are far off the path to two degrees. [9]

For ease of explorations of emissions in the building sector, which is nearly all CO2 related, we use the 800 GtBudget for 2 degrees, and 200 Gt budget for 1,5 degrees scenarios. (ie B2 and B1,5)

The 1.5 degrees scenario

The budget is ~200 Gtonnes CO_2. Assuming between now and 2050 population will rise to 10 billion, the average for the transition period is 8.5 billion.

Which implies a budget per capita of 23.5 tonnes of CO_2 remaining. If we would use the full proposedtransition period until 2050, the budget would be **0.7 tonnes of CO_2 per capita per year.**

As a reference, the total global budget emitted in 2014 was 35.9 Gt CO_2 That is per capita-year:(for the current 7.2 billion people) : 5 tonnes. That implies there is only 4.7 years left until we will have passed the threshold for 1.5 degree. [10]

The 2 degree scenario

The budget is 800 Gtonnes CO_2, which implies a budget of 94tonnes per capita. (the8.5 billion people-see above). Using the full transition period until 2050, it comes down to **2,5tonnes CO_2/cap-year**

With current global average use of 5 ton CO_2/cap year, with Business as usual, there are only 19 years to go.

In both cases after 2050 anthropogenic CO_2 emissions should be (net) 0.

Buildings and built environment

The Global Alliance for Buildings and construction (established at COP21) states that buildings and construction sector is responsible for 30% of global CO_2 emissions. This figure is growing rapidly and could reach 50% of CO_2 emissions by 2050. [8]

In these 30 to 50%, one considers the CO_2 emissions related to the construction and the operation of the built environment. In a recent analysis done by Bajželjet al. in 2013 (2013), one can clearly identify the share of GHG emissions depending on the different industrial sectors and related services (figure 1).One can see that the emissions related to the construction service are very comparable to those related to the warmth service for buildings.

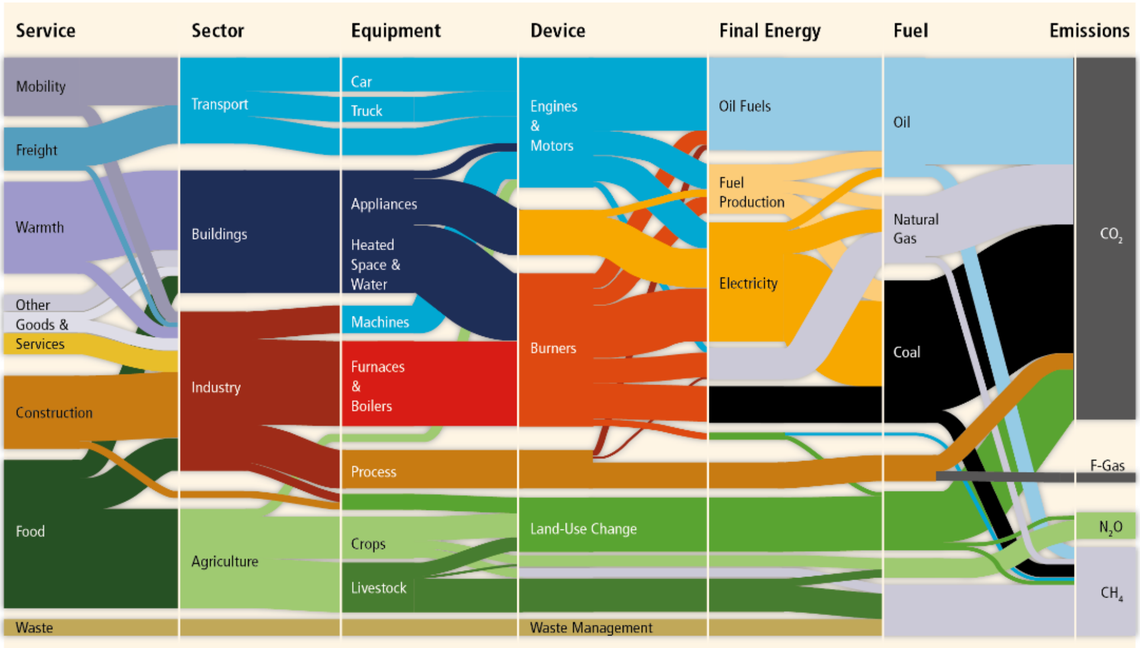


Figure 2: Sankey diagram of greenhouse gas emissions of human activities in 2010 related to the chain of technologies and systems required to deliver final services (Sce: [11]).

Actually, we could consider that around 40% of the total anthropogenic emissions are related to the built environment and that within these 40%, we include the construction of the buildings and their heating/cooling. For the moment, the share between operation and construction is about 60/40.

A reduction in these emissions implies a drastic change in the built environment, from the way we operate our buildings to the way we build them. The transition is slowly occurring, at small scale in industrialized countries, where retrofittedand new buildings are aiming toward a 0-energy standard (0-fossil energy operated buildings). However, this transition in the operation of buildings implies the remaining budget is dedicatedto produce the materials for this operation. Otherwise it's only shifting the impacts from one resource to another, filling one hole with other. [12]. This aspect of a totally 0 fossil building (operation and construction) is seldom considered.

Taking the Paris agreement seriously is the huge task for all due to the scale of changes that are required and the very limited amount of time we have to achieve this transition, so that we will not have to facelarge scale migration, increasing droughts, fires, starvation, etc…Furthermore, unlike people, the built environment doesn't move, which means that climate change will hit the built environment with very few possibilities to adapt to it or to flee - but flee to where?

The built environment at the world scale is quite a diverse agglomeration resulting from different living standard (influencing for instance the m^2 per capita), climatic conditions (influencing heating/cooling demand) and construction practices (influencing the materials used and the building typology). The figure 3 shows an indication of the amount of people per construction type, and a indication of the embodied energy consequences of choosing a different materialisation.

Figure 3: Living condition of human population in the built environment. Share of the different type of construction and their associated embodied energy.

Some operate without or with hardly any operational energy, mostly in more warm climates, and with low-income families. Some with very high GHG emissions, in colder or hot climates and by the more wealthy part of population (wealthy in terms of money) . The major contribution therefore has to come from the housing and building sector in the industrialized and wealthy countries. Though the general trends towards 0-CO_2 will remain the same everywhere.

People's houses and stuff , left USA countryside, right China countryside. [13]

Issues/counter effects

The actual available CO_2 budget per capita and/or sector will probably be much lower. Since some trends in society will increase emissions, or enlarge the time peoples claim on budgets, even if reduced. In an article [14] the trends are more elaborate described, but a few of the issues are summarized here:

- Medical science expects that lifetime of people can be increased this century, up to 120 years, coming from around 80 now. This implies a factor 1.5 more environmental impactper capita. This effect is not included in most population scenarios.
- Banks are stimulating economy, and the extra money brought into circulation could be upto 50% of all capital circulating, above normal business, between now and 2050. This capital injectioncan be assumed to be primarily spent on resource consumption.
- Two thirds of the global population is developing fast and increasing welfare, which could triple the demand for resources and related CO_2 emissions. China alone exploded from 13 kilo of meat consumption in 1982 to 63 kilo per capita per year today. For more than a billion people![1]- Population will grow from 7.2 billion at the moment of writing towards 10 billion by 2050. Not only will this decrease the budget per capita, but these people will require additional housing to be built, adding to the CO_2 to be invested to house people.

It's highly probable that this will reduce the remaining carbon budget per capita even more. In this paper these trends are not yet included, unless otherwise mentioned.

National / regional implementation, policies & strategies

Strategies, policies and programs that will govern implementation of GHG emission reductions (as committed to at COP21 and subsequent inter-governmental meetings) must be carried out at sub-regional or national levels and, in the case of large countries, sub-national levels. This reflects the fact that all specific locations have characteristics that will greatly affect the pace of carbon reductions and the sectors they will occur in.

This document does not explore this directly, its rather an outcome of these explorations, that feed into the decisions to be made at national or regional level. However, the topics can be addressed in new explorations, as long as they explain the reference to the fair share of the maximum of 800 Gt maximum to be emitted, and explain how they differ from that.

In the conclusions phase, when all contributions are evaluated, a translation can be made or proposed how to implement and govern the required measures. (See also conclusions)

iiSBE has already 2 parallel initiatives, that deal with policies and strategies :

Plan B, a position paper on "Climate Change and Plan B", which outlines some of the major climate change issues that affect the built environment, and what steps may be taken to address them. See the iiSBE website.

Together with partners Global ABC, CIB, UNEP and FIDIC, a international GHG survey is being carried out, listing major policies that should be executed on short term.

[1]it should be mentioned that China announced a policy to reduce meat consumption by 50%. [15]

Question-examples

There are many question arising from these findings. Some of the many questions could be:

- how much of the budget can be attributed to the building sector, per country, per inhabitant? Possibly corrected for development level?
- What is the most effective way to provide (renewable) energy to buildings, in terms of least CO_2 impacts?
- Is there still budget to construct new (0-energy) buildings, or should we refrain from that and organize our current sheltered space more intelligently?
- How to bring CO_2 emissions to 0, without shifting burdens to others sectors?
- How to deal with growing population globally, which will require housing anyhow? Should we in the West with limited population growth, refrain form part of the budget for this?
- What are the daily consequences for living in buildings, occupying shelter/space?
- How should the budget be used?
- How to remain a certain comfort level, or, what level of comfort can remain?

In this report the focus is basically on the direct and concrete consequences, in terms of energy supply and consumption, materials input, in relation to social and comfort issues in the built environment . The focus is not on policies to empower this, nor on financial economics to establish this. Both have to be a result from actual measures to absolutely decrease limit the CO_2 emissions from the built environment.

Assumptions and starting points

Contributions to this compendium, should comply (with some freedom of interpretation) , with the following guidelines:

1 The Carbon Countdown project follows the clock at the Guardian website, based on scientific papers. That implies: currently there is 792 Gtonnes of CO2-e left , before 2(!) degrees is out of sight.

For all explorations: this is the given maximum limit. All contributions should relate to this number : How to stay within that budget, whatever you explore or plan to do.

2 global population rises to 10 billion, from 7,2 now. For the next 35 years on average there will be 8,5 billion people around, which is what we use for projections over decades.

3 When calculating a CO2 budget for your sector, country, related to a per-capita budget, we assume a fair share for everyone in the world: so the Carbon budget divided by the global population. If you wish to use another distribution, you have to motivate this. To come to a sector budget, use the same distribution over sectors as currently customary.(6)

4 the explorations are not about solutions directly, nor are they economic or political explorations. They are also not directly aiming at the construction sector. It's about evaluating adaptations in the built environment, in order to limit CO2 emissions to within 2 degrees of climate change. They can be aimed at finding out what can be done with that budget, or how much would be needed for a planned activity or existing strategy. But always tested against the given maximum global CO2 budget. The solutions, strategies and policies can be develop from these findings in a next phase. .

5 After the 2 degree budget is consumed, people should live from a 1 ton CO_2/cap-year limit (assumed as being within natural regeneration capacity) . That is to read as: The best way forward would be that already immediately people would shift to a 1 ton/cap-year budget, to stay within the 1.5 degree limit. If not, and the 880 Gt budget for the two degree limit is spent, the budget should anyhow stay within the 1 ton CO_2 per capita, to maintain a balanced CO_2 level globally.

Hungry planet: what people eat (and how theycook):
Left Germany, right Mali. [12]

Questions/topic matrix

The expert explorations are organized in a matrix, to provide a flexible approach in the essays.The matrix consists of two main entries: by system size explored, and by type of building/housing to address. Any contribution should make clear what combination is explored, and how the partial budget for that section is broken down. The matrix in first phase looks as follows:

overall

built environment (subsection besides food, water transport supply)

explorations **by use**

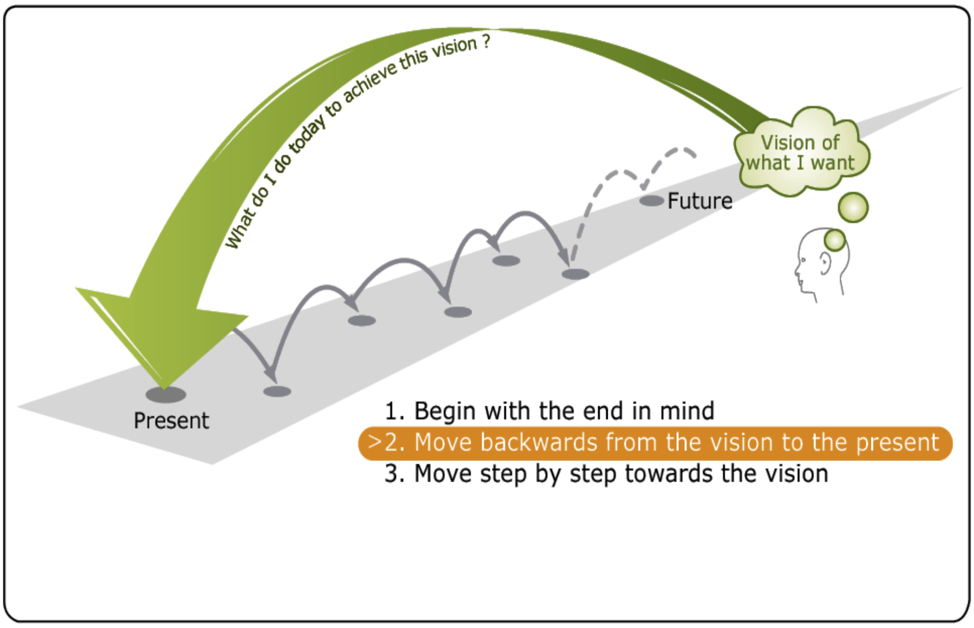
by location	housing existing	housing new	buildings existing	buildings new	building operation	housing operation	Infrastr. new	infrastr. existing	
global									
industrialised countries									
developing countries									
continental									
counrty									
region									
urban									

Developing conclusions and strategies process.

The joint explorations, when sufficient in amount, will provide the clues for how to organize and manage the built environment to stay and maintain within the CO_2 limits. As such it provides a point at the horizon to aim for, which can be used to analyze on how to act to establish that situation. For this we will use the backcasting approach.

The moment when the route and actions are known is the moment when policies, technologies and economy can enter again. (It's a sister project initiated by iiSBE, launched at COP21 in Paris, and now run under the Global Alliance initiative).

the process can be illustrated by the backcasting approach:



Summary of joint findings

to be added when more contributions are available: check the website for regular updates.

Overall conclusions & recommendations

to be added when more contributions are available. Check the website for updates on the report and (preliminary) conclusions.

The final conclusions process, as described above, will be announced, possibly in the form of a meeting.

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and the datasheet

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PART B: Explorations

Essays by

Ronald Rovers

1) Retrofitting for 0-energy (ZEB housing)

Guillaume Habert

2) Global quality of housing within CO_2 budgets

Thomas Lützkendorf

3) Exploring consumer CO2 budgets

Ronald Rovers:

4) EROI versus CO2/kWh under a 800Gt scenario

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Retrofitting for 0-energy (ZEB housing), Ronald Rovers

880 Gt overall

built environment (subsection besides food, water transport supply)

explorations **by use**

by location	housing existing	housing new	buildings existing	buildings new	building operation	housing operation	Infrastr. new	infrastr. existing	
global									
industrialised countries									
developing countries									
continental									
counrty									
region									
urban									

To make the consequence of (remaining) CO2 budgets imaginable, the introduction of a basic calculation can show the scale of the transition required, for a industrialized country.

The Netherlands has 17 million inhabitants, if the CO2 budget is equally divided globally, The Netherlands can claim 17million out of 7 billion = 0,0025 part the budget (B), or ~**0,5 Gt CO2** under the 1,5 degree scenario (B1,5), and**~2,0Gt**under the B2 degree scenario. Which is optimistic, since global population is growing and the trend is for increasing demand, further reducing local and per capita budgets. If we assume that for the reform of society the attribution per sector remains the same, then 40% can be attributed for the building and housing sector, operations and investments, or **B1,5 = 0,2 Gt CO2 and B2=0,8 Gton**(- remaining to be emitted from the building and housing sector).

For only the housing sector, in The Netherlands this is around 20% of total energy consumption.

Co2 budget Gt	**global**	**NL eq share**	**Built env 40%**	**Housing 20%**
B 1,5	200	0,5	0,2	0,1
B 2	800	2,0	0,8	0,4

How does this relate to housing related emissions? Assume no new housing construction need, and all existing houses to be retrofitted to 0-energy (0-emissions from operational energy) To retrofit a house to 0-energy, requires materials, which have been produced with fossil fuel energy , so called Embodied energy. For a standard row-house retrofit , as currently practiced , this comes down to an estimated 3,4 Gj/m2-floor (near- passive house level, PV on roof for energy, in total “0”) [1](this is a low estimate, including PV panels but not installations/equipment)

With a standard house in NL being around 100 m2, and 7,2 million houses, the investment will be estimated at 100 m2 x 7,2 million x 3,4 GJ/m2 x 75 kg/GJ[2] /1000 (ton) = **0,183 Gt**

In the B1,5 scenario that is nearly the total Built environment budget, or twice the housing budget! In the B2 scenario this is nearly half the housing budget or nearly 25% of the total Built environment budget .

While in that case still only part of the built environment has become 0-CO2 :

- All maintenance and replacement thereafter is not included, for which no CO2 is left. Like replacing for instance solar panels in 2041 (after 25 years of service) etc.
- If we assume developing countries are entitled some more CO2 budget, the available budget becomes less , say half of that, implying the full budget is needed only to address the housing stock.
- This is only existing houses. Not new houses, offices, or other buildings or infrastructure .
- This is exclusive depletion of resources, or increased energy investments for same amount of material from ores.

From another point of view:

The current CO2 emissions per capita in The Netherlands (NL) are around 10 tons/year (everything included) . Adding up for a total for NL of 0,17 Gt/year. Following this scenario NL will run out of its total B1,5 CO2 budget in 3 years, in 2020. Given that the budget is equally divided per capita, and developing countries do not get a larger share. However. Population by 2050 will be 10 billion. That will reduce the NL share even earlier. It is easy to see that if we wait a few years with transforming society, the budget will have been used, and 1,5 degrees will be definitely out of sight. For B2 it will be overall ~12 years, still very short.

3% retrofit scenario

With a focus only at housing in NL , even if we retrofit all 7 million houses, and do that in the next 33 years,(until 2050) that is on average 3 % of current stock per year . Which implies that after the 1st year, 97 pct of stock still consumes considerable fossil fuel for operational energy, and after year 2: 94 % etc. Knowing that the Dutch household energy demand is 450PJ fossil energy a year, or emitting 0,033 Gt per year, this leads to:

B1,5: Which implies that with a retrofit rate of 3% , after 6 years the whole *"built environment budget"* for 1,5 degrees will be used up, with only 18 % of houses retrofitted …

To stay with B1,5 scenario, we have to retrofit 20% of houses a year, for the next 3 years, an impossible 1,45 million houses a year.

[2]There is many ways to decide on the amount of CO2 released by energy consumption. Most basic is to divide global energy related CO2 emissions by world energy consumption : 3,89 10*11 GJ [2] by 40Gt [3] , giving 102 kg CO2/GJ .

If only grey electricity is addressed, its even higher: around 140. Depending the calculation methods, the Netherlands uses 63 to 78 [4]

Since this exploration is not meant to do a scientific analyses for that, but to provide an indication of effects using an average. Here its set as 75 kg CO2/GJ , not specific for the Netherlands, but as a generic figure. For each country or sector it can be adapted.

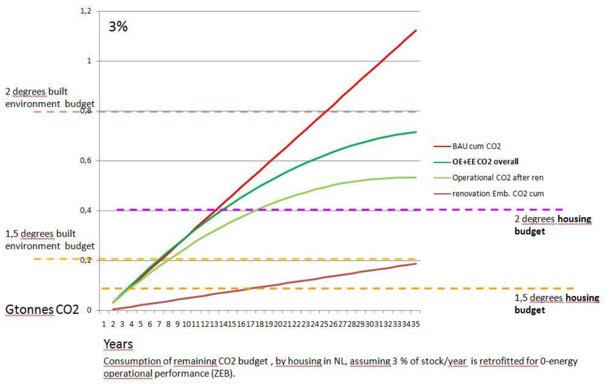
B2: In the 2 degrees scenario, if we do nothing, the Built environment budget is blown away after 25 years. (this is because we use the whole budget for existing housing). With 3% of stock retrofitted each year, investments and savings balance somewhat, and by 2050 all houses are retrofitted, while by then the available (*built environment* -) budget is spend. The savings in operational energy in that speed scenario have provided just enough space for material investments, and delay budget spending to 2050. In B2 this is still 220.000 houses a year to be retrofitted for 0-energy. (of total 7,2 million) . The emissions for retrofitting houses gostill way over the 'housing budget' under 2 degrees, which is half of that of '*Built environment'*To stay within the housing budget of B2 we need another scenario:

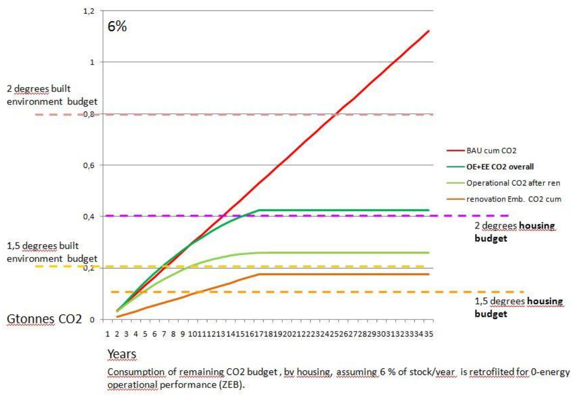
6% retrofit scenario

If we do 6% of housing retrofits a year in B2 , it takes 17 years , And stays just within the B2 *housing budget*. Half the Built Environment budget is left then, for all other building related use. Consider that, with 6%, thisimplies 450,000 houses a year to be retrofitted..

There are however a few caveats in all cases: this is only housing, while all other buildings and infrastructure are not covered , offices, new houses, etc. Plus, there is no budget left/included for maintenance and replacement;If after 25 years Solar panels have to be replaced, that is impossible. And the first that will have to be replaced will be in 2041.

In the case we focus at the B1,5 scenario, and only use the 'housing budget' for housing, things get very difficult: in B1,5 with 3% houses retrofitted, its 3 years before we run out. We have to retrofit 33% of all houses a year, that is 2,8 million/year, again, impossible.





Left the 3 % retrofit scenarios, right the 6% scenarios. (See larger graphs below)

Extrapolating beyond The Netherlands : EU and OECD .

These data are for the Netherlands. We are hardly growing, The Netherlands could do without too much new construction. For many other countries the data will be worse, new construction demands more embodied energy, assuming they are constructed as 0-energy houses. If not, its impossible by definition to stay within any budget.

The EU has 255 + million houses, which partly are under a colder climate conditions, partly warmer, with cooling. If we assume the total resembles the average NL situation, since the Netherlands is in a moderate climate, in that case with a 6 % scenario, in the EU 15 million houses a year have to be retrofitted for 0-energy .

If we look at the OECD data, as comparable industrialized countries , we find that CO2 emission per capita are higher as in the Netherlands or Europe, while housing sizes are comparable (data available in rooms per capita: NL 1,9, OECD average 1,8 [5]) . The situation for OECD therefor looks at least the same if not worse.

Overall we could conclude that B1,5 is impossible for the building sectors part, and B2 requires immediate and broad action, to keep the target in sight. That applies to most industrialized countries. For developing countries there might be some more maneuvering space, but only if 0-energy is targeted for operational energy as well. Otherwise a lock-in is created while still emitting considerable amounts of CO2. It must be said that 0-energy does not mean by definition to invest that much (embodied) energy: here its was used in calculations assuming the prevailing *comfort levels* are maintained: In Industrialized countries that is to have the whole house 24 hours a day acclimatised (In the Netherlands: 21 degrees, expressed as “21/24”) .

Conclusions

It can be concluded that to stay within the B1,5 scenario seems unrealistic, and to stay within the B2 scenario requires immediate and immense action to reduce CO2 to within budget limits.

Even then, it requires to invest a lot of materials to reduce fossil energy demand(embodied), especially in the housing sector. (by insulating and PV production) . Which is the main burden to the remaining CO2 budget, assuming that retrofit leads to 0-(operational) energy housing. If not, CO2 targets are impossible to meet.

Even the B2 and 6% scenario is a challenge for which reasonable doubt is in its place if the construction industry can upscale fast enough to that level, even if supported by policies. Therefore efforts should go to direct reduction by limiting the direct demand of energy by behavior related measures. For example: Scale down housing sizes, in any case limit heated or cooled areas. Reduced comfort is unavoidable, its impossible to maintain current comfort levels, and have innovation provide new technologies to do this within current budget levels, before budget limits have long been passed.

Before starting to retrofit and insulate these (limited) indoor areas and invest indirect CO2 emissions via materials and technologies (embodied energy) , its seems more wise to focus at reforming the industry first, and make industry produce 0-Embodied energy/ 0-CO2 materials and products. In that case retrofits require hardly any embodied energy, while the industry has to transform anyway as well. Better start with the industry there so that the application of products is not so critical anymore.

To reduce embodied energy in building industry and products manufacturing fast and large, will require the application of low impact materials and processes, or a move away from abiotic materials towards biotic materials, and a greater input of labor. Its a similar transition as for food: away from high-impact food (meat), and move to large scale bio-vegetarian diets . Which brings me to summarize the built environment transition required as one towards: vegetarian building, plant based.

In general: : this explorations shows that its highly required to add a a CO2/embodied energy value to every action in society, not holistic approaches, but direct information on CO2 impacts of every single action/ product, to reduce CO2 levels absolutely and fast. To have a 66% chance to stay at least below the 2 degree scenario.

Ronald Rovers October 2016

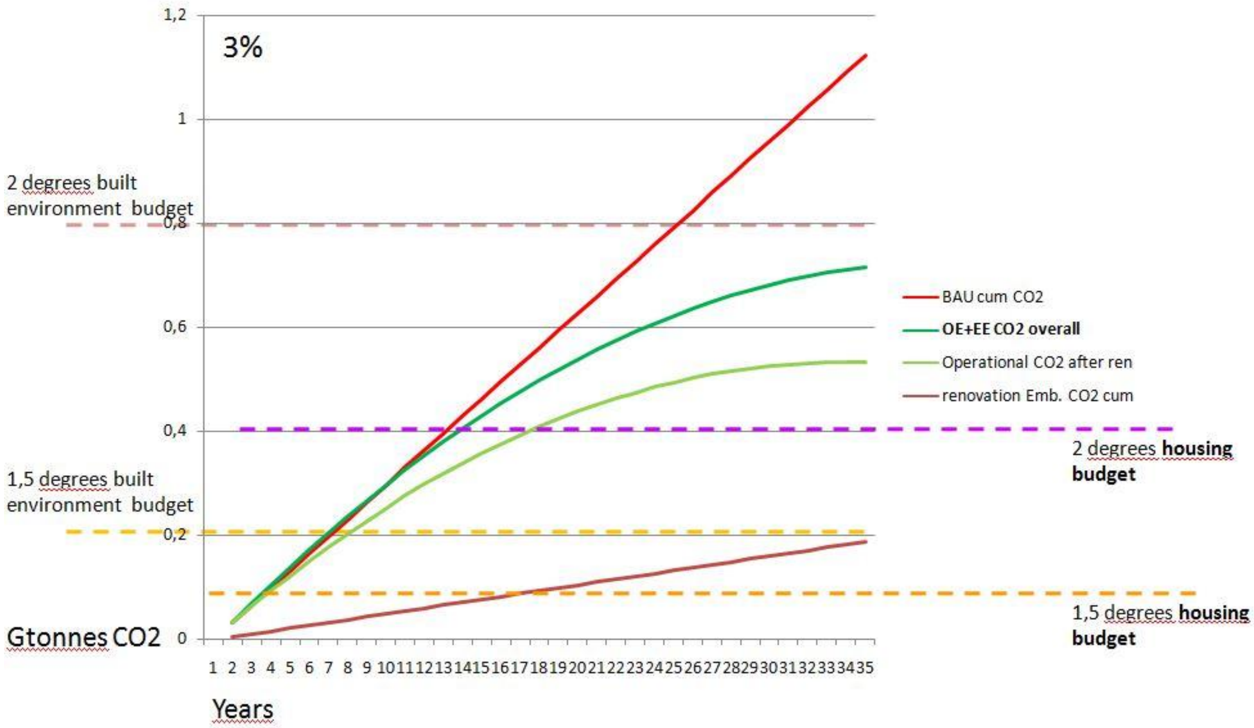
[1] Ritzen,M., Haagen T., Rovers R., Vroon Z., Geurts C., Environmental impact evaluation of energy saving and energy generation: Case study for two Dutch dwelling types Building and Environment, Volume 108, 1 November 2016, Pages 73–84 http://dx.doi.org/10.1016/j.buildenv.2016.07.020

[2] "Key World Energy Statistics 2015" (PDF). www.iea.org. IEA. 2015. pp. 8, 37.

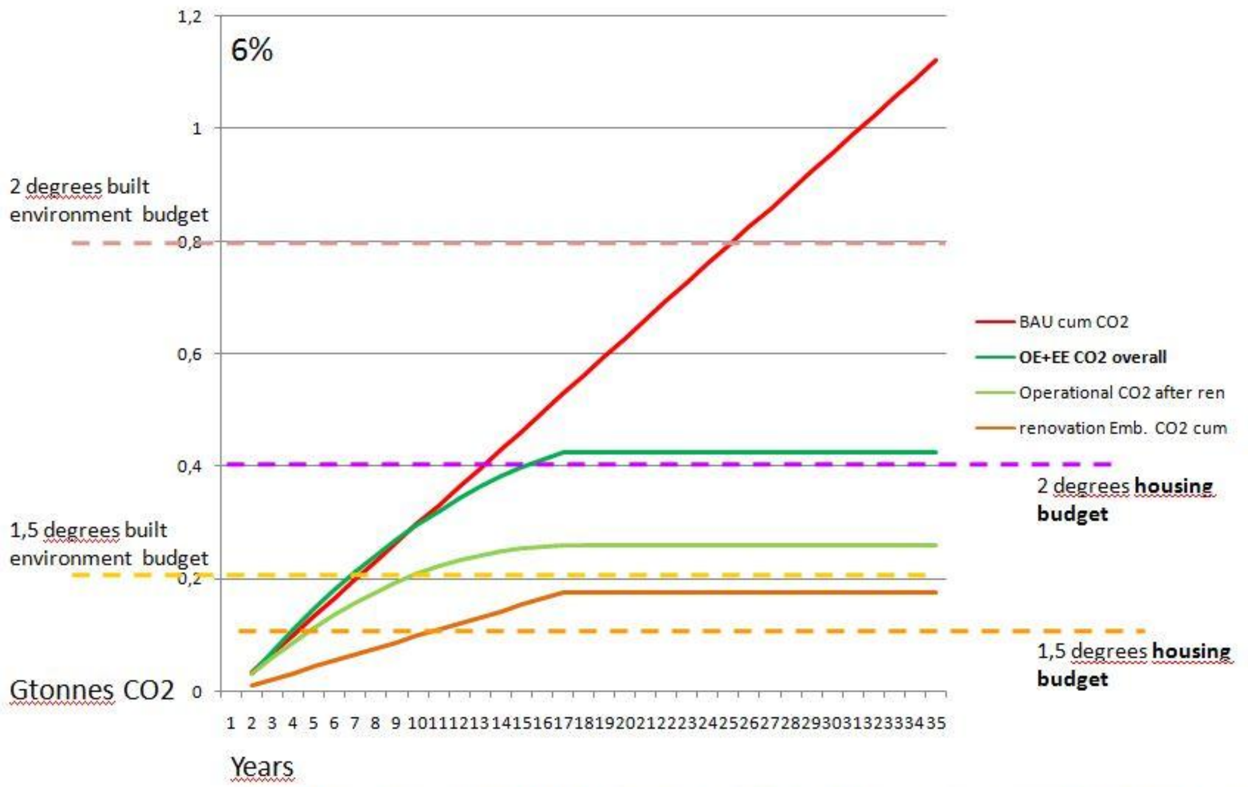
[3] via Carbon Brief, https://docs.google.com/spreadsheets/d/1odltJu_rxabdVXv_pACMBNIRiFSkc_HqJn-V8z0av2w/edit#gid=731498129

[4] Berekening van de CO 2 -emissies, het primair fossiel energiegebruik en het rendement van elektriciteit in Nederland, sept 2012 , Agentschap NL , CBS, ECN,PBL.

[5] OECD, accessed January 1 2016: http://www.oecdbetterlifeindex.org/topics/housing/



Consumption of remaining CO2 budget , by housing in NL, assuming 3 % of stock/year is retrofitted for 0-energy operational performance (ZEB).



Consumption of remaining CO2 budget , by housing, assuming 6 % of stock/year is retrofiited for 0-energy operational performance (ZEB).

2

Global quality of housing within CO_2 budgets, Guillaume Habert

880 Gt	overall								
built environment		(subsection besides food, water transport supply)							
explorations	**by use**								
by location	housing existing	housing new	buildings existing	buildings new	building operation	housing operation	Infrastr. new	infrastr. existing	
global									
industrialised countries									
developing countries									
continental									
counrty									
region									
urban									

1. Introduction

IPCC experts consider that buildings offer the largest share of cost effective opportunities for GHG mitigation among the sectors examined by them[3]. However, achieving a lower carbon future will require very significant efforts to enhance programmes and policies for energy efficiency in buildings and low-carbon energy sources well beyond what is happening today.

In their reports[4], the main focus is put on the operation energy, the energy to heat and cool buildings, because for typical standards of building construction, the embodied energy is equivalent to only a few years of operating energy. Over a 50-year time span, reducing the operating energy is normally more important than reducing the embodied energy.

However, for traditional buildings in developing countries, the embodied energy can be large compared to the operating energy, as the latter is quite low. Furthermore, the emissions related with the construction of the building will be released in the beginning of the life cycle of the building while those related with operation will be released over the life cycle which in developed countries is often assumed around 50 to 60 years. This time period expands well beyond 2050 which means that a part of the operation emissions does not count in the carbon budget until 2050 but in the later consideration of the 1ton CO2 per capita. Finally the embodied energy is also the part of the energy required for a building that is the most difficult to reduce.

In the current paper, we evaluates the pertinence of the sustainability target implemented in the building sector compared to the global target fixed at the COP21 and considering the future perspective of urbanization growth in the next decades.

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[3]IPCC, 2014: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[4]idem

As the most constraining target, we considered the energy label promoted in Switzerlandas the so called 2'000W society. The vision of this energy efficiency path is that every person would consume not more than the energy corresponding to a continuous power of 2'000W. This budget can be used for all human activities: housing, mobility, food consumption the construction of all infrastructure sustaining human activities and other consumption pattern. The efforts to reach this goal are enormous since Switzerland is currently consuming around 7'000 W pro person. Concerning the built environment, this consumption pro person can be translated in a budget pro square meter assuming a given square meter per capita and is separated by guidance value between the different sectors related to the built environment: the energy to build houses, to operate them and to move from the building that has been built to his work. These guidance value for the three sectors have *in fine* to be lower than the target value and new construction as well as renovation project can be compared to these target values (table 1).

Table 1: Guidance and target value of Greenhouse Gas emission for Swiss building (according to SIA energy efficiency path)

	New construction	Renovation
Guidance value (kg $CO_2/m^2.a$)		
Construction	8.5	5
Operation	2.5	5
Mobility	5.5	5.5
Target value (kg $CO_2/m^2.a$)	**16.5**	**15.5**

The current Swiss standard can be considered as a high embodied energy construction practice as most of the budget is spent on the construction (table 1, new construction), but with a high quality of living associated.

In the current paper, we wonders if these target values are relevant for the expected future construction at the global level? And if too high, which appropriate target values should we consider?

2. Assumptions on building typologies

To answer these questions we considered different housing qualities which have already been evaluated in previous studies.

We consideredthe embodied energy of an average post disaster reconstruction house to be able to evaluate the lowest quality standard that international organisation would recognise for housing. The data are coming from the average of 20 post disaster houses done by the red cross[5].

The current Swiss construction is used to test the consequence of a worst case scenario from the

[5] Zea E., Habert G. 2015. Global or local construction materials for post-disaster reconstruction?Sustainability assessment of twenty post-disaster shelter designs. Building and Environment, 92, 692-702.

environmental perspective, if everyone is building like this[6].

The 2000W society target is considered to be the current sustainability goal.

Finally, we considered a bamboo-based construction in order to include the potential carbon sequestration represented by bio based construction[7]. It has to be noted that not the whole house is made with bio-based materials and therefore positive CO_2 emissions are also recorded but the total CO_2 emissions is negative. This provides us with data for 4 housing types shown in table 2.

Table 2: CO_2 characteristics of different houses studied (Swiss standard and efficient: SIA 262; Average shelter: Zea, 2016; Bamboo House: Zea et al., 2016)

	Current Swiss construction	Swiss efficiency target	Average post disaster shelter	Bamboo House
Construction	*0.7*	*0.5*	*0.001*	*0.04*
Stored biogenic CO_2	*0*	*0*	*0*	*0.6*
CO_2 emissions (ton/m^2)	0.7	0.5	0.001	-0.6
Expected service life (yrs)	60	60	5	15.0

Left: High quality and high environmental concern ,Targetted Standard of the 2000W society (Swiss sustainability standard)Middle: low quality, but minium housing requirement accepted as Average post disaster reconstruction housing, Right: moderate quality and high concern for bio based materials,(Bamboo house project in Philipines)

As the service life of all the construction type is obviously not the same, it is important to consider the replacement of each house at the end of life. The figure below is illustrating this concept. For the bio-based house, we considered at the end of life that all the bio-based materials are burnt which release in the atmosphere the carbon stored. However, the new house that replace the old one is storing again carbon. No avoided impact is included in order to be able to quantify the real CO_2 release. These assumption are very first approximation as the dynamic of carbon storage in timber construction is more complex. However, as this paper’s aim is to provide a rough estimation of the challenges and open research direction, we believe that these assumptions are reasonable. For further reading on carbon dynamic in timber, one can read[8].

[6]Wyss F., Frischknecht R., Pfäffli K., John V. 2014. Target value for environmental impact of buildings, feasability study. (in German) Bundesamt für Energie BfE; Bundesamt für Umwelt BAFU; Amt für Hochbauten der Stadt Zürich AHB.

[7]Zea E., Habert G., Wohlmuth E. 2016. When CO_2 counts: Sustainability assessment of industrialized bamboo as an alternative for social housing programs in the Philippines. Buildings and Environment. 103, 44-53

[8]Peñaloza, D., Erlandsson, M. & Falk, A., 2016. Exploring the climate impact effects of increased use of bio-based materials in buildings. *Construction and Building Materials*, 125, pp.219–226.

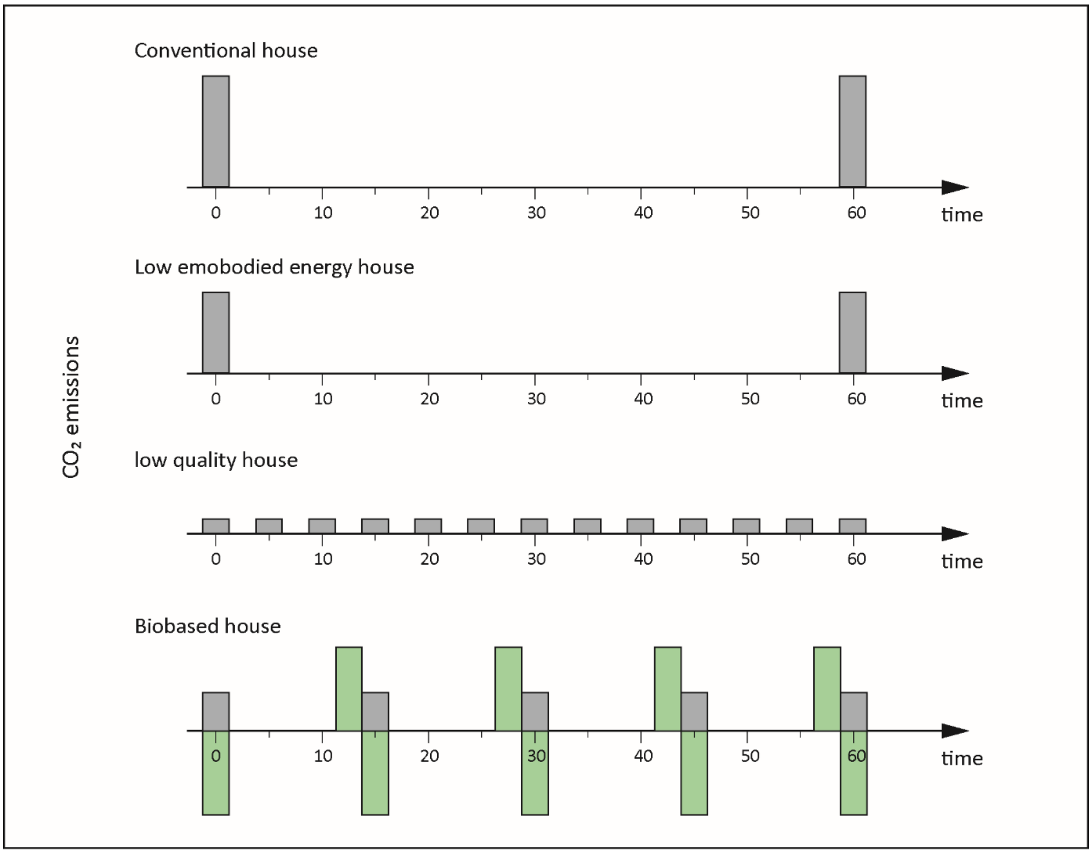


Figure 1: schematic Evolution of CO2 emission

The result in term of carbon emissions over time extrapolated for these four housing type, is schematized in the figure below. The main interest is to highlight that a low quality house that has to be refurbished very often might in time release a non-negligible amount of CO_2. Similarly, the non-bio-based materials which are part of the bio-based house contribute to regularly reduced benefits of the initial carbon storage. This has large consequence on the way we design timber or bamboo based houses. Actually, the concrete part of these houses (for slabs and foundation) can annihilate all benefits of the bio-based materials. This is the case for current timber construction in Switzerland (see Heeren[9]).

[9]Heeren, N. et al., 2015. Environmental Impact of Buildings - What Matters? *Environmental Science and Technology*, 49(16), pp.9832–9841.

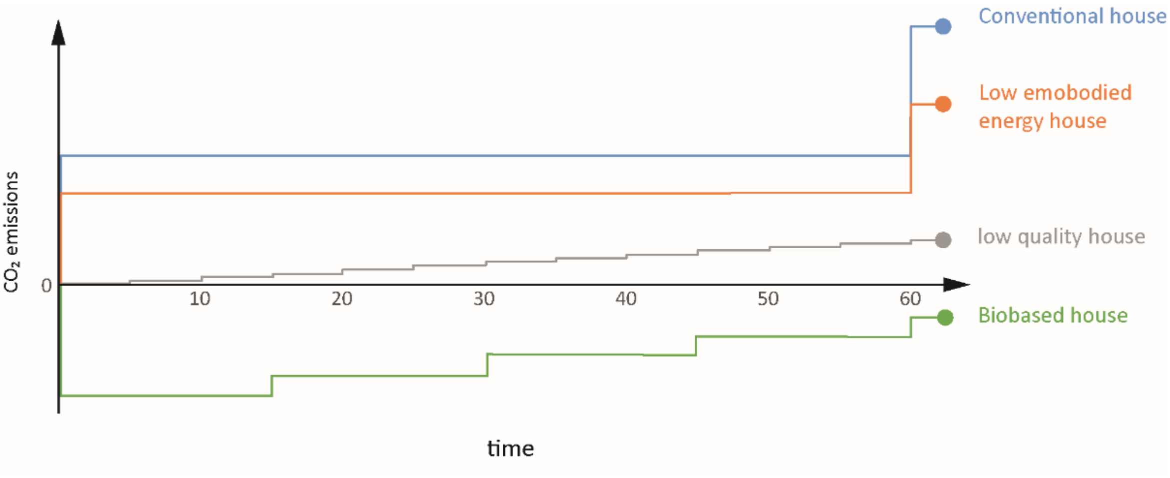


Figure 2: Evolution of CO_2 emission

3. Assumptions on building stock

However all these considerations are based on a system boundary where the environmental impact of one single house are assessed over the next 60 years. One can expand these system boundaries to the assessment of the total built environment that will be used and built from now to 2050.

The International Energy Agency recently drew some perspectives on the future built environment considering scenario of GDP growth and associated comfort level per capita (nb person/household, m^2/cap,…). Table 3 is summarizing these results and provides a value for the global residential floor area to be built and maintained over the next forty years.

Table 3: Guidance and target value of Greenhouse Gas emission for Swiss building

Time	GDP (trillion 2012 USD)	Population (billion)	Households (million)	Average persons per household	Residential floor area (billion m^2)	Average m^2 per person
2011	80.8	6.95	1894	3.6	164	24
2030	161.4	8.36	2840	2.9	266	30
2050	272.7	9.48	3518	2.7	354	37

The consequences in term of CO2 emissions for the total built environment from now to 2050 are shown in table 4 and 5.

The table 4 shows the emissions related with the construction and maintenance of the buildings. A renovation rate of 2% per year of the existing built environment, has been considered.

Table 4:CO_2 emissions for the construction and maintenance of the built environment from now to 2050

	Current Swiss construction	Swiss efficieny target	Average post disaster shelter	Bamboo House
CO_2 emissions for new construction (Gton)	136.3	97.4	1.2	-106.2
CO_2 emissions for renovation of existing building stock (Gton)	149.1	106.5	1.2	-117.6

The table 5 shows the emissions related to the operation of the built environment from now to 2050. For the calculation all built square meters have been considered to be either heated/cooled at a level of 2.5 kg CO_2/m^2 which is the highest efficiency level for the 2'000W society standard or at 25 kg kg CO_2/m^2 which is the average CO_2 emissions of European residential sector.

Table 5:CO_2 emissions for the operation of the built environment from now to 2050

Operation mode	Efficient (2.5 $kgCO_2/m^2$)	Standard (25 $kgCO_2/m^2$)
CO_2 emissions for Heating/cooling of the built environment (Gton)	26.6	266.3

One can see that with the current European construction practice (Swiss current practice and standard operation energy), operation and embodied energy have similar contribution. With an efficient operation energy consumption, the influence of the embodied energy is around 20 times more important than the operation energy when construction is done according to Swiss standards. Bamboo construction proposes a radical alternative as the CO_2 is negative (even when renovation every 15 years is considered).

4. Results

Considering the objective ofthe global target adapted for the residential built environment. We considered that 40% of the carbon budget could be allocated to the built environment and that half of it would be for the residential sector.

We can compare the total emissions calculated for the built environment on table 4 and 5, to the maximum CO2 release of 160 Gt which correspond to 20% of the 800Gt budget given to have 66% chance to stay below the 2°C target. Table 6 shows the final results.

Table 6: Final results. Total CO_2 emissions for the built environment from now to 2050 considering construction and operation of residential buildings. Different building typologies for new construction and renovation are considered as well as different energy efficiency standard for operation. Green represent value that allow to stay below 2°C target (66% chance).

	Current Swiss construction	Swiss efficieny target	Average post disaster shelter	Bamboo House
CO_2 emissions with high operation energy needs (Gton)	552	470	269	43
CO_2 emissions with high operation energy needs (Gton)	312	230	29	-197

As a main conclusion, one can state that the Paris agreement target cannot be achieved with the highest energy efficiency standard of current green buildings (2000W society).

Drastically reducing the quality of the built environment or massively using wood/bamboo in the built environment seem to be the two solutions.

5. Discussion

The simulation that has been done is extremely simplistic. Among the main issue, one can highlight the lack of dynamic assessment of the stock and its transformation over time, the consideration of the informal sector and the calculation on the heating/cooling demand.

The evolution of the square meter built has been modelled with macro-economic data. However, one can observe transformation of the building stock without increasing the number of square meter. For instance, the massive urbanisation is translated by the fact that a rural building stock is abandoned and that a new urban one is built. This has been studied for instance in China (Yang and Kohler, 2008). This transformation has been considered only by considering 2% renovation of the building stock every year, which is more characteristic of an already urbanised building stock that is then maintained and transformed. **As a consequence, the impact linked with the new construction is underestimated in our model.**

The modelling of the square meter requirement is done with country specific GDP value and average trend and relationship between square meter requirement per person and GDP. This makes the hypothesis of the pertinence of an average value per country while it is clear that this hide very large diversity/inequalities between people. For instance, this modelling is probably not extremely accurate when assessing the informal sector. There is then probably more square meter built, but in poor quality.

Those two simplifications of the model tends to lower the impact of the construction. On the contrary the hypothesis that has been considered for the operation of the building overestimates the consumption. We have actually considered that all square meter built would need the same energy consumption than European while most of the population leaves in climate where the need for heating and cooling is lower and where the level of income does not allow to heat or cool all the square meter built. **The operational energy is then probably overestimated.**

6. Conclusion

Considering the total built environment and its associated emissions from now to 2050 gives a radically new perspective:

- The operating energy seems to be of less importance than the embodied energy.

- The type of material used to build and retrofit our built environment will have fundamental consequence on the final emissions.

The current trend in construction is leading to a trajectory that is way beyond the Paris agreement target and even the strongest sustainability standard of the 2000W society do not fulfill the target.

Drastically reducing the quality of the built environment (e.g size) or massively using wood/bamboo in the built environment seem to be two solutions.

3

Exploring consumer CO2 budgets, Thomas Lützkendorf

880 Gt overall

built environment (subsection besides food, water transport supply)

explorations	**by use**								
by location	housing existing	housing new	buildings existing	buildings new	building operation	housing operation	Infrastr. new	infrastr. existing	
global									
industrialised countries									
developing countries									
continental									
counrty									
region									
urban									

In the past, the demands for a further reduction of the consumption of non-renewable energy sources, and in particular for a significant reduction of greenhouse gas emissions, were described in a relative abstract way. Often, the owners and users of buildings may not realize how great their influence is and how their behaviour can contribute to achieve these goals.

The owners and users of buildings are the ones who ultimately decide on the energy consumption and impact to global and local environment. This happens through

- the choice of an energetic standard either when constructing a new building or when renting/ purchasing an existing building
- the choice of an energy source/ source of energy supply and thus the type and extent of the use of renewable energy sources
- the demand for a specific (living) area
- the demand for a specific level of comfort in winter and summer
- the demand for hot water
- the demand for household electricity in connection with the amount, type and use of household appliances
- the user behaviour and the operational mode
- the type and extent of maintenance and repair

There is a clear relationship between the assessment of constructed assets and the assessment of lifestyles or the demand patterns/ behaviour of its occupants. The quality of buildings and energy supply are not the only important factors for the achievement of climate change objectives, but also the behaviour of their owners and users. From the perspective of the owners and users, the strategies for efficiency, sufficiency and consistency can be usefully combined. This comprises the reduction of energy demand, the improvement of the energy conversion efficiency, reasonable demands for space and comfort level as well as the use of renewable energy, an appropriate behaviour of users and the regular maintenance of building services.

One approach to involve the owners and users of residential buildings is to make them aware of their personal CO_2 footprint. There is an extensive experience in this field and related calculation tools and visual aids are freely available on the Internet see Figure 1 and http://www.nature.org/greenliving/carboncalculator/

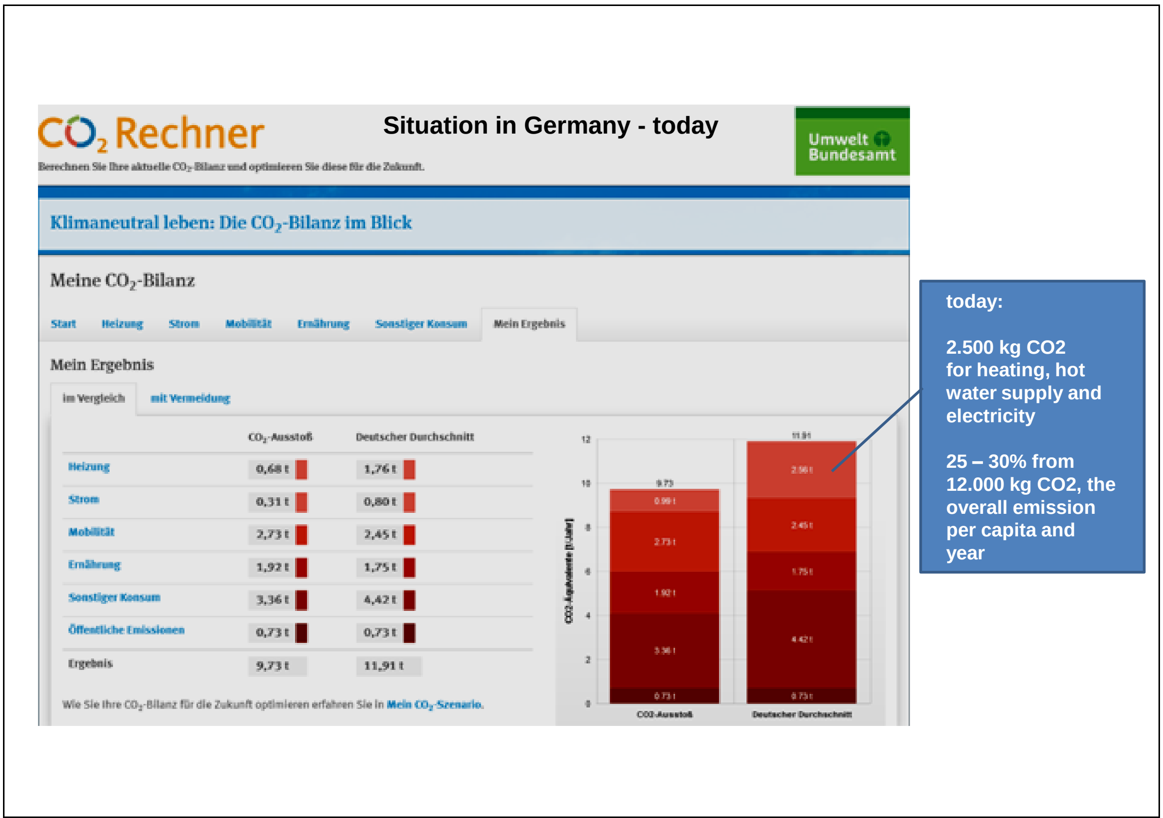


Fig.01 : Example for a CO2-calculator from Germany (the current individual CO_2 emissions are compared with a national average) see http://uba.co2-rechner.de/de_DE/

For the situation in Europe the following estimation can be made:

The annual per-capita CO_2emissions are around 10 tonnes. Of this total, about 2- 3t CO_2 / capita and year relate to the energy requirements of residential buildings (heating, hot water supply, electricity for lighting, pumps, household appliances). There is a clear need and aim to reduce the total number to 1-2t CO_2 / capita and year. Maintaining the share of the CO_2 emissions associated with energy requirements of residential buildings of the total means that a budget of about 300 - 600 kg CO_2/ capita and year are available for housing (use stage). The idea of a “personal budget” for the greenhouse gas emissions has already been increasingly discussed in the literature. The question arises as to what the level of a budget for the societal need “housing” is, and whether this budget is sufficient taking into account the technologies and options for action already available today.

This goal is realistic and can be achieved even today through the implementation of a series of measures. An evaluation shows that the following measures (selection), when combined, are sufficient for achieving this goal:

- renovation to low energy or passive house standard, or alternatively, complete switch to renewable energy sources when it comes to heating
- limit the living space to about 30 m²/capita

- limit the power consumption to about 500 kWh/ capita and year and predominant use of green power
- use of solar thermal energy for heating water

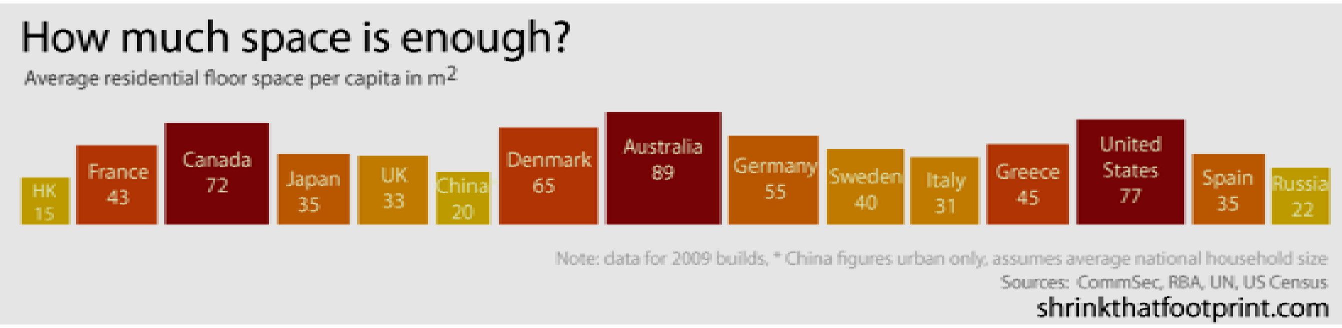
Emission factors/coefficients			
Heating oil EL		**313**	**g/kWh final energy**
Natural gas H		**241**	**g/kWh final energy**
Houeshold electricity (mix)		**617**	**g/kWh final energy**
Green electricity		**129**	**g/kWh final energy**
Situation in Germany			
		Version 2000	**Vision 2050**
Living space per capita	**m²/P**	**40**	**30**
Heating energy demand	**kWh/m²a**	**200**	**20**
Domestic hot water demand	**l/P * d**	**40**	**30**
Energy demand fort hot water	**kWh/l**	**0,058**	**0,058**
Solar fraction HWS	**%**	**0**	**50**
Electricity consumption	**kWh/P * a**	**1.000**	**600**
Type oft electricity		**electricity (grid)**	**green electricity**
Energy source		**Heating oil**	**Natural gas**
CO2 heating	**kg CO2/ P * a**	**2.504**	**145**
CO2 hot water supply	**kg CO2/ P * a**	**204**	**77**
CO2 household electricity	**kg CO2/ P * a**	**617**	**77**
total	**kg CO2/ P * a**	**3.325**	**299**

T. Lützkendorf 11/2016

Fig. 02: Example calculation for the situation in Germany

Fig. 02 shows, by using data from Germany as an example, that it is already possible today to reach a target of less than 300 kg CO_2/ capita and year for "housing". The example below assumes an average household of 4 persons. The target value can be reached through the combination of different measures:

- The required living space in a multi-family house can be reduced to approx. 30 m² per capita. Currently, the average living space in Germany is about 47 m² per capita. Examples from Europe show that values of 25 - 35m² /capita can also be achieved. Optimised floor plans is a prerequisite among others.



- Builders, buyers or tenants can ask for buildings or apartments with low energy requirements. Such buildings are offered in the market – built as passive houses or energy-efficient houses. Energy efficient buildings are also available as prefabricated houses. A prerequisite is the provision of reliable information on the energy performance of the building - e.g. in the form of an energy passport.

- The remaining energy needs of the building can be covered by efficient systems (condensing technology, heat recovery) and environmentally-friendly energy supply (e.g. solar district heating).
- A reduced consumption of hot water can be achieved through conscious behavior, water-saving fittings and household appliances. A value of 30 liters/person and day is realistic considering an economic use of water.
- The energy consumption for hot water preparation can be reduced through the use of solar thermal heating. Coverage ratios of 50% to 65% can be achieved.
- Electricity consumption for domestic appliances can be reduced through conscious behavior (e.g. avoid standby power consumption) and energy-saving appliances. As a rule, the use of electric tumble-dryers should be avoided.
- Current electricity-related emissions can be reduced through the purchase of green electricity or the integration of a PV system into the building. (The amount of energy required to produce the PV system has to be taken into account in an overall assessment).

The “budget” principle can be expanded by including standards for the limitation of energy consumption and environmental impact of the construction and maintenance of residential buildings – see part 2 of G. Habert in this document. It is clear that the values should be achieved on average level and compensations are possible. However, the perception of the problem and the willingness to take action can only be supported on an individual level. Additionally, the decisions regarding the construction type/method of a building and the selection of building products are taken by the building owner.

Conclusions

By combining a mix of measures to limit the need and demand, to increase efficiency and the use of renewable energy sources, a target of around **300 kg CO2eq. /capita and year** for “housing” (heating, preparation of hot water and household electricity consumption) can be achieved in Europe.

As a way of collecting and awarding relevant examples, a campaign is proposed having its focus on (North) Europe ***“How to live with a budget of 300 kg CO_2/ capita and year?”***.

4

EROI versus CO2/kWh under a 800Gt scenario, Ronald Rovers

880 Gt	overall								
built environment		(subsection besides food, water transport supply)							
explorations	**by use**								
by location	housing existing	housing new	buildings existing	buildings new	building operation	housing operation	Infrastr. new	infrastr. existing	
global									
industrialised countries									
developing countries									
continental									
counrty									
region									
urban									

Every kWh produced, comes with some some CO2 emissions, even from renewables. If we would make a complete energy supply from wind and solar, under the 800Gt scenario, we could slow down emissions, still pass the 2 degree barrier, but only in 175 years .Assuming we have all set up and running, of course. Which we have not. The budget is fast decreasing....

But lets start with the analyses where it should: at the beginning, our current interest in a transition towards renewable energy sources and conversions. For which many calculations are made based on costs, in cts/kWh, and wind and solar now seem to become very cheap. Which is positive, but cost unfortunately do not say anything about the effectivity of those technologies. The financial calculations are pretty misty, due to many impacts not internalized in cost calculations. Besides, in the end this transition is not about money, but about real converted renewable energy, with the lowest CO2 emissions possible .

An important indicator in this transition towards a low-impact renewable energy based transition is the EROI, or the Energy return on investment: How much energy is invested to get another unit of direct useful energy out of it . Which should of course be higher as 1 to start with, otherwise you are losing energy from the start, and the conversion process stops. EROI calculations are difficult, we have developed a quit complex energy supply system. But a lot of research is available, which give good indications. Here I chose to use the data by Hall, who has conducted extensive research at several moments and with different colleagues. [1] And these data show that currently hydro power has the best performance, with a EROI of 100:1. below are fossil fuels, gas and oil with 20:1, and coal with 80: 1. There are a few remarks to make: First of all calculating for

	eroi x:1
biopower	1,3
Solar PV	6
Solar CSP	1,6
Geothermal	9
hydropower	100
oceanenergy	15
windenergy	18
nuclear	14
nat gas	20
oil	20
coal	80

these fuels starts at the moment as if they are just available, without addressing the fact there has been a long proces in advance, of cooking and pressurizing biomass in the earth crust. This is left out of the equations , (I wrote about this in another article [2]) Besides the use of fossil fuels have nasty side effects, we will come back to this. Below the fossil fuels are all the other technologies, with wind as most effective.

For all these technologies the energy for materials processing has been included, but not the energy that should be invested to counter depletion of resources, or the regeneration of resources. In fact you should calculate the (E+M)ROI, energy and material return on investment. Materials also deteriorate , get lost and should be suppleted. Nevertheless, thats for another analyses, here I focus on the EROI data, that already provide a good insight in the positions.

	gr. CO2 eq/kWh
biopower	18
Solar PV	46
Solar CSP	22
Geothermal	45
hydropower	4
oceanenergy	8
windenergy	12
nuclear	16
nat gas	469
oil	840
coal	1001

But EROI does not provide the full picture, certainly not in this era, where reducing climate change is top priority. Which is all about reducing Greenhouse gas emissions, and mainly CO2. So its interesting to look at the CO2 data as well, , that is: the CO2 emissions incorporated for the conversion technology per delivered kWh. Something the IPCC has already looked into, and specifically in the annex 2 reports from WG3 [3].

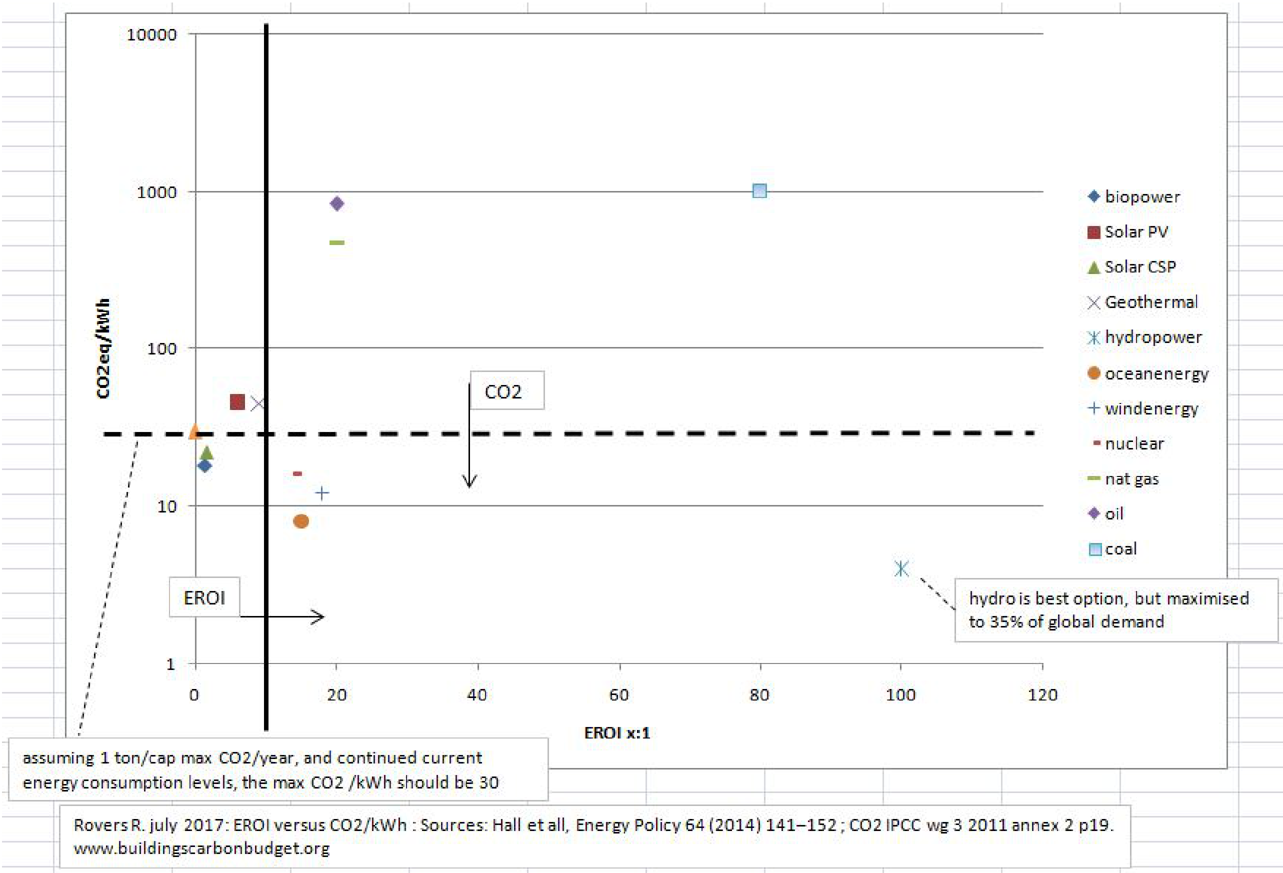
Its not amazing the fossil fuels now score very badly, a factor 10-20 more then any other technology, per delivered kWh. Very low scoring is biomass (which has some other deficiencies) and not totally unexpected: solar mirror plants: one of the most effective when it comes to CO2 emissions. Now it gets interesting, I have put these two together in a graph, since what we want in the end is a high EROI with a low CO2. To be able to judge this, we have to know where are the bottom lines for EROI and CO2, In that case we can design a cross in the graph and see in which quarter both parameters score well.

For EROI the literature proposes a minimum of 10 , to be really effective, below that threshold the investments hardly pay back. [4] Next is CO2, which has to be much lower of course as the 469 of gas and the 1000 level by coal.

But then , what is a acceptable level line for CO2 ? There is a way to calculate the bottom line, as follows: In the Netherlands we are currently at 10 ton CO2 per capita per year. It is estimated that with 1 ton of CO2 emissions per year per capita would be acceptable to bring the CO2 situation back in balance. [5]. for the total population in NL that would be 17 million tonnes. If that is the maximum to maintain our current energy consumption level, which is 2000 PJ,[6] , a simple calculation shows how much kg can be emitted per kWh: being 0,03 kg/kWh … The bottom line is at 30,0 gr/kWh. Would we average over the whole world energy consumption, which currently is 157500 TWh, [7] With 7,5 billion people and 1 ton/cap-year, , the max to emit would be 0,05 kg/kWh, or 50 gr/kWh. Nearly double, but still very low.

There is only 3 (technical) conversion routes within range: Hydropower, ocean energy, windenergy, (I neglect nuclear here) . Solar PV, in its current form, is not in range, for both criteria.

How does this relate to the 800Gt CO2 emissions ceiling? Assuming we will generate all energy with a combination of wind and solar PV, say 50/50 , that would have a (46+12)/2=29 gr/kWh CO2 emissions. So with the 800 Gt budget 28000000 Twh could be generated. Divided by our yearly global current supply (157500 TWh, see before) is enough for ~175 years: we will still pass the 2 degree barrier, but only in 175 years.



And for the B2 scenario. For the B1,5 scenario, this would be ~45 years. But again, *only if installed and generating*. For the moment we use coal and gas with 500-1000 gr CO2/kWh, and the budget is fast decreasing. Every year delay, reduces the available RE production years in the B2 scenario with around 10% . In 10 years or so we can't even afford Wind and PV anymore....

If we could succeed in generating everything with the best available technology, hydropower (4gr/kWh) , it would be ~1200 years (B2). Only it happens that just a few weeks ago a paper was published with extensive research into the potential of hydropower. [8] And this reveals that a maximum of 33% of all current energy demand could be generated by hydropower. The other 2/3 has to come from a combination of other , for the moment higher CO2 impacted technologies.

conclusions

Of course, these are rough indications. I have seen calculations that show higher CO2 emissions per kWh for several technologies. But indicators are secure enough to see limitations, and as somewhat alarming: To have any chance to stay below 2 degrees of climate change, with a reasonable EROI to avoid other impacts (like too much land use) , the current energy demand will have to be reduced drastically, by means of behavior and use of services, before we count on mega investing in technologies. Which implies less energy consuming appliances, less travel, smaller living areas [5]. As well as to look at Labor-power again, as a 'free' energy source reinstalled [9]. But also : to put enormous effort in developing some new technologies, like OPV (organic PV cells), and Airborne wind-turbines [10]. A promising conversion route, with expected much lower gr. CO2 /kWh . Besides, this is solely about energy and CO2 emissions. Whether we have the material stocks to install all this, has to be seen, there are many publications that show limits in that as well. [11][12][13] . The challenge remains, to reduce our demand drastically.

R.Rovers / May 2017

*Note

Not included in the graph, and the data lists , are non conventional or innovative sources and conversion routes. A few data collected from different sources are presented here, as a rough reference.

Non conventional fossil fuels.

Tars sands, shale oil and shale gas are all far below an EROI of ten. With tar sands even suspected to get close to 1…! [14]

When it comes to CO2 data are difficult to obtain. Sources found give large differences. I assume that all are at least in the same range as the “easy fossils”. (maybe even higher when peatland is destroyed) .

New generation renewables

Airborn wind energy, (flying turbines, by cable) are estimated at EROI >300 [15]. That could make a difference. Classic windturbines , have a hugh material impact, which is not included in the data and graph used above. Also here airborne or high altitude devices are significantly less massive (20 tonnes for 3 MW) than traditional turbines of equivalent rating (417 tonnes of steel and 902 tonnes of concrete). This provides a double advantage. Since the CO2 per kWh will be much lower, as well as exergy losses by material depletion.

Solar cells, the panels as we know now, are not in the preferred range . There are a few new promising developments: Thin film, flexible, solar cells, and Organic PV: Solar cells made of biobased components, mimicking nature.

Thin film (a-Si) has a eroi of close to 15 .[16] The CO2 data are not available to me. OPV: The first impressions from raw research data suggest the eroi for OPV to be double compared to conventional PV. But this could still improve if research could raise the efficiency of these cells types, which are around 1-2 % now. CO2/kWh data should be significantly better, but to early to judge.

There are other options, like energy from algea, but not yet documented (data welcome!)

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Part C

preliminary conclusions from 1,2,3,4 :

findings and trends from 3.1:

3.3.1 : retrofitting all existing houses for ZEB operation creates a huge rebound effect in materials application. Such that it is unavoidable to reduce heated areas and limit materials input for retrofit .

3.3.2 to avoid an end of pipe approach and rebound effects in retrofitting houses, (see 3.3.1), it is more wise to put all effort in reforming the industry first, and make industry produce 0-embodied energy/ 0-CO2 materials and products.

3.3.3 : a shift for low impact materials is urgently needed, to focus at biobased building/retrofit. The strategy required is comparable to that of food: vegetarian building.

findings and trends from 3.2

3.2.1 : operation energy seems to be of lower importance than the embodied energy of (new) buildings.

3.2.1 : Drastically reducing the quality of the built environment or massively using wood/bamboo in the built environment seem to be the two unavoidable solutions.

3.2.1 : new construction for the global need should be based on renewable ie biobased resources.

findings and trends from 3.3

3.3.1 : to be able to live within natural balanced CO2 emissions schemes, household energy demand will have to be reduced significantly

3.3.2 : Some of the measures required to bring energy demand within balanced CO2 managed levels, are: reduced living area per capita, no cooling , and limit the power consumption to around 500kWh /cap-year

findings and trends from 3.4

3.4.1 : the current energy demand will have to be reduced drastically, by means of behavior and use of services, before we count on mega investing in technologies.

3.4.2 : enormous effort to put in developing some new technologies, like OPV (organic PV cells), and Airborne wind-turbines

Conclusions Overall

Work in progress…. More chapters to follow.