Part I - Introduction to sustainability concepts

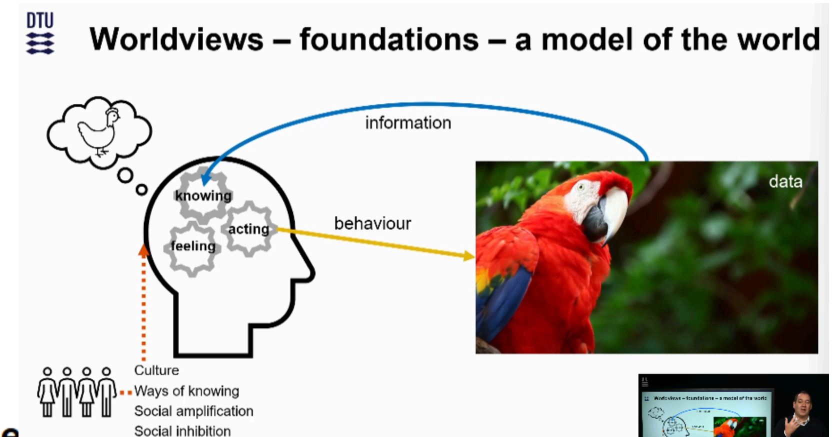
Sustainability concepts, three dimensions and Sustainable Development Goals

What is sustainability?

Sustainability is a concept which touches on the key aspect of a human experience.It forces us to think as an individual what it means to live with others and interact in nature and with nature.These reflections are shaped by your experiences as an individual, and since everyone has a different experience and belongs to different communities, they have unique interactions with people and nature that will shape their world views.

The ways we view the world and how we place any new experience we are going to get in the ledger of our life.These worldviews will influence how people interact with nature and others and what they get from these interactions.It means that the value we ascribe to these interactions will differ depending on our world views. For example, a parrot for you might be a chicken to someone else.

But a little problem emerges with this. If we all ascribe different values based on our world views to experiences,does that mean we all have a different view on what the relationship between nature and people is?



Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

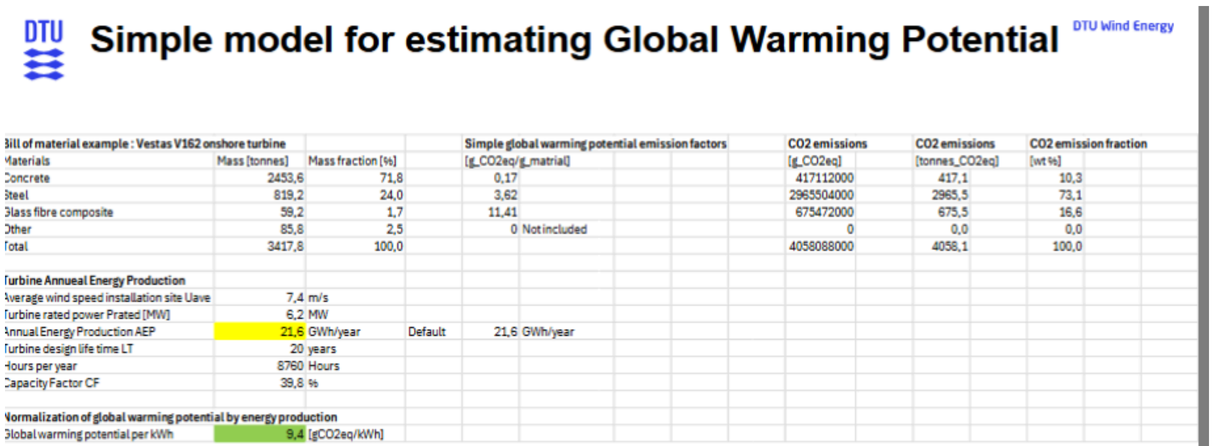
Well, yes, and we can categorise these into three broad word categories.

Perceptions about the world

- Humans have special place in nature: people feel that we have a special place in nature, and that nature is where dominion that is.But people should choose to do what they want with nature in a circle with you here.

- Nature needs protection: People also feel that they have a really special place in nature, that they are stewards of nature, and nature needs their protection.And we have a special role to play to do so
- Humans are not special: people are just another species on the planet., We have no special role beyond trying not to take too much space so as to not damage opportunities of others.

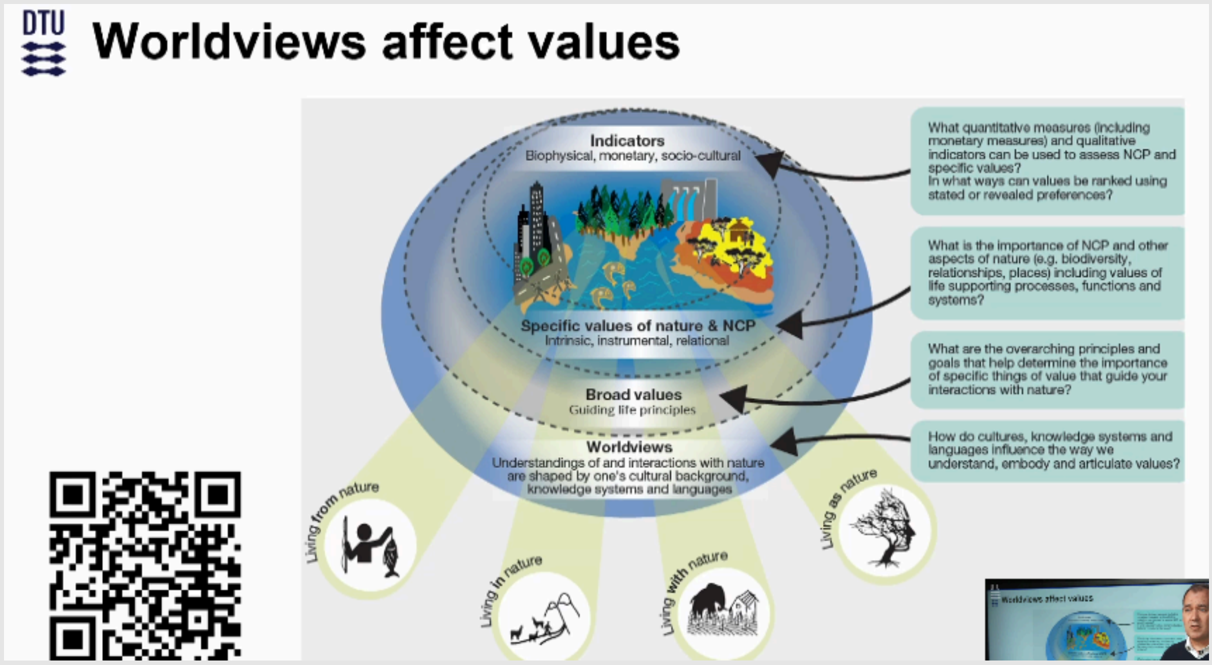
So some really nice work is emerging at the moment as part of intergovernmental synthesis to help find solution to a biodiversity crisis,which really helps to frame our values we ascribe to nature.Actually, also, our values we ascribe to others are influenced by world views.



Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

But in short, here we can find that people ascribe different specific values to,for example, nature contribution to people depending on their world views. So we have these jerarquies of value formation, if you prefer.



In this framework, we have four worldviews that are categorised which are defined by these values.

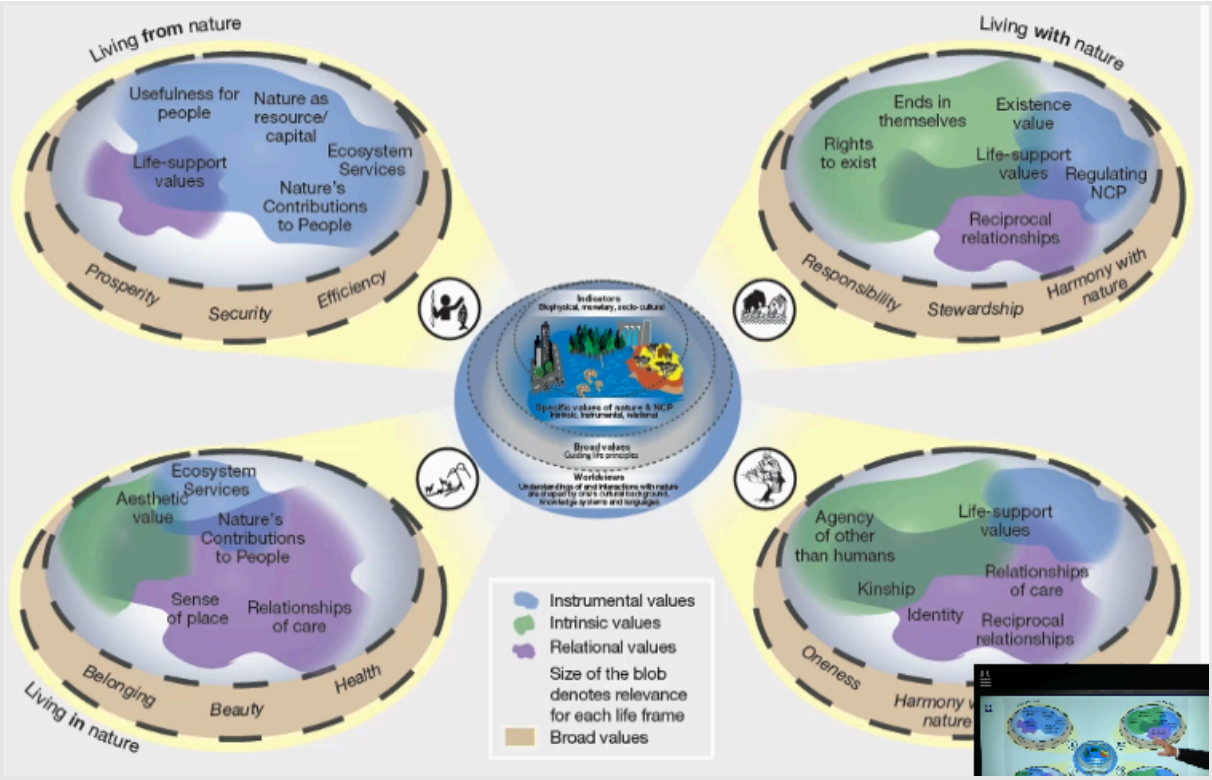
We have living from nature, living with nature, living as nature, and living in nature. I want you to get familiar with those.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



Many of us sustainability challenges we want to tackle are global in nature, even locally.You will find that people have diverse world views. So how can we build a common vision about sustainability if we can't agree on what is valuable?

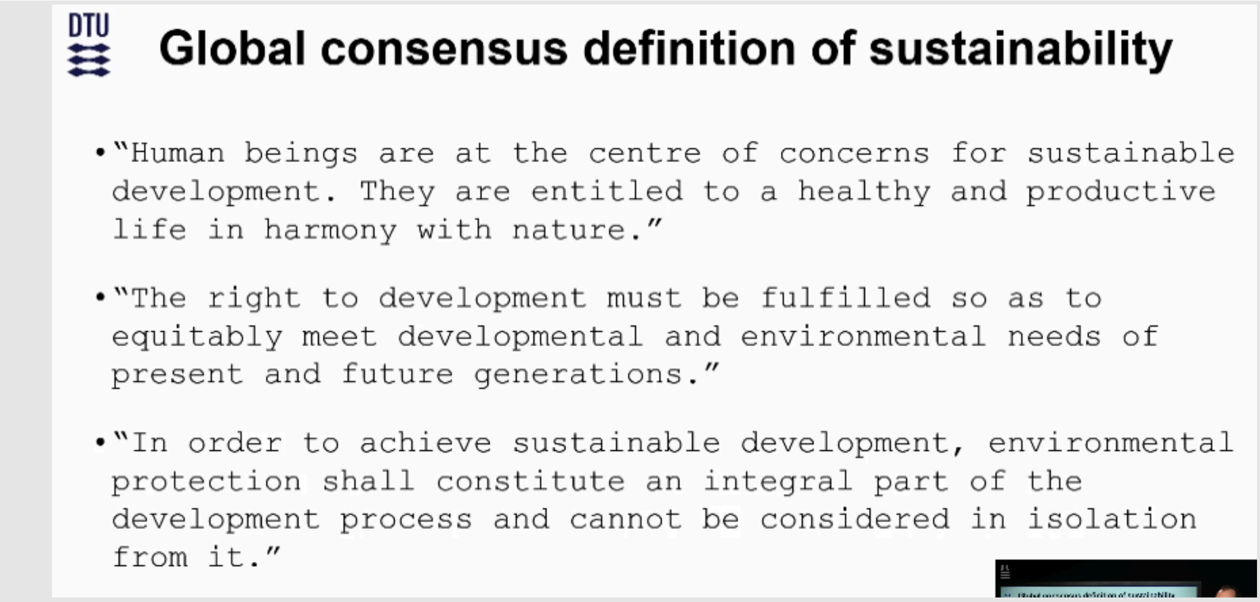
<u>Definition for sustainability</u>

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

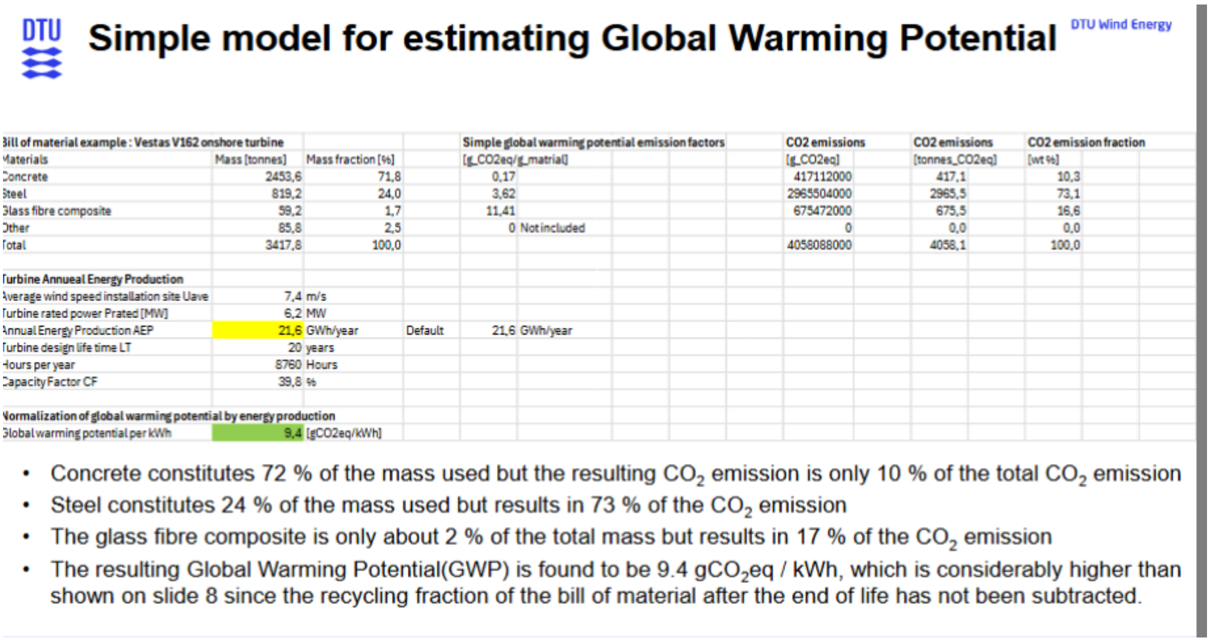


In 1992, the United Nation declared in Rio de Janeiro.A common definition for sustainability.

Human beings are the centre of concern for sustainable development. They are entitled to a healthy and productive life in harmony with nature.The right to development must be fulfilled so as to equitably meet developmental and and vulnerable needs of present and future generations in order to achieve sustainable development and governmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.

Takeaways:

- Sustainability is a diverse concept- We all have an intrinsic view of this concept, but those views differ slightly and sometimes actually diverge about how we understand.



Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Sustainability depends on our world views about the relationship between people and nature.
- The challenge is that, well, almost everybody is right. There is not one optimal definition. So how do we move forward? How do we find out how to measure sustainability if it is so hard to define it?

How can we coordinate globally such a varied concept?

Introduction to Sustainability Measurement

We began by discussing the concept of sustainability and how to move from a theoretical idea to measuring whether an activity is sustainable. First, we need to frame the definition and define the dimensions of the problem.

Global Definition of Sustainability

Currently, sustainability is globally defined as being about people—how they use the environment for their well-being and development without jeopardizing future generations' opportunities. This means preserving the environment as an asset for future people.
Historical Context

- 1992: The Rio Declaration established a consensus on sustainability, but implementation has proven more complex than anticipated. It was said that we would be able to build a sustainable world by 2000.
- The international conversation on sustainability has emerged from the interaction between the work on economic development and the environmentalism movement
- 1972: The Stockholm Declaration recognized that human actions could impact the global environment, not just local communities. This was a pivotal moment, as it highlighted that our activities have limits and raised questions about equitable opportunities among nations.

DTU

Simple model for estimating Global Warming Potential

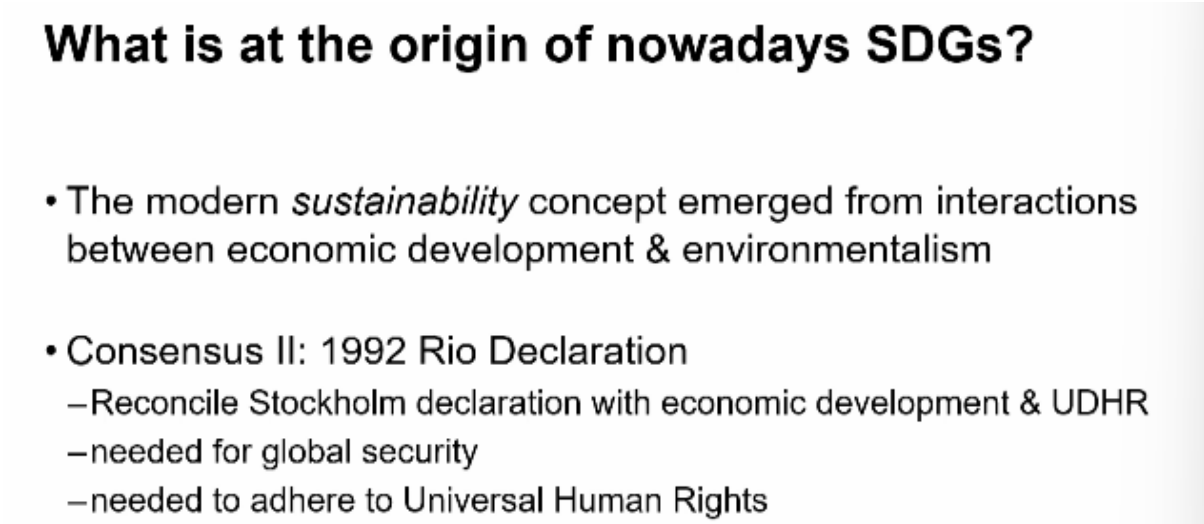
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

- 1948: The Universal Declaration of Human Rights affirmed equal rights to opportunities, creating a need to reconcile environmental and developmental goals.

So how do we reconcile these views? In an equitable manner? That is the conundrum the work towards the Rio 1992 meeting set to achieve and aims to address.



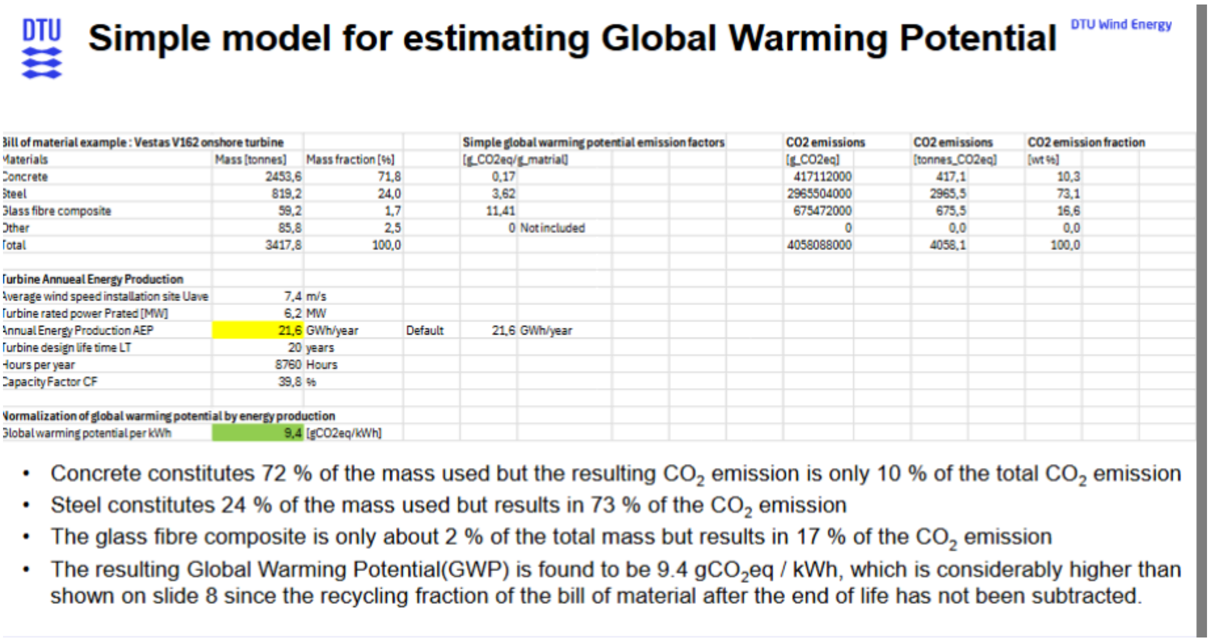
This is important to note: the global efforts to define sustainability are framing the human development paradigm. The effort is address towards the challenges for low and middle income countries. So how do we frame this?

Framing Sustainability

Sustainability emerged from the intersection of economic development and environmentalism. The challenge is balancing equitable economic development with environmental preservation.

The Three Capitals Framework

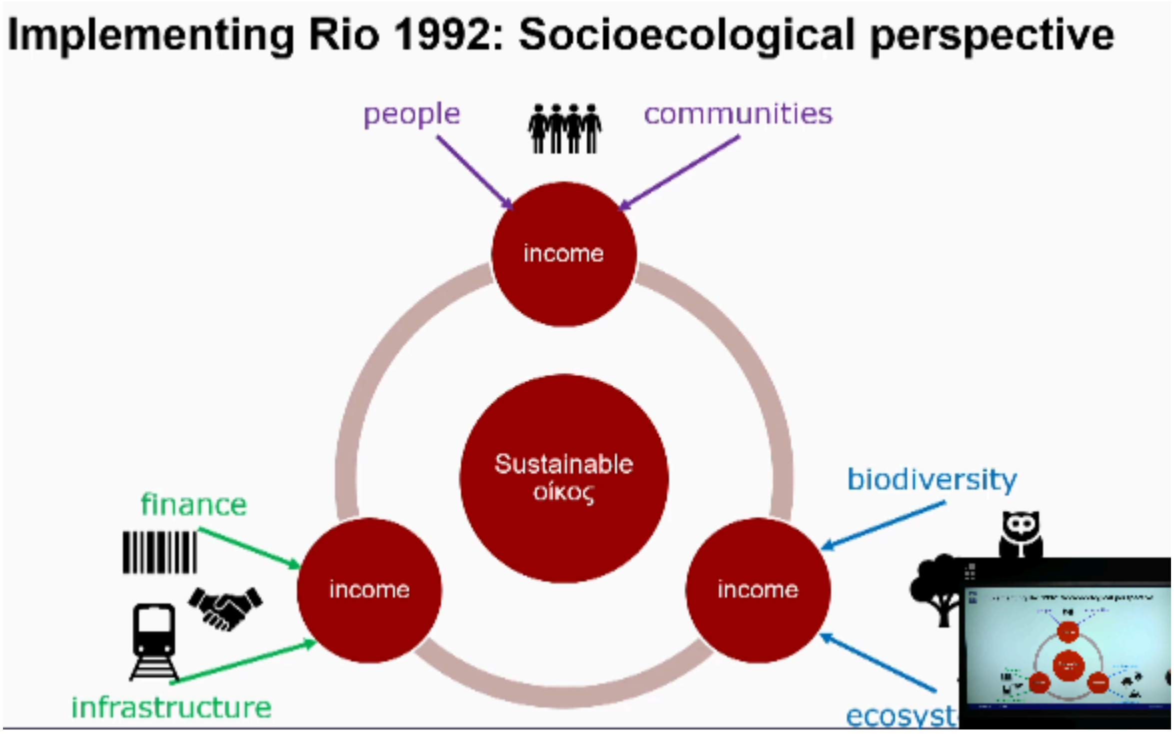
We have a social and economical and financial capital. And we are deriving some



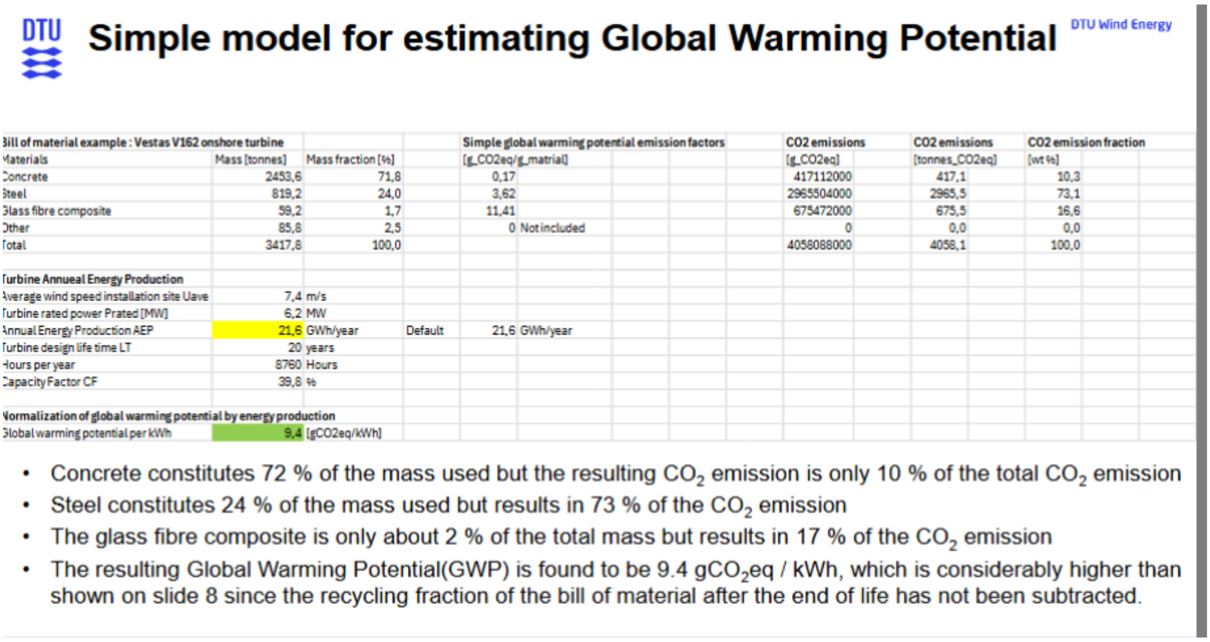
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

income from this capital to maintain / sustain the house (greek notion of house). We aim to find ways to make sure that we can derive these incomes without reducing the capital for future generations.

The three capitals can be thought of as composed of agents: the infrastructure, the people and the species and what links them (economies, communities and the ecosystems).



Sustainability is often visualized through three interconnected capitals

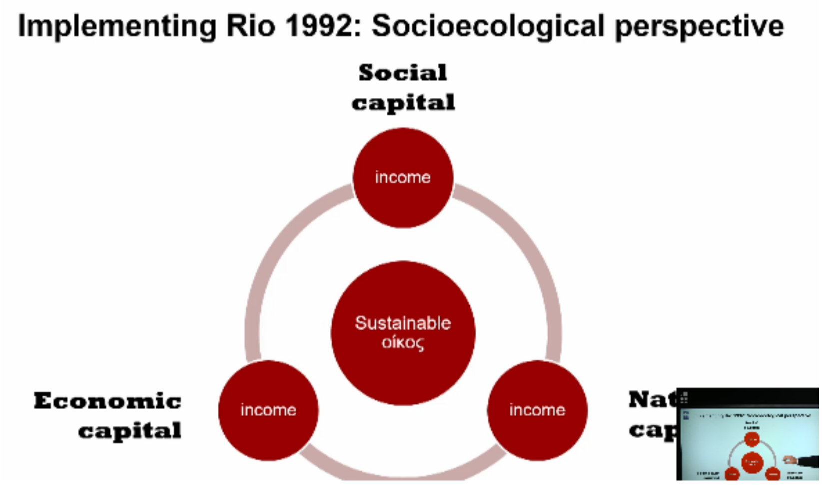


Simple model for estimating Global Warming Potential

DTU Wind Energy

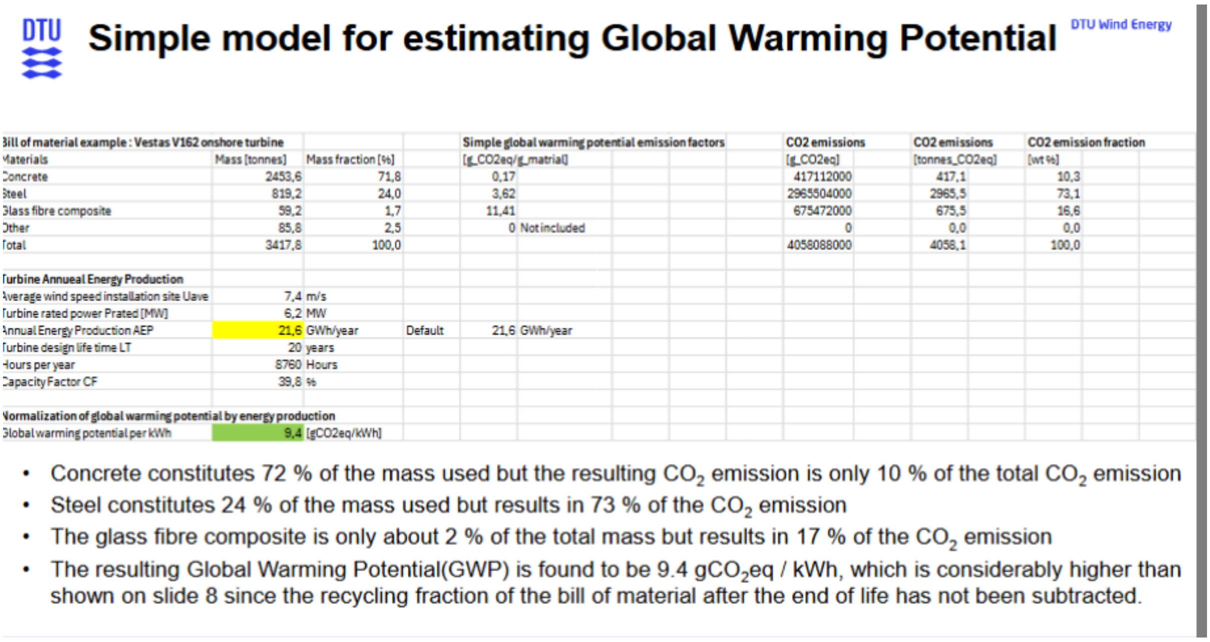
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



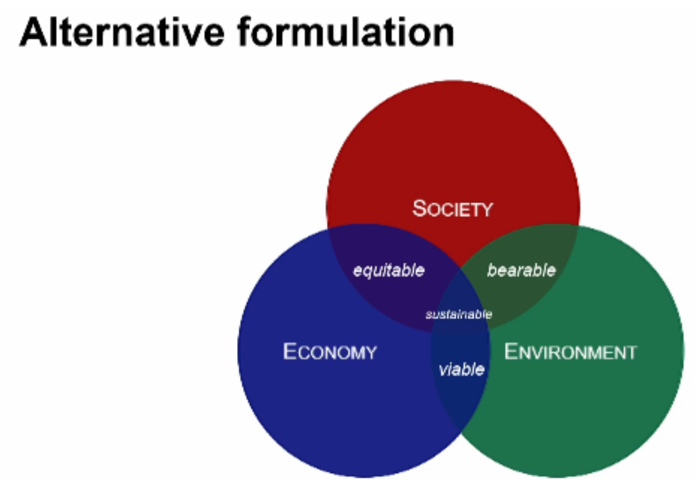
1. **Social Capital**: Communities and people.
2. **Economic Capital**: Infrastructure and economies.
3. **Environmental Capital**: Ecosystems and species.

The goal is to derive "income" (benefits) from these capitals without depleting them for future generations. Alternative frameworks also exist, emphasizing bearable, equitable, and viable outcomes.

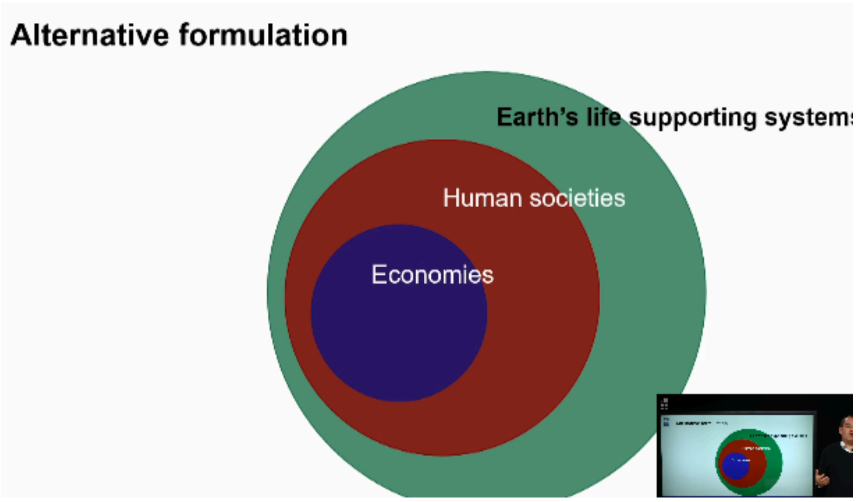


Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

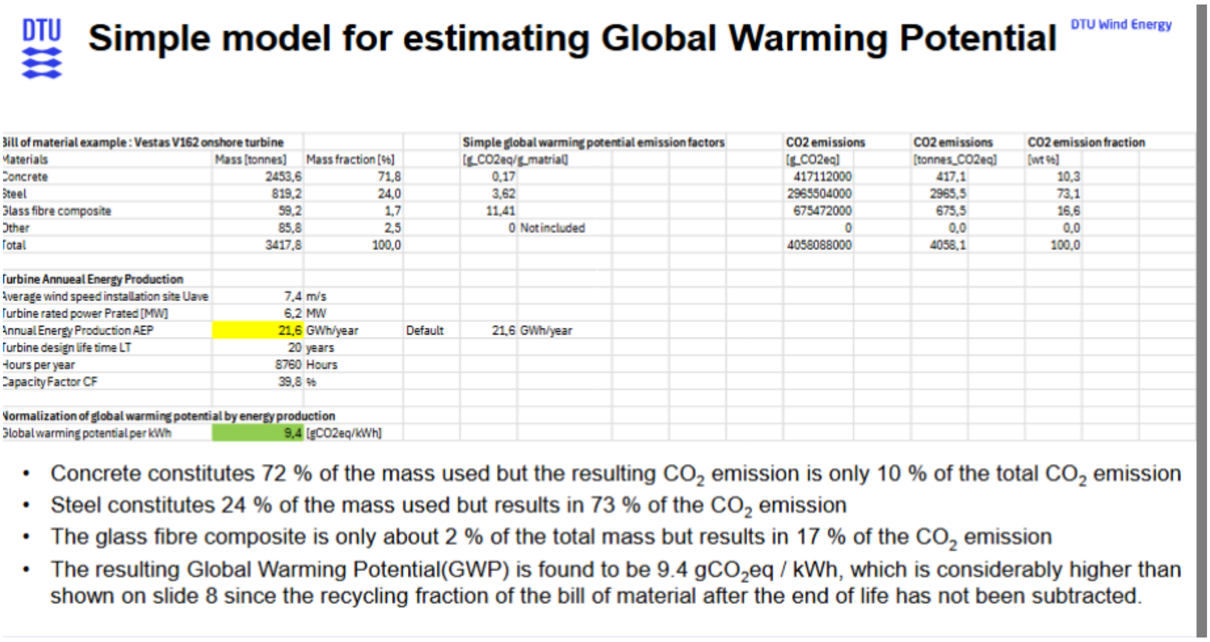


Embedded Pillars View



Another perspective sees societies and economies as embedded within planetary limits:

- Societies cannot exceed the planet's capacity.



DTU Wind Energy

Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

- Economies cannot grow beyond societal and environmental means.

Conclusion

We now have a consensus definition and framework to operationalize sustainability across different worldviews. Key takeaways:

- Sustainability is about people.
- It requires balancing social, economic, and environmental needs.
- Consensus-building takes time (e.g., from Stockholm in 1972 to Rio in 1992, and now 30 years post-Rio).

Final Reflection
Will we have enough time to achieve the ambitions set for sustainability? This remains a critical question as we move forward.

DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

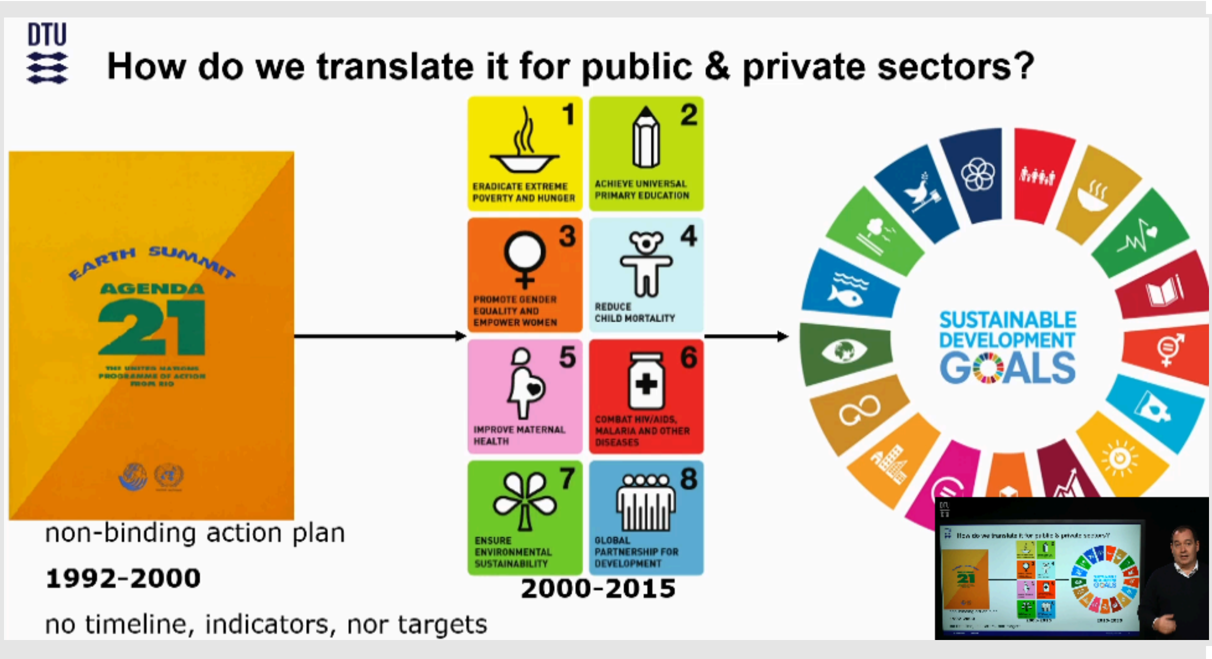
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

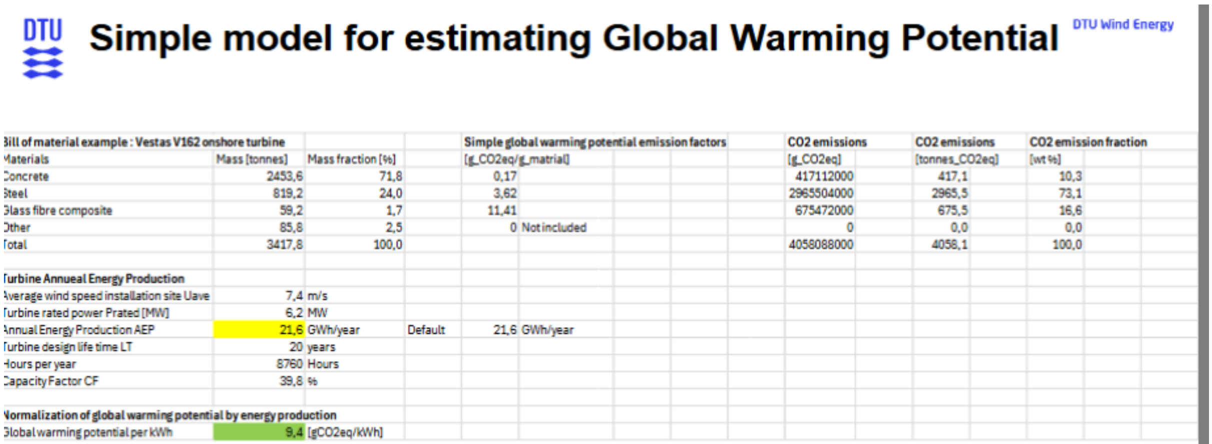
A framework to measure sustainability

From Theory to Measurement: Operationalizing Sustainability

- Sustainability is often framed through the **three pillars (social, economic, environmental)**, but how do we measure it in practice?



- **Agenda 21 (1992)** was an early attempt—a non-binding action plan with no clear indicators, targets, or timelines. By 2000, little progress was visible.
- Agenda 21 was released to help public and private sector to assess how the activities might be contributing to a real ambition and how could they be sustainable. It was like a recipe, was a non binding action plan. How to achieve sustainability grounded in theory. It had no timeline, indicators or target. Was it successful? We dont know because no timeline, indicators or target….



Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

2. Learning from Past Efforts: MDGs to SDGs

- **Millennium Development Goals (MDGs)** addressed some shortcomings but had mixed success. We didnt know what would be smart indicators of the three pillars. It was then decided to try and establish a SMART objective on tractable problem.There was confusion between objective and ambitions and it whoed we didint make large progress
    - **Success**: Progress on reducing child mortality.
    - **Failure**: Poorly defined goals (e.g., Goal 7) saw little traction.

SMART: Specific, Measurable, Relevant, Achievable and Time bound objective. From this , SDGs are born.

- **Sustainable Development Goals (SDGs)** emerged as a refined approach:

DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

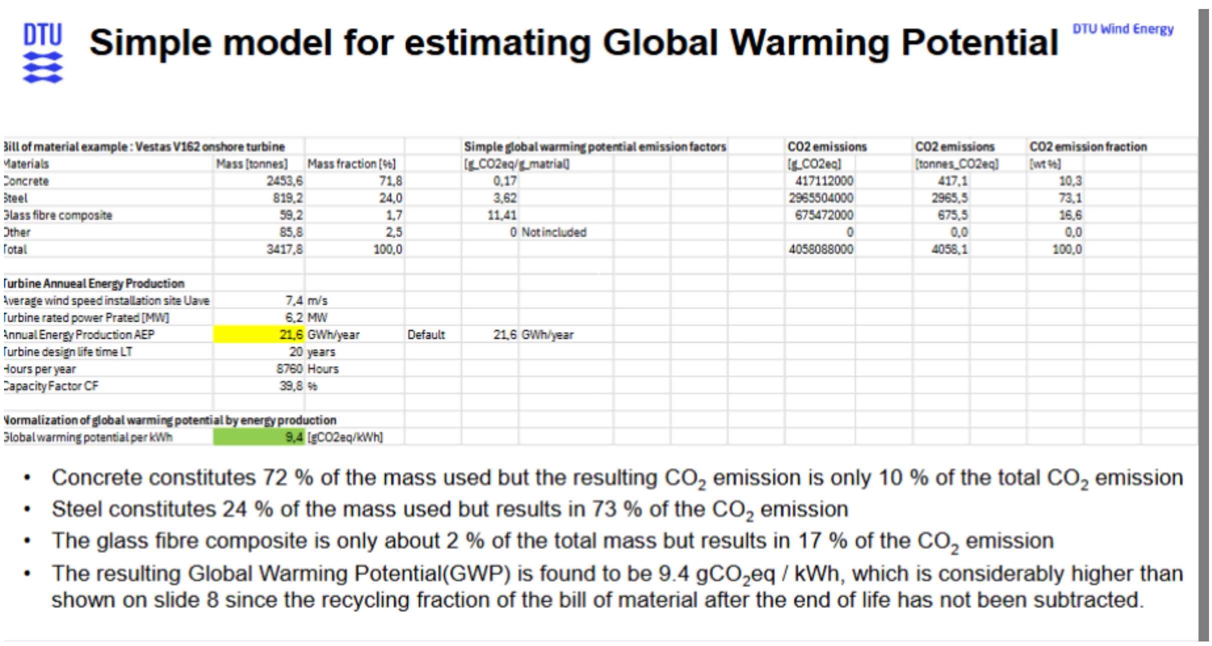
- **17 Goals, 169 Targets, 210 Indicators**—we start to have goals that are square and center relevant o all countries.now applicable to **all countries** (not just developing nations).
- **Key Challenge**: Distinguishing between **strict objectives** vs. **aspirational ambitions**. What is the point of setting quantifiable targets if we dont aim to meet them

The next pitfall that has emerged when setting SMART univariate objective for a complex multidimensional challenge is that these objectives need integration. Example: we need to combat climate change in order to maintain relative sabe and long conditions for people to survive and hopefully also thrive. How i try to achieve this, will have consequences on other aspects of people's lives. Just one example of interactions among the goals. There are positive interactions: if I progress in one goal, the goals associated with that goal will also progress. And there are also negative interactions.

Architecture of these networks varies within countries, particularly among income groups. In low income countries, there are no conflicts emerging from these interactions. Which means that all goals can be progressed in tandem and we will have a greater compounded effect on all goals by prioritizing to alleviate poverty. The size of the node in the network tells about the vast structural importance.

But in high income countries it is different: there is a conflict between climate action and reducing inequalities. Which emerges from indirect interaction between both goals within the system, within the network of interactions. So that means we have a trade off to think about, and that is not easy in some countries.

3. Integration and Trade-offs Between SDGs



DTU **Simple model for estimating Global Warming Potential** DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

- Progress on one goal can impact others (**positive or negative interactions**):
  - **Low-income countries**: Goals reinforce each other (e.g., poverty reduction boosts other targets).
  - **High-income countries**: Conflicts arise (e.g., **climate action vs. reducing inequality**).
- **Data gaps persist**: Many indicators lack global coverage due to measurement challenges or lack of focus.

Recall that sustainability efforts are focussed historically on low income countries, so maybe by paying more attention to high income countries, new sustainable solutions will emerge

Indicators: data remain sparse despite their clear need. There are some goals that are not well informed across the planet. There is both a capacity challenge which is causing this as well as simply a lack or focus or difficulties to measure these indicators even in countries that have the infrastructure to produce such statistics

Conclusions:

- We need SMART objectives & targets. Note that the achievable part is not clear for some objectives. Both in public and private
- They need to capture the 3 dimensions of sustainability (economy, society and environment)
- Data remains sparse
- Globally we still confuse ambition and objective.

Note:

Ambition vs. Objective in Sustainability

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Ambition

- **Definition**: A broad, aspirational vision or long-term goal.
- **Characteristics**:
    - **Qualitative** (e.g., "achieve climate neutrality").
    - **Lacks strict metrics or deadlines** (e.g., "eventually eliminate plastic waste").
    - **Inspirational**—motivates action but doesn't specify how.
- **Example (SDGs)**:
    - *"End poverty in all its forms everywhere"* (SDG 1) is an **ambition**—it sets a direction but doesn't define exact steps.

Objective

- **Definition**: A concrete, measurable target tied to actions.
- **Characteristics**:
    - **Quantitative** (e.g., "reduce CO_2 emissions by 50% by 2030").
    - **Time-bound and actionable** (e.g., "install 1 million solar panels by 2025").
    - **Follows SMART criteria** (Specific, Measurable, Achievable, Relevant, Time-bound).
- **Example (SDGs)**:
    - *"By 2030, reduce at least 45% of marine plastic pollution"* (SDG 14.1) is an **objective**—it includes a clear metric and deadline.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Sustainable Development Goals and influence on companies

The UN Sustainable development goals have different focuses and aspects. A number of these are focused in the socio economic aspect, a number of them are focus in environmental aspects. And a LOT of them are technology driven. That actually means we can improve our way to that target through different technologies

United Nation's Sustainable Development goals

17 goals to 'end poverty, protect the planet, and ensure prosperity for all as part of a new sustainable development agenda'

How does this influence companies?

How does this influence companies?

- Probably the strongest external factor industry has yet seen in the sustainability area
- Should affect prioritisations and action internal in the company
- SDGs are expected to be translated to national programmes containing a targeted mix of legislation, regulation, financing, and price governing mechanisms that companies have to relate to

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

How does companies relate to these SDGs? Sometimes it is difficult because SDGs are in principle developed on a nation level. So how does companies take that up? In order to do that, the SDG Compass was developed. This is about how we understand the SDGs, what we need to do and how we define priorities and define goals. We need to integrate the goals and how we put efforts to get there and we need to report and show if we achievved them

SDG Compass

- Objective to support companies in aligning their strategies with the SDGs and in measuring and managing their contribution
- Developed by GRI, the UN Global Compact and the World Business Council for Sustainable Development (WBCSD)

4. Corporate Engagement with SDGs

- **SDG Compass**: Helps companies align with SDGs by:
    - **Prioritizing relevant goals**.
    - **Setting measurable targets**.
    - **Reporting progress**.

- **Benefits for Companies**:

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

- Cost savings (e.g., waste reduction).
- Enhanced reputation and employee satisfaction.
- Innovation and competitive advantage.

Sustainable alternatives have various advantages.

- It will create direct value by reducing energy costs and reduced waste processing costs, and by avoiding pollution taxes that embraces CSR.
- It will diminish vulnerability regarding future energy costs and other material costs as one would consume less.
- It will be the basis for a sound and positive reputation.
- It might result in a stronger company spirit and a collective company goal improving the company's synergy.
- It will facilitate the acquirement of licenses.
- It will stimulate learning and innovation. New opportunities and emerging markets
- Last but not least, it will lead to more employee satisfaction. It can fulfill people's desire for good citizenship. Personal motivation of management and other employees can increase, improving social behavior and other business results.

Some academic studies have shown that there is a positive relationship between sustainability performance and firm value. In terms also on the stock and market value of the company. So there are some company and financial benefits in engaging sustainability

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Some academic studies

- Yu et al, 2015
  - positive relation between sustainability performance and firm value, after controlling for variables that have been found to affect firm value in the existing literature.
- Lourenco et al, 2012
  - Their findings suggest that CSP is positively associated with the financial performance of large and profitable firms which are able to signal their sustainability performance, and has a negative association with the performance of large and profitable firms that are not able to signal their sustainability performance.
  - CSP has significant explanatory power for stock prices over the traditional summary accounting measures such as earnings and book value of equity.
- Lo & Sheu, 2007
  - a significantly positive relation between corporate sustainability and its market value is found. We also find a strong interaction effect between corporate sustainability and sales growth on firm value.

- **Different initiatives to engage in:**
  - **UN Global Compact**: Members commit to sustainability reporting. You send a message that you care for sustainability
  - **Science-Based Targets**: CO_2 reduction benchmarks. As a company you commit to reduce greenhouse gas emissions
  - In buildings sector - DGNB
  - **Increased transparency**: More companies now disclose both **positive and negative impacts**.

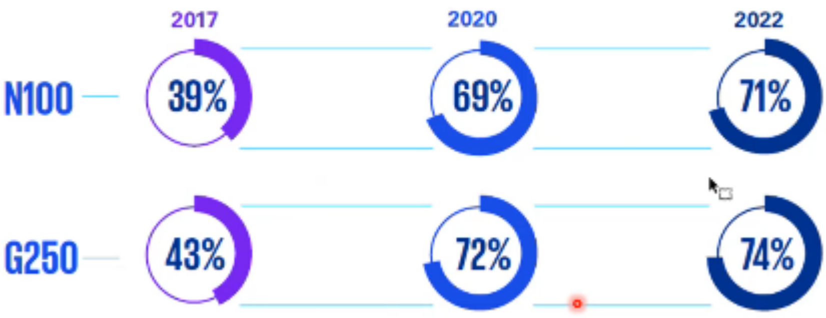
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Figure 29: Global SDG reporting rates (2017–2022)



Base: 4,581 N100 and 240 G250 companies that report on sustainability or ESG matters
Source: KPMG Survey of Sustainability Reporting 2022, KPMG International, September 2022

Examined a lot of reports of companies. N100 (100 largest companies in the OCD companies). G250 (biggest 250 companies from the global perspective).

The interest in reporting is growing since 2017. There is a tremendous increase!

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Figure 33: Frequency of prioritized SDGs (2022)

Base: 3,275 N100 companies identify specific SDGs they consider the most relevant for their business

The most prioritized goals from the companies are generally: decent work and economic growth, climate action, responsible consumption and production, clean energy and industry innovation and infrastructure.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

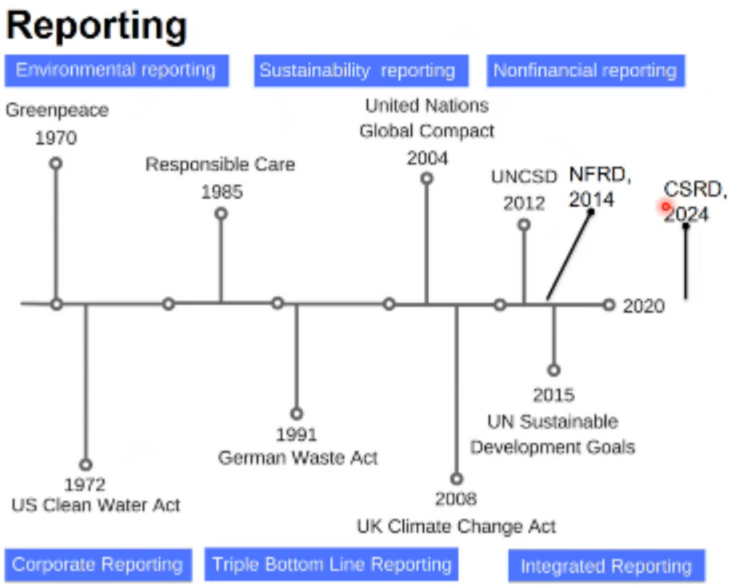
You can see which SDG you have a positive or negative influence on. Some companies report both positive and negative, and there are some that dont report

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



NASDAQ ESG REPORTING GUIDE: guidelines on how to report.

Now there are requirements from the EU:

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Streamlining diverse approaches

- EU Requirements
  - Corporate Sustainability Reporting Directive
  - Non-Financial Reporting Directive

- How?
  - European Sustainability Reporting Standards
  - Technical Screening Criteria

Non-financial reporting requirements

- EU-directive
  - >500 employees (from 2025 >250 employees; from 2026 all quoted companies)
  - Business model and strategy
  - Sustainability policies
  - Performance:
    - environmental matters
    - social matters and treatment of employees
    - respect for human rights
    - anti-corruption and bribery
    - diversity on company boards (in terms of age, gender, educational and professional background)
    - ......

  - EU reporting standards ESRS developed by European Financial Reporting Advisory Group (EFRAG)

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

European taxonomy for sustainable investment: is a way to rank different investments opportunities according to if the investment is sustainable or not

Taxonomy Regulation

- environmental objectives:
  - 1. climate change mitigation;
  - 2. climate change adaptation;
  - 3. the sustainable use and protection of water and marine resources;
  - 4. the transition to a circular economy;
  - 5. pollution prevention and control;
  - 6. the protection and restoration of biodiversity and ecosystem
- Social objectives (to come):
  - 1. employees;
  - 2. customers;
  - 3. sustainable and inclusive communities

Take home messages

- Engaging in sustainability can have positive effect on companies
- An increasing focus on sustainability from society incl. Authorities
- Requirements for non-financial reporting

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Life Cycle Sustainability Approach, Framework, updated "MECO"

Conceptual framework.

The challenge of sustainability was already stated in 1971. At that time the challenge was that there was a common conception that population growth has no relation to environmental impacts. They also found that indirect effects on the environment that are caused by our consumption were an even larger threat to the environment than if it was caused by direct pollution from production facilities.

This was at the same time when a group in MIT founded the Club of Rome, that modelled the implications of continued worldwide growth. They showed that most scenarios of growth would lead to a total collapse of the systems. But also imposing some limits on production of material goods could enable a state of equilibrium.

IPAT equation:

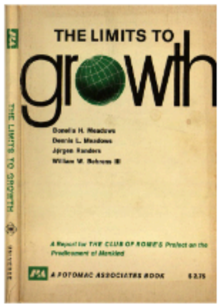
The sustainability challenge

$$I = P \cdot A \cdot T = Pop \cdot \frac{GDP}{person} \cdot \frac{I}{GDP}$$

Ehrlich P, Holdren J (1971) Impact of population growth. Science 171, pp. 1212–1217.

Commoner B (1972) The environmental cost of economic growth. In Ridker RG (ed.) Population, Resources and the Environment, pp. 339- 63. U.S. Government Printing Office, Washington, DC.

Graedel and Allenby (1995) Industrial ecology. Prentice Hall, New Jersey.



- I is the environmental impact
- *Pop* is the **global population**
- $\frac{GDP}{person}$ is the **Affluence**, the material standard of living
- $\frac{I}{GDP}$ is the **Technology factor** – environmental impact per created value

Simple model for estimating Global Warming Potential

DTU Wind Energy

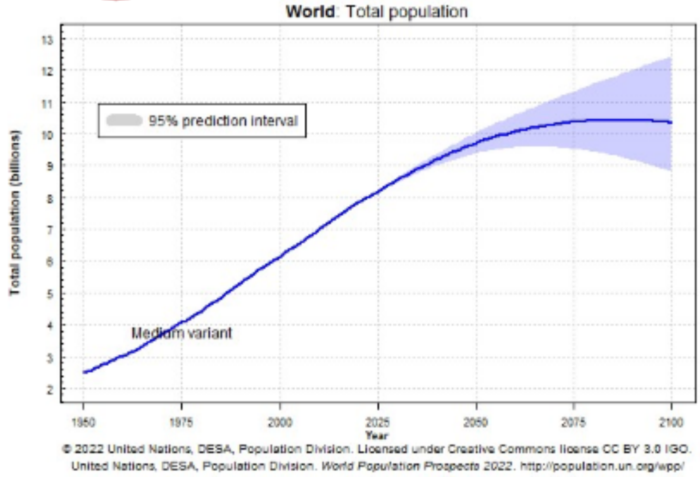
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

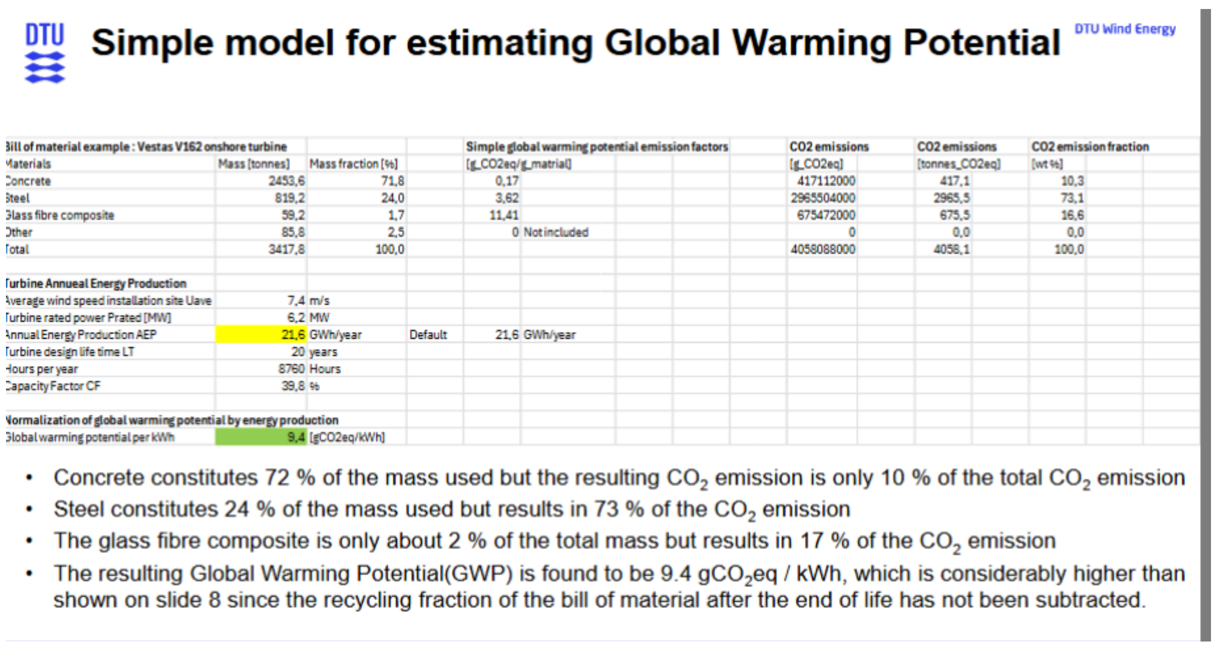
This equation should not be seen as mathematically correct, but it is to represent that the total environmental impact is a function of how many people we are, how much each person consumes and how good we are producing stuff without creating environmental impact.

During the last 50 years, the global population has almot doubled and the UN predics a further increase of the population until 2075 (10.5 billion people)

$$I = Pop \cdot \frac{GDP}{person} \cdot \frac{I}{GDP}$$



o this part of the IPAT equation will increase.



Simple model for estimating Global Warming Potential

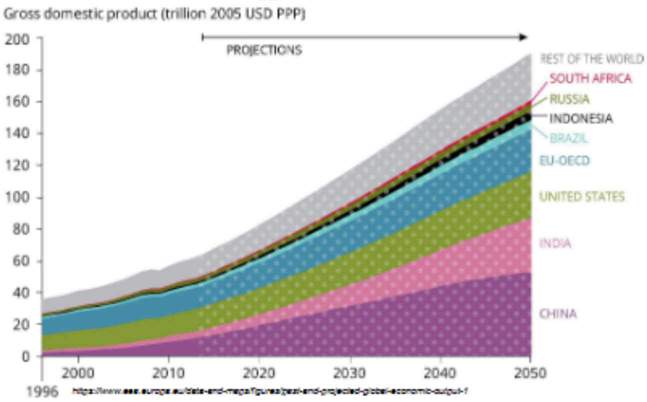
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

The affluence is increasing

$$I = Pop \cdot \frac{GDP}{person} \cdot \frac{I}{GDP}$$



The affluence: economic growth is widely regarded as a key goal in national and international policies. Our entire economic system depends on growth and collapses when growth ceases. The development and global economy is illustrated in these projections from the European Environmental Agency and from this its clear that especially the BRIC countries (Brasil, Russia, but specially china and India) are looking into high economic geoth rates.
Overall you can see that all countries and regions are expected to have a seignifcant economic growth. Which means that this part of the equation will centrainly increase as well.

Simple model for estimating Global Warming Potential

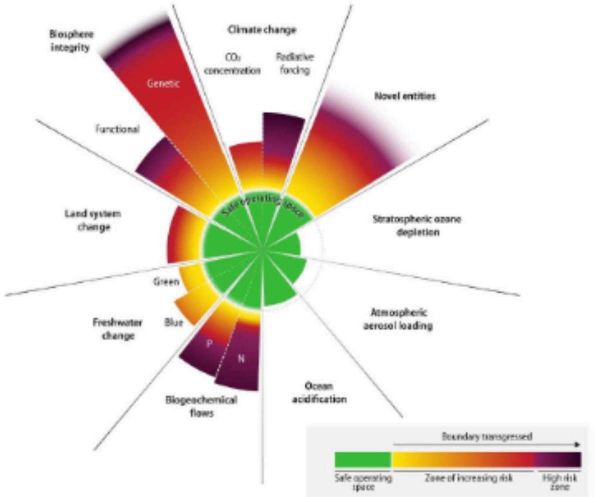
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

The environmental impacts should be reduced

$$I = Pop \cdot \frac{GDP}{person} \cdot \frac{I}{GDP}$$



Richardson et al., Sci. Adv. ***9****, eadh2458 (2023)*

If for a moment we disregard the technology factor and focus on the total impact of the I. Planetary boundaries have been stable for the last 10k years (Holocene period), but since the industrial revolution, human actions have become the main driver of environmental change and we are entering a new wea called Anthropocene.Where human activities push the Earth's system outside the until now stable environment.
They aim to identify a threshold for a number of different biophysical processes and define a safe operating space for humanity, where these thresholds are not surpassed and therefore non unacceptable environmental changes will occur. They identified 9 biophysical boundaries and assessed the current state of the environment for climate change, soil, atmospheric loading, ocean acidification, biogeochemical flows, etc.
Six of the 9 boundaries have been transfressed to at least a zone of increased risk. So overall there is a need to reduce the I in the function.
So.. How much should this technology factor be reduced to compensate for the increase in population and affluence?

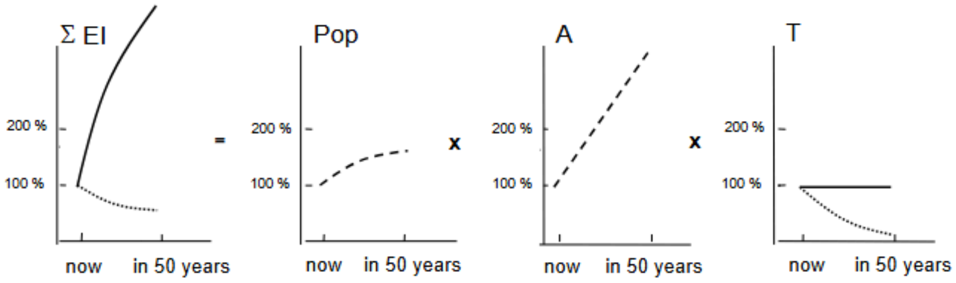
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

How much should the technology factor be reduced?



P · A = the total human demand/consumption will grow by at least a factor of 4-5 in 50 years

Σ EI = the total human impact on the environment will grow accordingly, if the technology factor remains unchanged

T ($\frac{I}{GDP}$) should be reduced by a factor 4 to 20 to achieve environmental sustainability

The technology factor should be reduced significantly in order to counterbalance this expected growth in population and affluence or in material consumption. So the size of the reduction is a discussion but in general by a factor by 4 and 20.

Need to address the consumption/demand
- Rebound effect
- Increasing human demands

We certainly see technology improvements in this size and unfortunately the consumption P*A is not always independent of this T factor. As technology improves, it gets more efficient. It often also gets cheaper, meaning that we have more money to spend either on more of the same or something else.
Example: light: we use more
An effect of this increas in affluence, we also see that the overall human demand increase, which drives the consumption even further. This indicates that addressing the technology factor alone, will NOT be sufficient to achieve environmental sustainability

Simple model for estimating Global Warming Potential

DTU Wind Energy

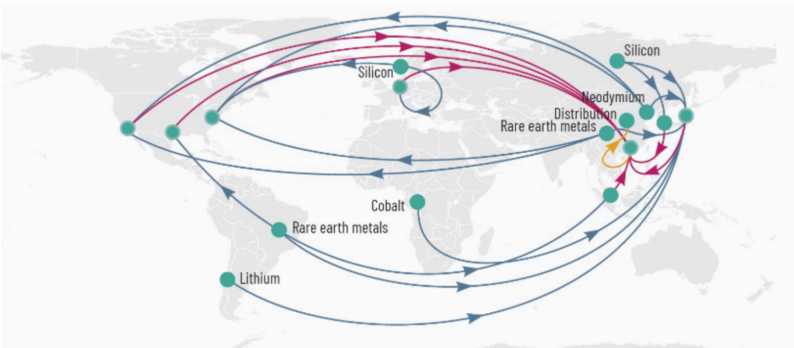
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Take aways
• The global environmental impact is driven by human consumption and demands
• We can achieve some reduction of the impact by technology development, which should be a factor 4-20 more efficient
• But we also need to address the human consumption by it self

<u>The assessment framework.</u>

Value chain is the life cycle - from cradle to grave



The value chain of a product can include, for example, the extraction of raw materials, manufacturing of components and assembly of components. And add to this, the use and the end of life products. Just like the value chain, the lifecycle of a product is complex and global, covering many countries and regions. And additionally, the product can also extend on time. So when we assess the environmental impact of a product, it's not enough to look at the product itself.

Simple model for estimating Global Warming Potential

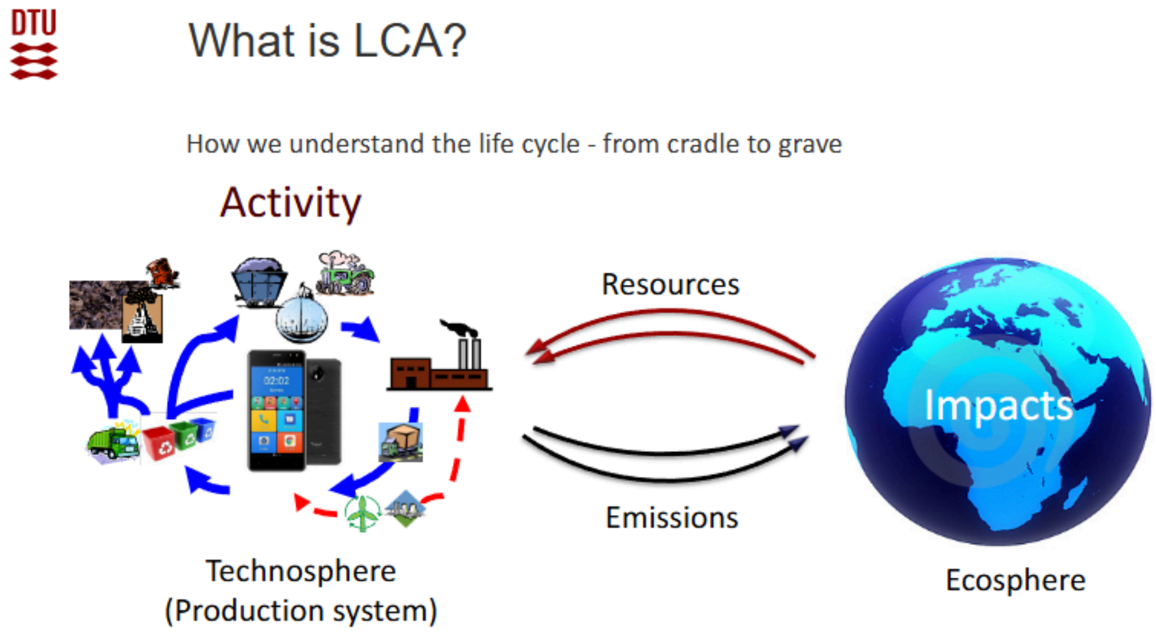
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Example: smartphone: if its lying on the table, it has no environmental impacts. The impacts of a smartphone arise in the production and assembly of the components: from the transportation, extraction and production of raw materials, from production of power to use the phone and produce the components. And when the product is disposed, some components may be reused or some materials can be recycle and enter into new products. this is what we understand as a lifecycle of a product.

LCA: Life cycle assessment



The product lifecycle is the assembly of activities that occur throughout the entire lifecycle, which happens in the technosphere. The environmental impact that we want to asess occure in the ecosphere, and they are caused by the emissions arising from the activities that our product as well from the extraction of resources to be use in these activities.

Simple model for estimating Global Warming Potential

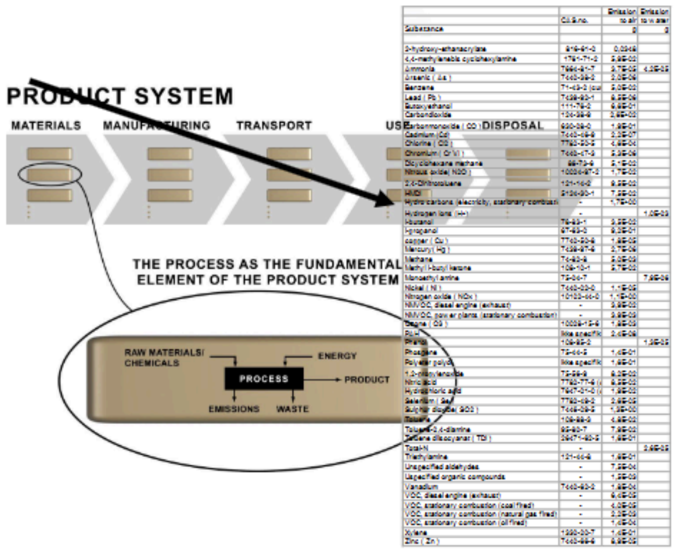
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Life cycle is often illustrated as a cycle and as a circular system: but life cycle assessment is NOT dedicated to circular systems. It does not distinguish between circular and linear, but is to a large extent actually use for assessing linear system.

The common principle is that inputs and outputs from all activities are processes occurring throughout the lifecycle and they are invontirez into a list of elemental flows that can be translated into environmental impacts as done in the lifecycle impact assessment.



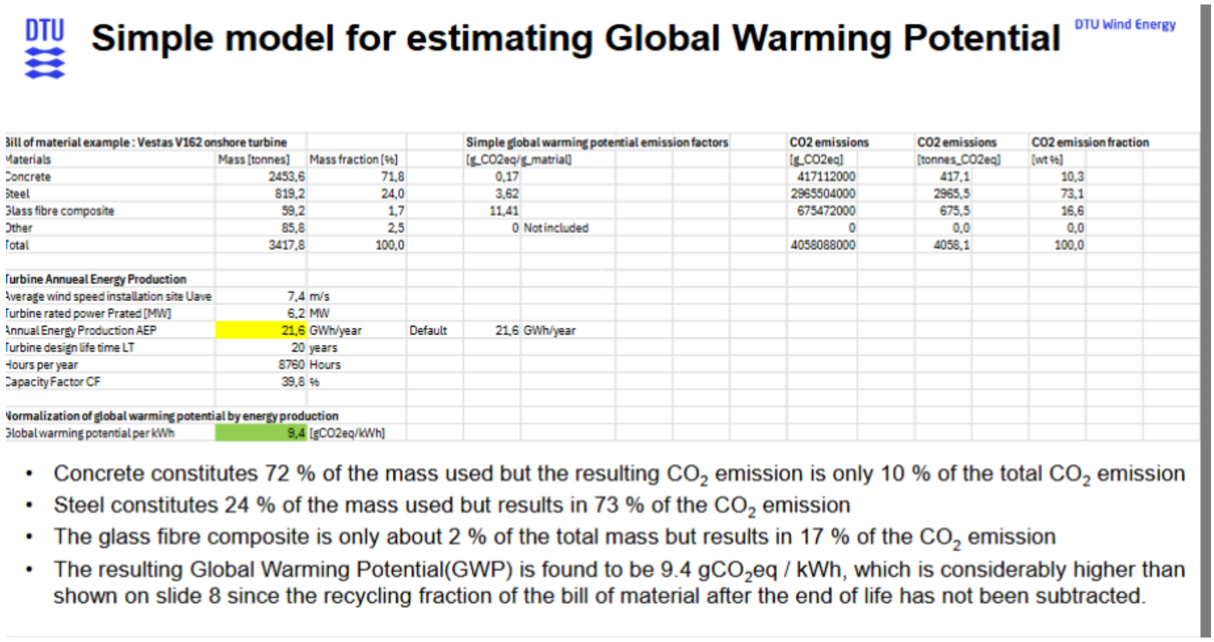
What is LCA?

The process of doing a lifecycle assessment is standarized in the International standarization organization and contains the following phrases:

• Definition of goal of assessment - “what is the question?”

• Scoping of system

• Collection of data on emissions and resource use



Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

• Translation of emissions into environmental impacts

• Interpretation of results - answer to the question

In principle, the system to be assessed is almost endless and entails most of the technosphere. Therefore, there is also a need to draw system boundaries, meaning that we need to scope the system that we want to assessed. Scoping here involves for example, taking decisions as to which methods to apply and which environmental impacts to include. The next phase is then to collect data on inputs and outputs for the defined system and then translate this inputs and outputs into environmental impacts. Finaly: results should be interepretad with the aim of answering the question that was defined .

A fundamental feature of LCA is that the assessment focus on the service provided to the society. And this is operationalized as a functional unit.

So for example if we want to assess 2 different ways of packaging milk, a glass bottle and a pack. We wont just compare the packages, but we will compare the functions they provide (in this case the packaging) and we also need to quantify the service. So the glass bottle can be reuse 30 times, but that reuse require washing and transport of the bottles. We would need 30 packs to obtain the same function.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

A fundamental feature of LCA is the focus on service

Defining the object of assessment

Another essential feature is that LCA is for comparing different ways of delivering the defined service of function. So LCA is a RELATIVE statement. For example: the transformation of one person, one km has a much higher impact by using a big car compared to a smaller car. To what extent the alternatives here are actually sustainable? Is generally not evaluated.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

LCA is for comparisons

Is better than

But is it OK for the environment?

(Absolute perspective)

LCA has a holistic perspective. LCA covers the entire lifecycle of the product or system. The methods to assess the environmental impacts of the system considers all relevant impacts.In sone cases even work environment is considered in the scope, and we are surely including the consumption of resources both mineral, fossil and biomass. Due to these features, LCA can help to avoid all to identify problems shifting between lifecycle stages. For example if you replace a plastic cup with a steel cup: you would be shifting the impacts from the disposal stage of plastics to the raw materials and manufacturing industry of steel.

Simple model for estimating Global Warming Potential

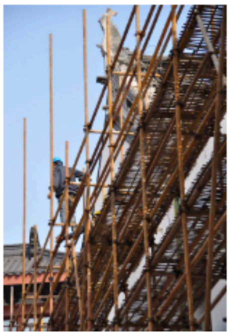
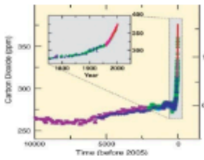
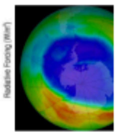
DTU Wind Energy

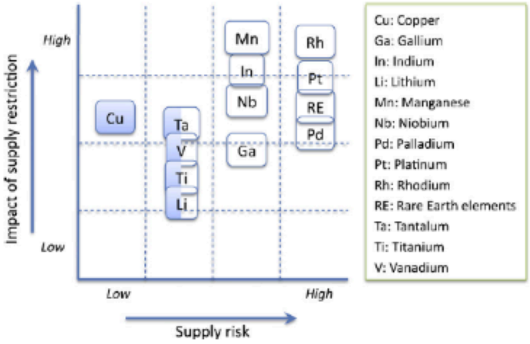
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

LCA helps avoiding problem shifting

- life cycle from cradle to grave
- All relevant environmental imapcts
- working environment
- resource consumption (biotic and abiotic)

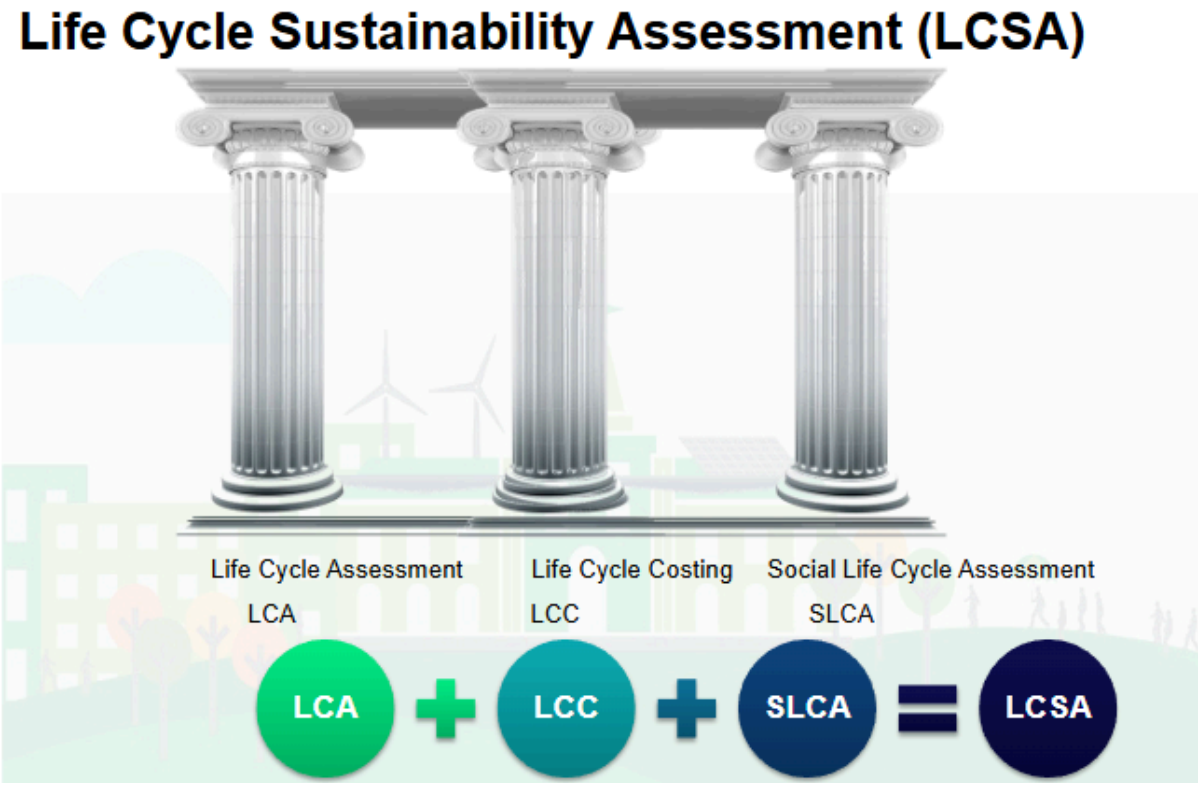
So far we have focused on the environmental sustainability only, but remember that sustainability refers to 3 dimensions

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



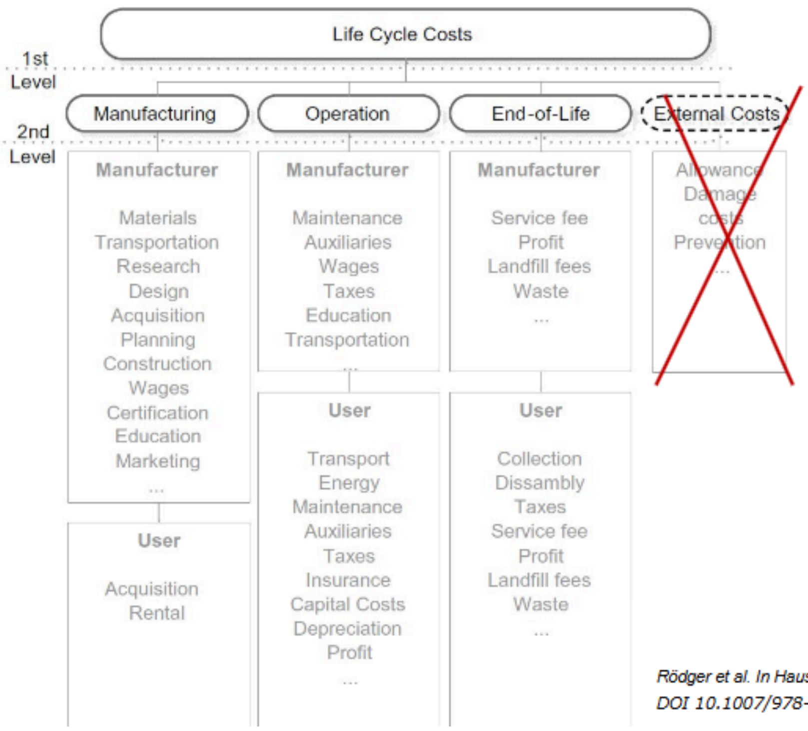
The economic aspects: all costs in the life cycle. Examples:

Simple model for estimating Global Warming Potential

DTU Wind Energy

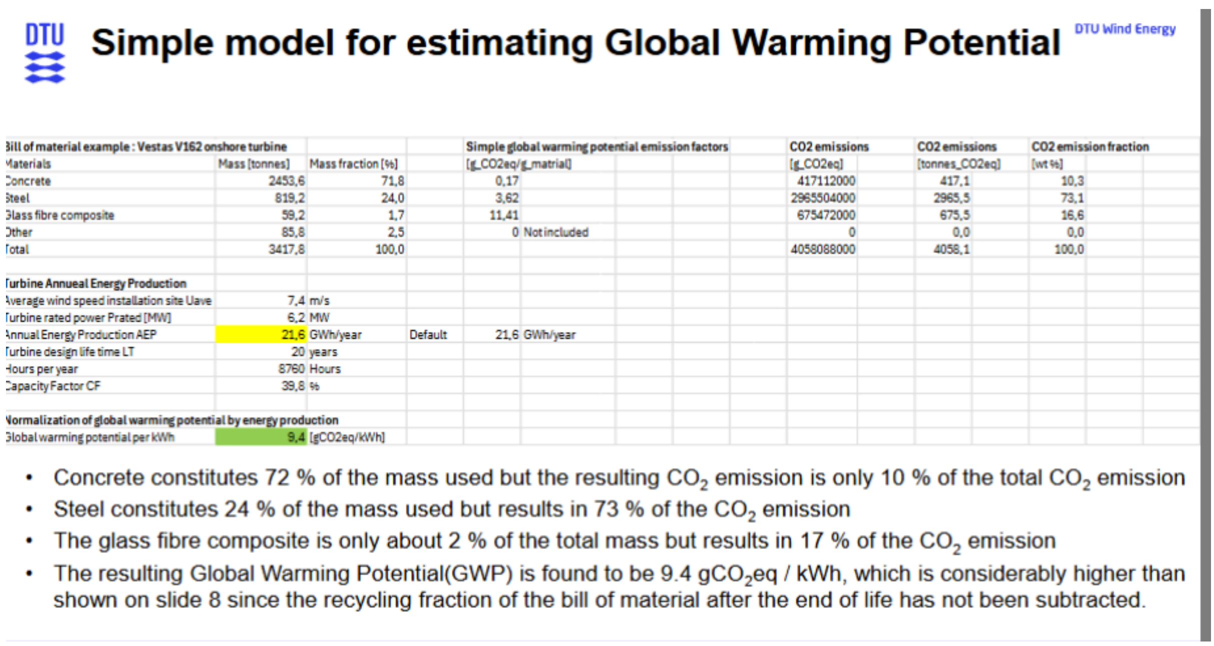
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



Rödger et al. In Hauschild et al (Eds) Life cycle Assessment, 2018
DOI 10.1007/978-3-319-56475-3_15

In this case external costs are not included since they are already covered by the environmental impacts in the lifecycle assessment.



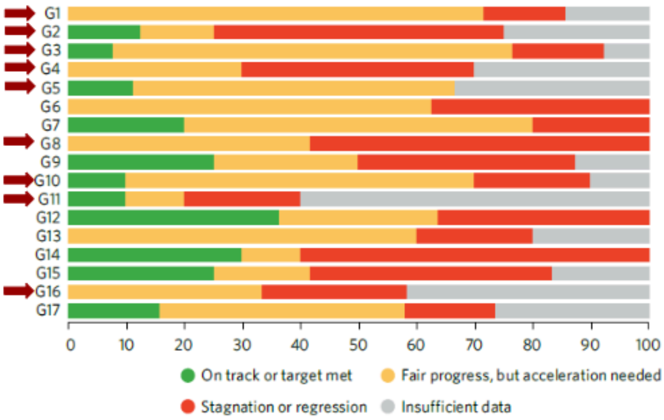
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

The social side



https://unstats.un.org/sdgs/report/2023/progress-midpoint/

The social aspects cover different areas. Issues like poverty, zero hunger, gender equality, etc. Only a few aspects are in good progress. This is further evidence of the need to address the social aspects in our assessment

<u>Guideline for social assessment:</u>

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Stakeholder categories	Worker	Local community	Value chain actors (not including consumers)	Consumer	Society	Children
Subcategories	1. Freedom of association and collective barganing 2. Child labor 3. Fair salary 4. Working hours 5. Forced labor 6. Equal opportunities/discrimination 7. Health and safety 8. Social benefits/social security 9. Employment relationship 10. Sexual harassment 11. Smallholders including farmers	1. Access to material resources 2. Access to immaterial resources 3. Delocalization and migration 4. Cultural heritage 5. Safe and healthy living conditions 6. Respect of indigenous rights 7. Community engagement 8. Local employment 9. Secure living conditions	1. Fair competition 2. Promoting social responsibility 3. Supplier relationships 4. Respect of intellectual property rights 5. Wealth distribution	1. Health and safety 2. Feedback mechanism 3. Consumer privacy 4. Transparency 5. End-of-life responsibility	1. Public commitments to sustainability issues 2. Contribution to economic development 3. Prevention and mitigation of armed conflicts 4. Technology development 5. Corruption 6. Ethical treatment of animals 7. Poverty alleviation	1. Education provided in the local community 2. Health issues for children as consumers 3. Children concerns regarding marketing practices

UNEP, 2020. Guidelines for Social Life Cycle Assessment of Products and Organizations 2020. Benoît Norris, C., Traverso, M., Neugebauer, S., Ekener, E., Schaubroeck, T., Russo Garrido, S., Berger, M., Valdivia, S., Lehmann, A., Finkbeiner, M., Arcese, G. (eds.). United Nations Environment Programme (UNEP).

<u>Approach assessment in a more simplified manner:</u>

Aim to prioritize the indicators for each sustainability pillar in terms of the goal and data availability. They suggest to look at contribution to climate change production cost and fair wages as the most relevant indicators for this initial assessment. The next steps in the chain approach increase the number of indficators within each sustainability pillar. T

DTU

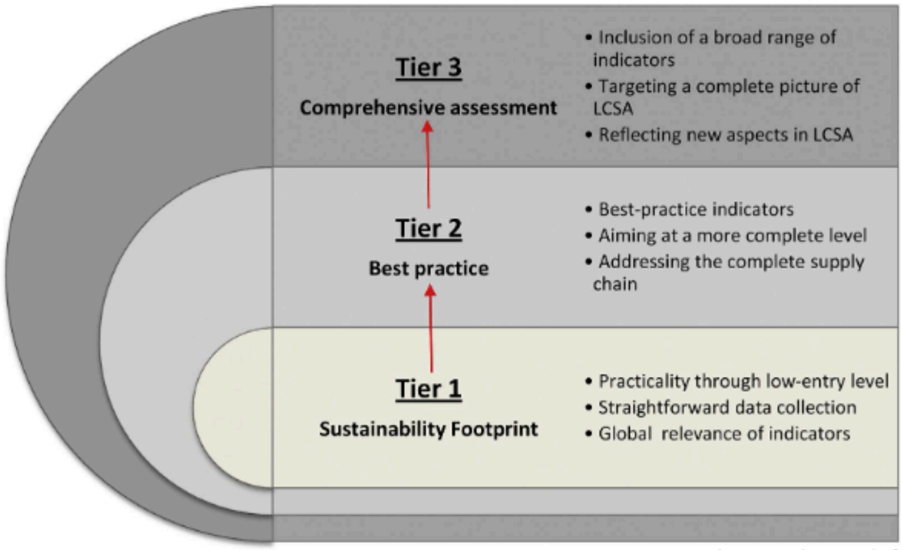
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Stepwise Life Cycle Sustainability Assessment



Neugebauer et al, Journal of Cleaner Production 102 (2015)
http://dx.doi.org/10.1016/j.jclepro.2015.04.053

At DTU they have developed the MECO approach. Which is also a simplified assessment of the impacts or rather the causes of the impacts of a product or system during the life cycle. The meco represents the use of materials, energy, chemical and others in the different life cycle stages. And each of these are drivers of environmental impacts. So materials drive the

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

depletion of natural resources, the energy represents the climate change, etc.

The MECO framework

	Life Cycle Stage				
Causes of Environmental Impact	Extraction of raw materials	Manufacturing stage	Use stage	Disposal stage	Driver for:
Materials					Depletion of natural resources
Energy					Climate change, acidification, photochemical ozone formation etc.
Chemicals					Human and ecological toxicity Ozone depletion
Others					E.g. land use, water use, social impacts etc.

In this course we will be using this:

Quantitative Sustainability framework

	Life Cycle Stage				
Sustainability Impact area	Extraction of raw materials	Manufacturing stage	Use stage	Disposal stage	Measured by:
Resources					Use of biotic and abiotic resources Circular economy indicators
Environment					Climate change, Carbon footprint Absolute boundaries
Economic					Costs
Social/Health					Socioeconomic impacts, health impacts
Transition					Qualitative or semiquatitative assessment

<u>Summary:</u>

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

• LCA is a comparative method that assess the environmental impacts of a product or system throughout its life cycle

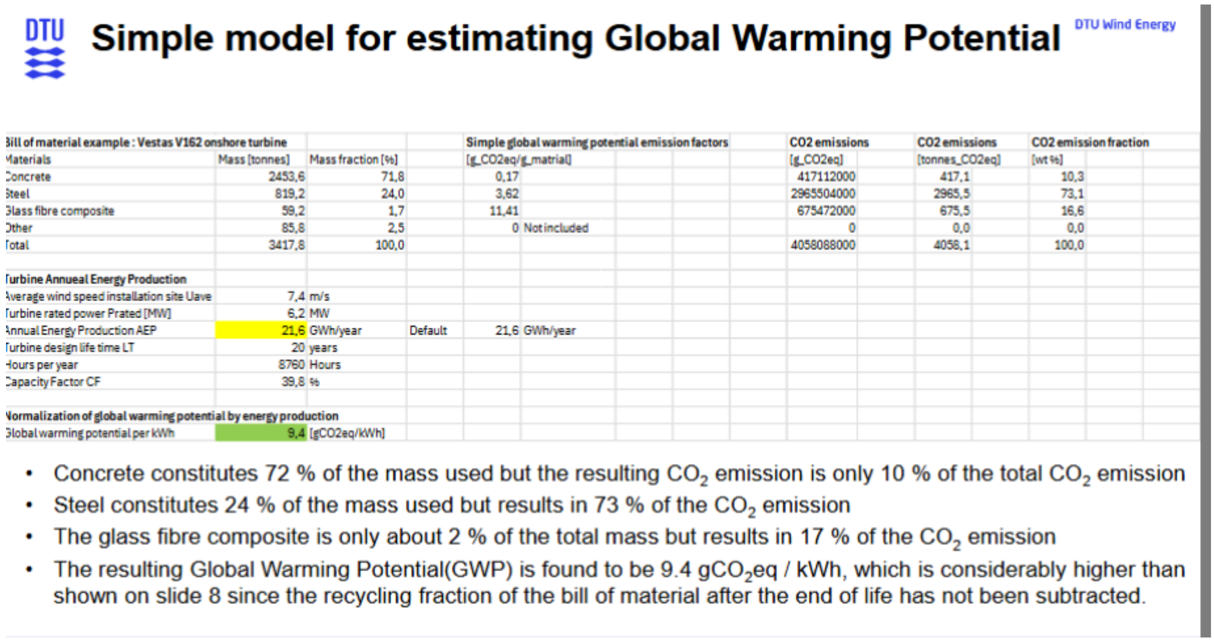
• It is important to precisely define the object of assessment

• Life Cycle Sustainability Assessment aims to additionally include the economic and the social impacts

• In this course we do not apply LCSA, but aim to cover all aspects in a life cycle perspective through a simplified approach

Defining the object of assessment

Defining the object of assessment is critical to compare different alternatives. We need to be able to describe why the product or system is relevant to society to define the central properties of the system. On this basis, you can define the object of assessment, which in this LCA terminology is called the functional unit.
Creating an overview of the product provides a good background for further definition of functional unit, specially when assessing products. We should try to answer the following questions:
What should the product be used for: this leads to a description of the basic tasks the product must carry out for the users. What does the product do? Describe what the product does, including also the technological principle and the features that the product must posses in order to deliver the service to the user. How long and how often: its about defining the time frames and the use patterns in which the product operates. Where in the world: the certification of the geographical area in which the product must operate and where it will probably be disposed off.
All of these responses lead to a very clear description of the product in the form of what is the value contribution that this product delivers to the user.



Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

As an additional preparation that can lead directly to the definition of the functional unit, is a good idea to identify the central properties of the product or system.

List the obligatory and positioning properties of the product or system you are assessing

- Obligatory properties:
  - Decisive for the customers perceiving the products as a product
  - Potential legal requirements
  - Helps define the product

- Positioning properties
  - Makes the product attractive to the customer and position the product in relation to comparable products

- **Obligatory properties**: are those that make the product or system perceived as fulfilling required functions by the consumers. Example: window: it should allow daylight entering the building through a physical barrier.
- **Positioning properties**: are often more qualitative and are those that make the consumer choose one product above another: color choices ,noise insulation,.etc

After doing all that, it is possible to start defining in detail the object of assessment as the functional unit through the use of context and central properties.

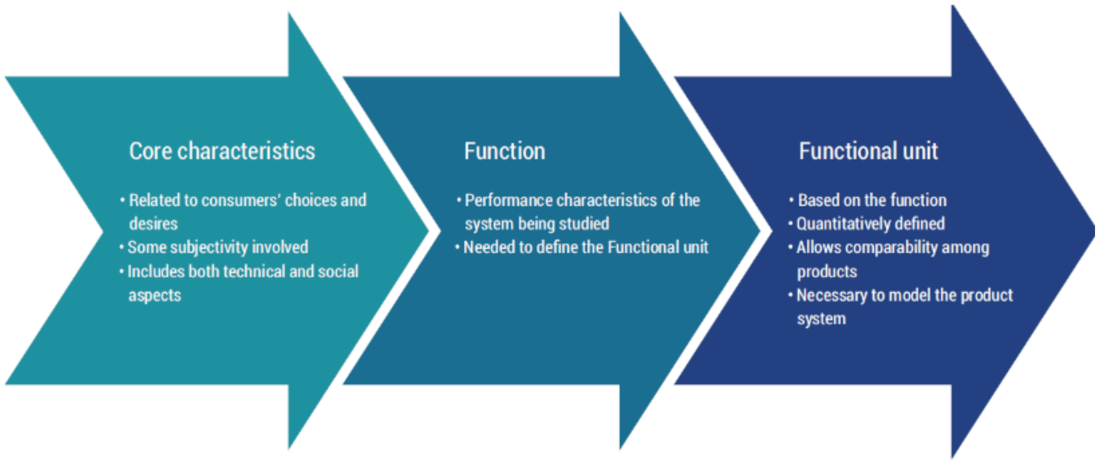
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Defining the object of assessment is key to comparative studies



The next step then is to define the functional unit. Which should be quantitatively defined. The functional unit is the object of assessment and as such it must be quantified. But also involves some more qualitative aspects that may be important, specially for comparative studies. For example, if comparing different food items, both should taste good. The service provided by the system is determined in terms of quantity.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Defining the functional unit

Defining the functional unit – quantification of service/function/ use context - is essential

- The functional unit is the object for the analysis:
- Expresses the service the product/system deliver in quantitative and qualitative terms
  - Quantity (weight, volume, area, use frequency………)
  - Duration of the service
- Central qualitities or properties
- Essential in order to ensure equivalence between the compared services/systems

Example of definition of functional unit

$\underbrace{\text{Complete coverage}}_{\textbf{What?}}$ $\underbrace{\text{of 1 m}^2}_{\textbf{How much?}}$ $\underbrace{\text{primed outdoor wall}}_{\textbf{What?}}$ $\underbrace{\text{for 10 years}}_{\textbf{For how long/ how many times?}}$ $\underbrace{\text{in Germany}}_{\textbf{Where?}}$

$\underbrace{\text{in a uniform color at 99.9 \% opacity}}_{\textbf{How well?}}$

Examples of functional units

- Water boiler:
  - Heat 1 liter of water to the boiling point three times a day for a year in Denmark
    What How much How well How many times How long Where

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

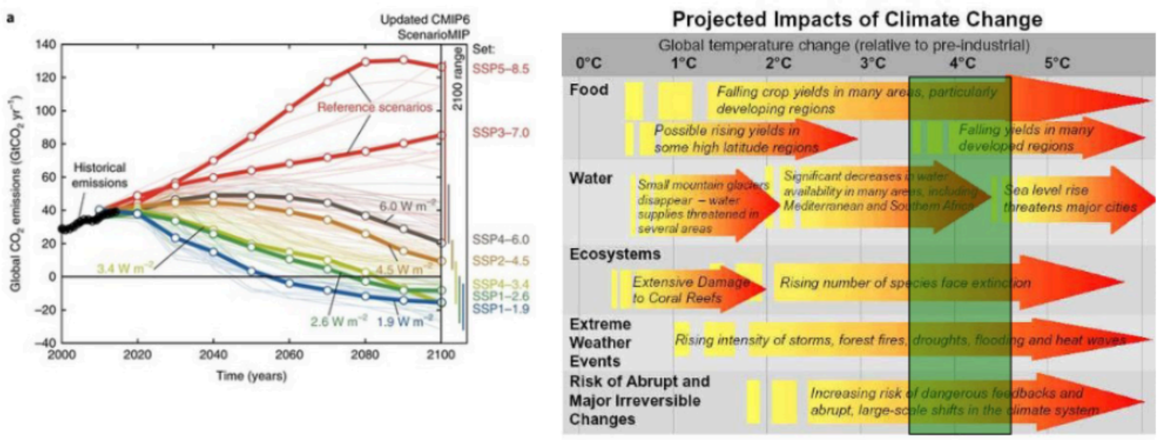
Part II – Assessment tools

Carbon footprint and environmental indicators

How do we quantify sustainability? We have many indicators but at different levels. How to consistently quantify sustainability?

Global warming: our world has increased temperature very rapidly. This is due to human effect. If it was because of solar or volcanic activity, it would be more stable.
This makes the ice melt, increase the sea level up to 1m or 7m.

The emissions projections and related impacts



Likely range of 'business as usual' by 2100

If we continue business as usual, we will probably have up to 8.5 degrees of temperature. As temperature is increasing, the type of effect we have in impacts is increasing and we see that we will have real problems

Simple model for estimating Global Warming Potential

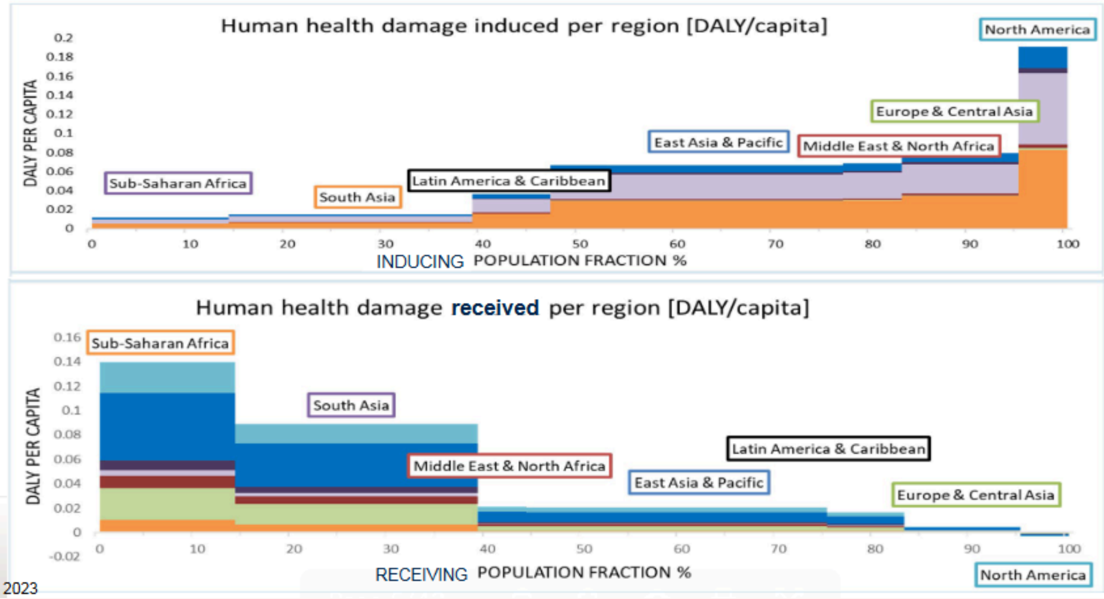
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

If we take some actions, we can maintain temperature

Disparities: Climate change impacts of heat and cold on health



Rupcic, 2023

Why is it important to consider this? Example comparing heat and cold. We see countries that are inducing the footprint: north america and europe. But as you sea, the human health damage received is africa and south asia. So those who controbute more to climate change are affecting those who dont contribute.

Simple model for estimating Global Warming Potential

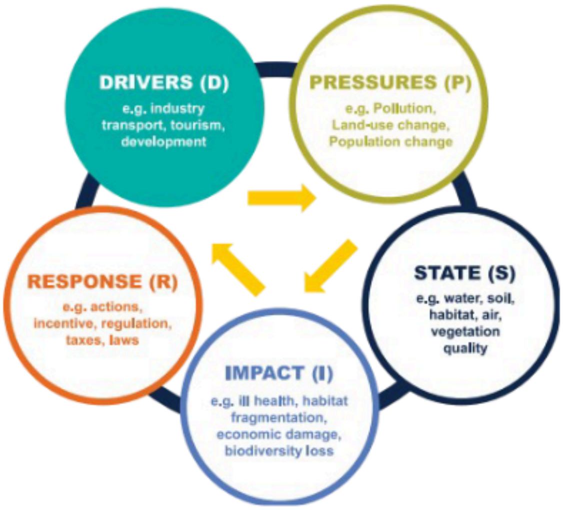
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

How would we characterize climcate change? Which indicators could we use to quantify this impact

The DPSIR model: to categorize and causally link indicators



This indicators can be at different stage of the cause effect chain: linking human activity to impact.

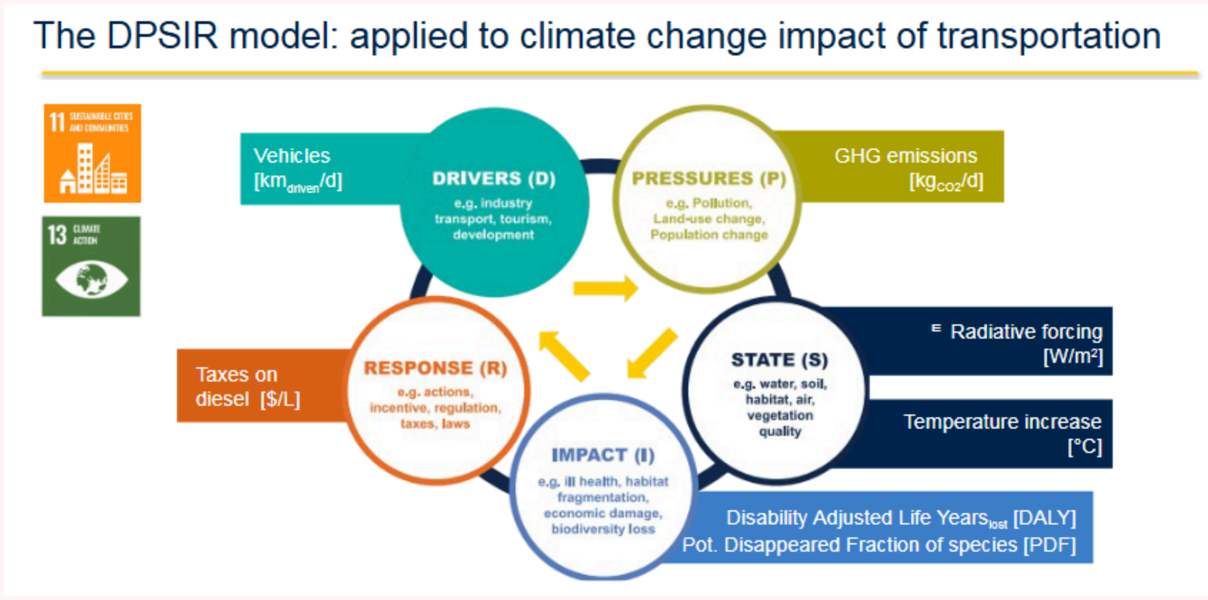
DPSIR drivers: if we look at them, the drivers are for example km driven by car. This cars are generating GHG emissions and these are emission flows that are the pressure on the environment. This make an increase in the radioactive forces: creating green house effect and reduce lossof radiation so our temperature is increasing. Once the temperature increases, we will have impact and finally once we have that we could have responses and indicators indicating responses: response that will modify the driver and potentially reduce this different impact

DTU Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



So when we want to measure the carbon footprint, it has been developed to compare this different emissions. If we want to compare, we need to understand sources and impact. GWP: global warming potential over 100 years and give equivalence with different gases.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Carbon Footprint: at personal and product levels

A **carbon footprint** is the weighted sum of greenhouse gas (GHG) emissions caused by an individual, event, organization, service, or product, expressed as carbon dioxide equivalent. GHG emissions are weighted based on their global warming potentials (GWP100, as defined by the Intergovernmental Panel on Climate Change, AR6, Tables 7.15 and 7.SM.7)

Greenhouse Gas	GWP100	
Carbon Dioxide (CO_2)	1	kg_{CO2e}/kg_{CO2}
Methane biogenic (CH_4)	27	kg_{CO2e}/kg_{CH4}
Methane fossil (CH_4)	29.8	kg_{CO2e}/kg_{CH4}
Nitrous Oxide (N_2O)	273	kg_{CO2e}/kg_{N2O}
Hydrofluorocarbons (HFC-32)	771	kg_{CO2e}/kg_{HFC}
Perfluorocarbons (PFC-14)	7380	kg_{CO2e}/kg_{PFC}
Sulphur Hexafluoride (SF_6)	24300	kg_{CO2e}/kg_{SF6}

If we take the average carbon footprint per capita in denmark: we introduce the GWP and we multiply to get the GW score. once they are in the same unity, we can just sum them.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

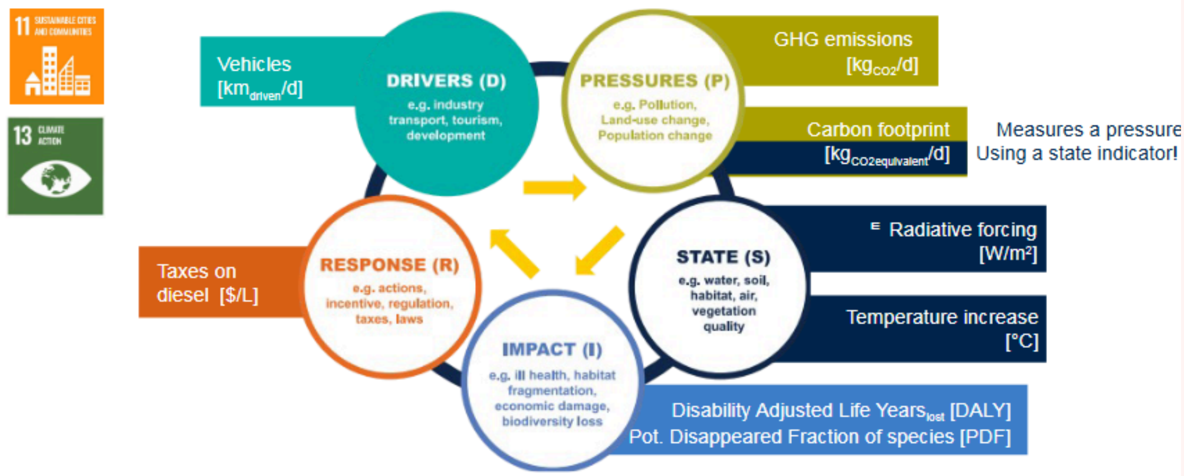
Average US carbon footprint per capita

Substance		Unit kg_i	Emissions kg_i/pers/y	GWP100 kg_{CO2e}/kg_i	GW score kg_{CO2e}/pers/d
Carbon dioxide	fossil	kg CO_2	8000*	1	8000
Methane	biogenic	kg CH_4	46.1	27.0	1250
Methane	fossil	kg CH_4	4.7	29.8	140
Nitrous Oxide*		kg N_2O	3.2	273	870
HFCs, PFCs,SF6					80
TOTAL kg_{CO2e}/pers/y					**10340**
TOTAL kg$_{CO2e}$/pers/d					**28.3**

*consumption based emissions

We can do this for any product or activity. At which level is the carbon footprint in this case? We are measuring between

At which level of the cause effect chain is the carbon footprint?

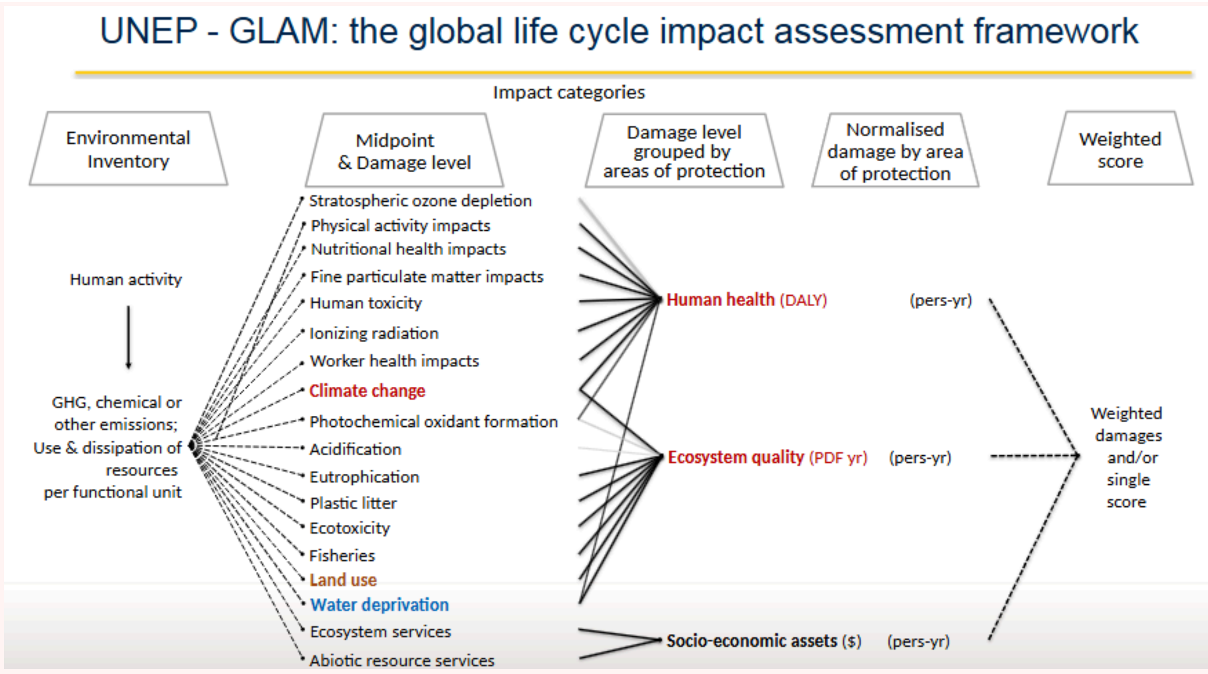


DTU Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



The carbon footprint is just one type of impact. There are different impact categories that we can take into account.

So we want to measure impacts that will help us to characterize the drivers better

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Resource management, scarcity and criticality

Fundamental Concepts

Natural resources

A first way to characterize natural resources is if they can renew themselves or not.
• Can the resource I exploit harness earth systems to make more of itself within a timeframe suitable for my exploitation?
• No: Non-renewable resource
–Minerals, oil, gas
• Yes: Renewable resource
–Soil, plants, animals, water, win

For example: oil is technically a renewable resource, but not at the rate of course which is fast enough from a human timescale perspective. And then we need to think what we are doing with this resource, are we taking it away? Are we consuming it? Sometimes our activities can reduce the pool of resource available by reducing the ability of that resource can rennew it self.

Exploitation types
• Do we extract resources or use products generated by resources
–Consumptive, non-consumptive
• When using products generated by resources, do we impair resource renewing when doing so?
–Consumptive?

DTU

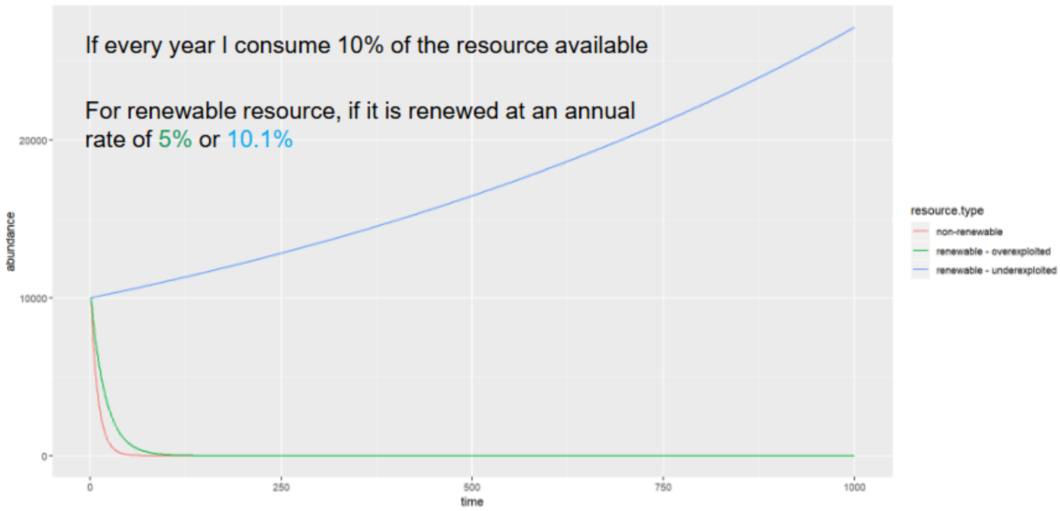
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

What does this mean?



For non-renewable resource, the pattern is very straightforward: we adapt the resource, our demand peaks and either we transition to a new resource or we abandon it because there is no more left. We can extend the timescale of this pattern by recycling, reusing the resource or reducing the consumption but we can not escape the shape of the curve.

Simple model for estimating Global Warming Potential

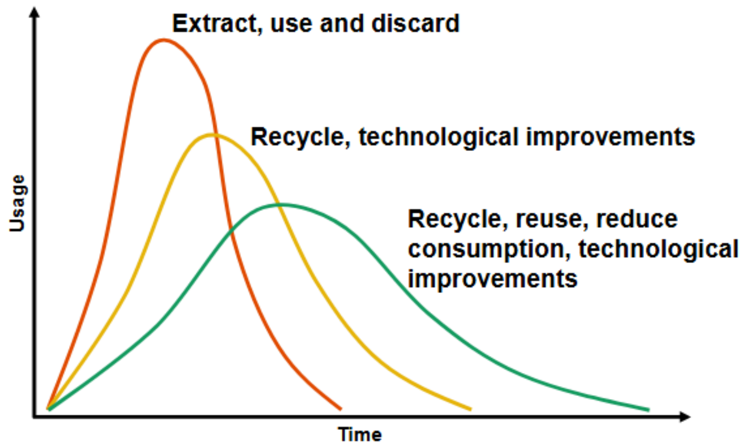
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Non-renewable resource use pattern

Adoption → demand peak → transition/abandonment



Renewable resources are a little bit more complicated: when we adopt a resource and our demand peaks, we can actually sustain that consumption if the rate of consumption does not exceed the rate at which the resource renews itself. We can also transition to a new resource, and in that case the resource can come back to pre exploitation level. Or we can over exploit the resource which will lead to extirpation of a resource

DTU Wind Energy

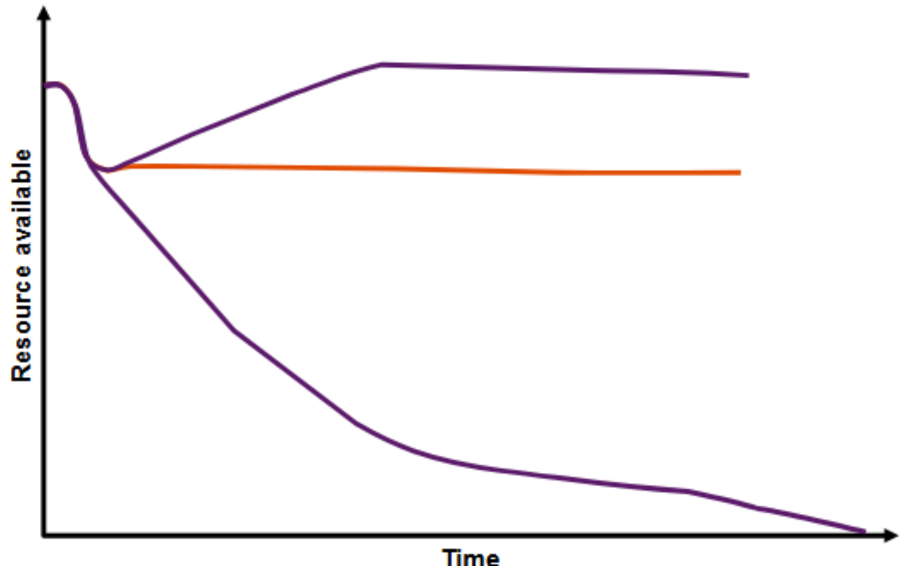
Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Renewable resource use pattern

Adoption → demand peak → transition/abandonment
Adoption → demand peak → sustained



Sustainability of exploitation

So when we think about whether renewable resource exploitation is sustainable, it was fount that the context for sustainability depended on 2 factors

• Ability to manage depends on:
–Whether extractions by one actor will diminish ability to extract that resource by another
–Actors can be excluded from extraction that resource

These 2 factors define 4 categories of resources.

Resource types

DTU **Simple model for estimating Global Warming Potential** DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Resource types

	Excludable	Non-excludable
Rivalrous	Private good	Common good
Non-rivalrous	Club good	Public good

Private good
• Competitors can be prevented to access the resource (private property rights can be assigned)
• use of that good (consumption) prevent others to use it
• e.g. parking space, bread, a field (I can put a fence around it)

Club good
• Property rights can be assigned
• Using that good does not prevent others to use it
• Eg, a cinema (I can buy a ticket) , alliance/club/union (services provided to members excluding non-members), a private nature park

Public good
• Access cannot be restricted
• The use of the resource does not prevent others from using it • E.g., knowledge, streetlights, public parks

Common good
• Short for common-pool resource
• Access cannot be restricted

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

• The use of the resource prevent others from using it
• E.g., fish stocks, but also… public park
–If the use of a natural place degrades it, then some of its use is prevented by the use of other

Conclusions
• Renewable natural resources lead to different exploitation patterns because they need not become exhausted.
• Our means and abilities to govern resource exploitation depends on whether people can be excluded from its exploitation and whether resource use by some diminish resource use opportunities for others

Common good resources seem to be a bit problematic

The Tragedy of the commons - Resource management

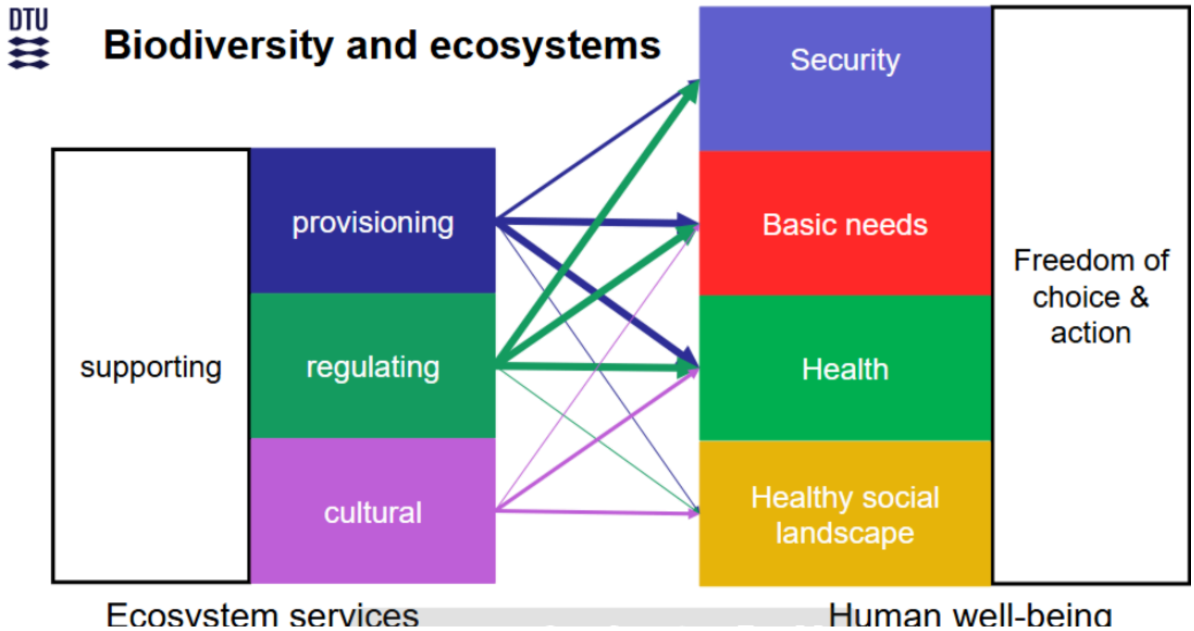
When we think about a resource, like a forest, we can actually use it in many different ways. The resource exploitation need not be just about the extraction of timber or hunting on it. That's important when we consider this because our activities can impose pressures on resources which are not the source of exploitation (climate, air pollution, biodiversity, habitat). Our footprints can go well beyond a boundary of where our activity takes place.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



Classical resource exploitation only accounts for one of the 3 ecosystem services we receive from natural resources. And common goods : biodiversity, clean water, etc, are direct contributors to different crucial aspects of our well-being through regulating services that we can receive from ecosystem services.

Regulating the use of these services is really hard. Degrading common resources affects the ability for others to extract benefits from them. This is what we call the tragedy of the commons.

Tragedy of the Commons

• several countries can exploit a fish stock, if a country has more fishing effort than allotted (e.g., more vessels) the stock can be overexploited

• The benefits of extra vessels are received by the one country increasing its fleet, but the costs are shared among all countries

• Without interventions – recall exclusion interventions are not possible – it will always be beneficial to defect

• Leads to a race to the bottom and resource collapse

Simple model for estimating Global Warming Potential

DTU Wind Energy

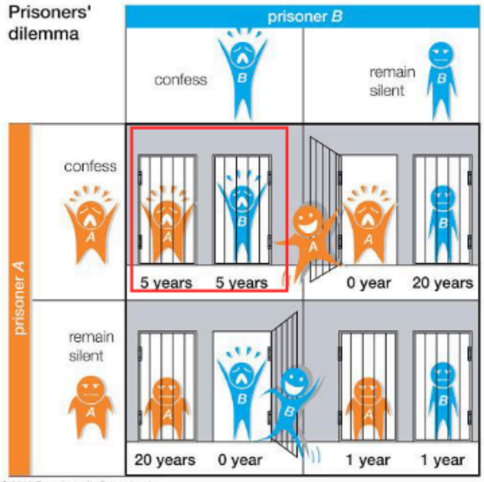
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

ToC game theory: Prisoner's dilemma

Decision consequences

- both confess, both go to jail for five years;
- neither confesses, both go to jail for 1 year (concealed weapons);
- one confesses & the other not, confessor is free (witness) and the silent one is jailed 20 years.



We have 2 thieves and are separated into different interrogation rooms. And they have to decide. The best outcome actually is both 5 years. why? Nash equilibrium:

• Nash equilibrium: no player can improve his payoff by changing his strategy from his equilibrium strategy to another strategy provided his opponent keeps his equilibrium strategy.

"You can't control what others are doing in this situation". Coupled decision making settled in the decision that is not what we would expect the optimal outcome to be.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Conclusions

- Common goods are complex to govern, unfortunately most regulating and cultural ecosystem services are common goods.
- How do we fix it? Assign property rights!
  - –Then common goods become private [/club] goods (e.g., quotas)
    - European "common policies" approach: common to club goods
- Can we actually sustain common goods exploitation?
  - –Ostrom: polycentric governance

ToC - fixes

• Assign property rights!
–Then common goods become private [/club] goods (e.g., quotas)
• European "common policies" approach: common to club goods
–(this is still a failure of common good governance)
• Can we actually sustain common goods exploitation? yes!

summary

• Renewable natural resources lead to different exploitation patterns because they need not become exhausted.
• Our means and abilities to govern resource exploitation depends on whether people can be excluded from its exploitation and whether resource use by some diminish resource use opportunities for others
• Common goods are complex to govern, unfortunately most regulating and cultural ecosystem services are common good

DTU Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Finding sustainable trade-offs

How can we quantify trade offs in resource exploitation in order to find ways to operate this exploitation sustainably.
Lets see at a fishing example, but this apply to any type of renewable resource management.

Population model of the Fish stock

- Let's formulate an equation describing the rate at which a resource renews itself

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t$$

- Where B is biomass, r is the intrinsic growth rate, C is catches and K is the carrying capacity (how much of that species the ecosystem can sustain)

We start by defining a model that will describe the dynamics of a population or stock of resources. We simply calculate the biomass of fish next year (t+1) depending on how much fish was this year + how much was produced this year, depending on the intrinsic growth rate of a population, which is often related to characteristic of species. And then subtract the amount we used.

Growth is, of course, not limitless. The maximum amount of fish the ecosystem can sustain is called the carrying capacity (Parameter K of the formula) . Note that the growth component of the model will go to zero as a biomass approaches K. Lets see how this looks:

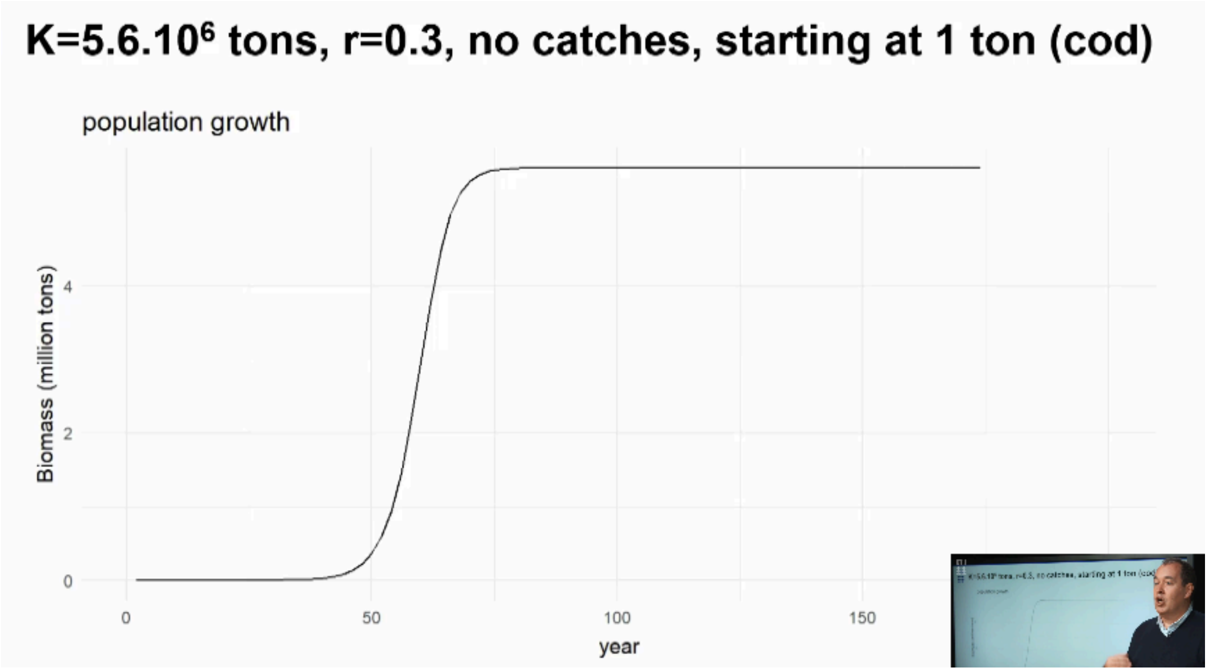
DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



If we start with stock very small, at first the growth starts to accelerate and then slows again as it i approaching the carrying capacity(K)

We can also look at these dynamics by looking at the behaviour of a net productive rate. The rate is maximum when biomass is low and then it drops to zero

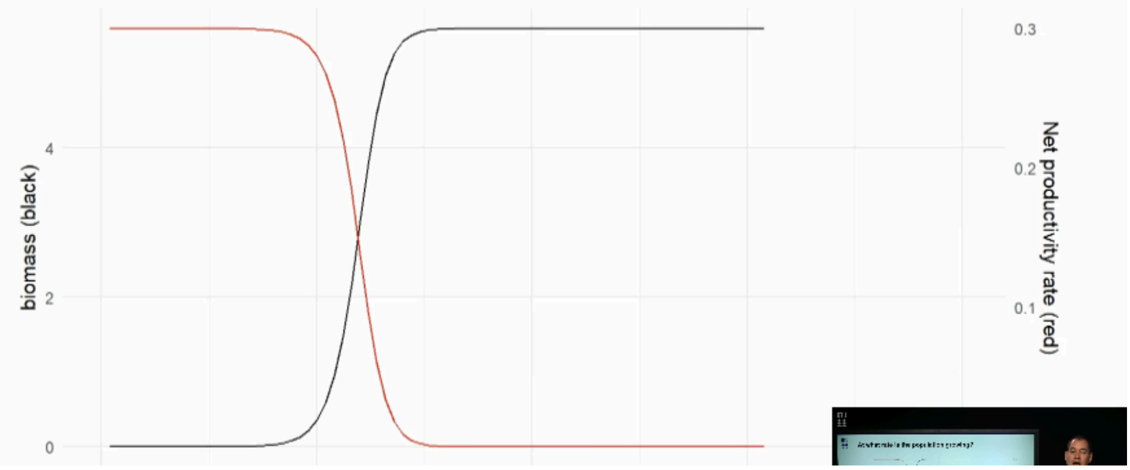
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

At what rate is the population growing?



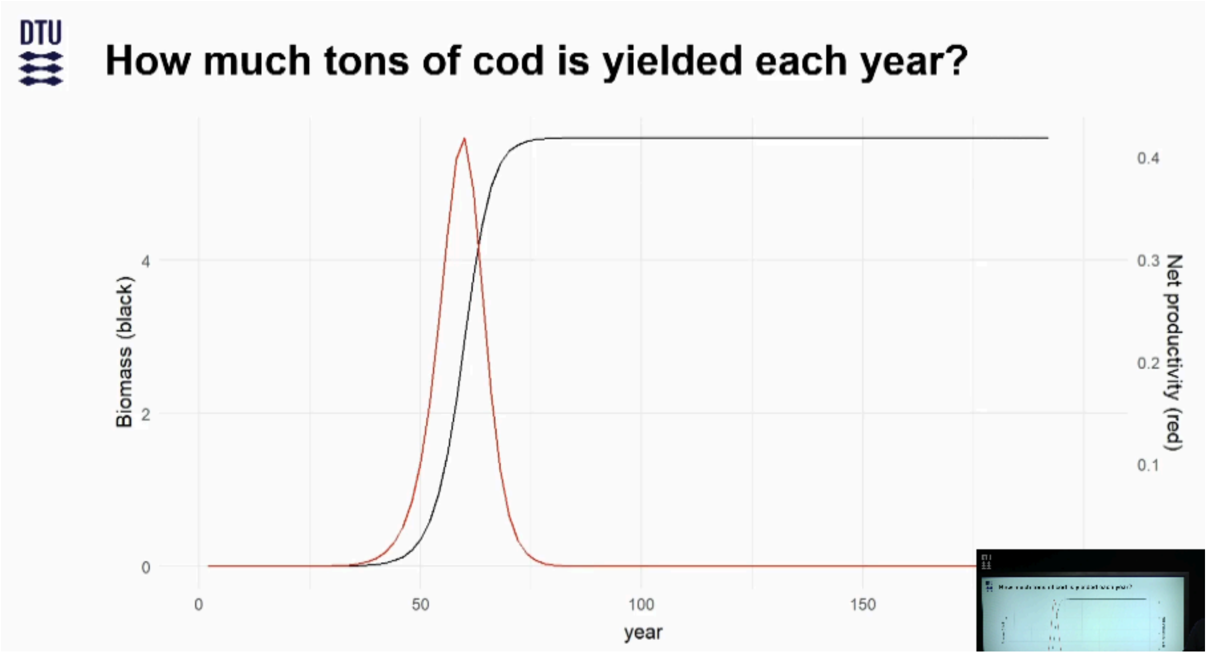
Both are features of the equation, so What if we puss them together?

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



If we multiply this rate by how much cod is there. **We then can see that the net productivity of a stock peaks when the stock biomass is somewhere (almost midway) between zero and K.This is when the yield will be maximized.**
If we have a very good understanding of the biology and ecology of a stock, then we canthis **MSY (maximum sustaibalble yield**) is the product of the intrinsic growth rate by the carryinn capacity divided by 4.
This maximum yield occurs at half of recurring capacity in the case of the model we use.
This values depend on the assumptions of the model!! If we use another model, the inflection point will be somewhere else.
In the real world, we dont know our K and therefore we need a few trick to get them.

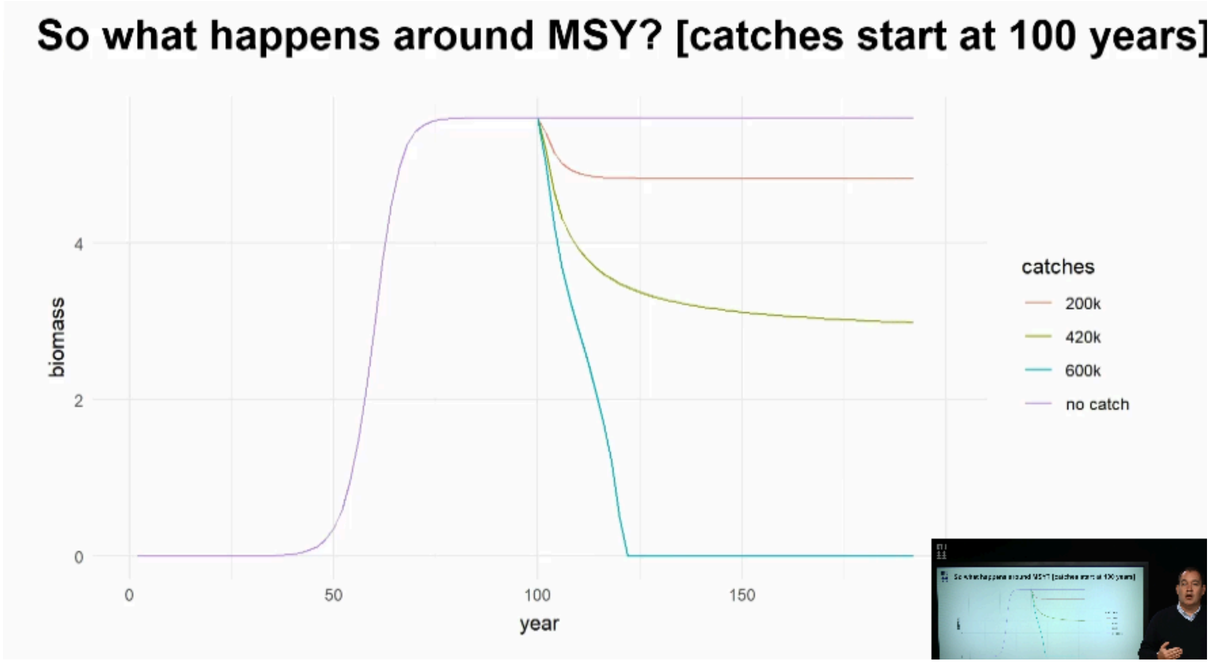
MSY: if we use the equation we have just seen with the example we had. Then, it results on 420 ronns.

Simple model for estimating Global Warming Potential

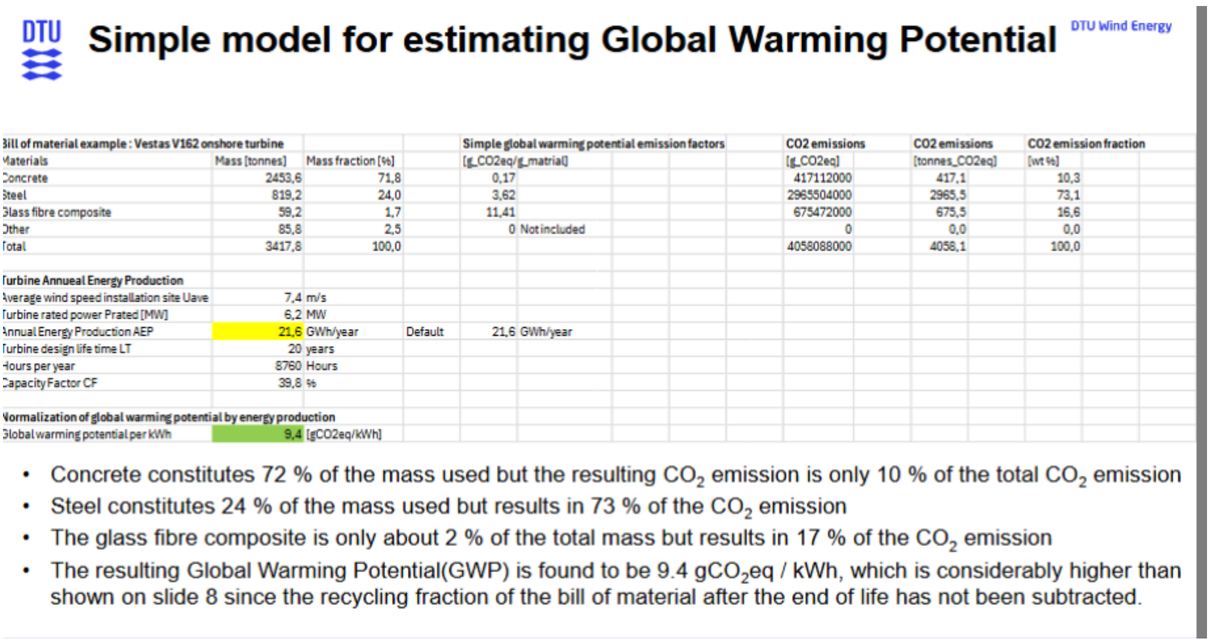
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



We can see that in this case we can sustain 420 k tonnes catches. If we exeed that, I will drive the stock to extinction. **So the Maximum sustainable yield is a maximum take I can have on a stock without over exploiting to extinction.**



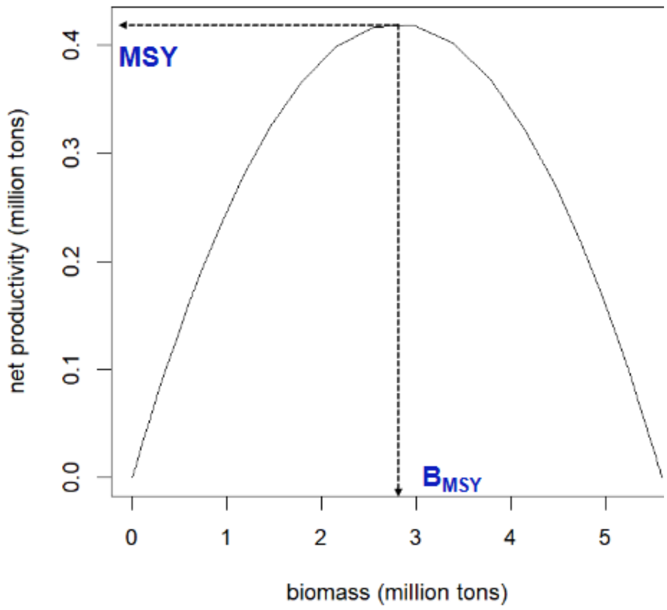
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

Maximum sustainable yield

$B_{MSY} = K/2$

$MSY = rK/4$

In the real world:
we don't know r & K;
we have time series of catches and how much effort was needed to achieve them



Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Catch per unit effort

All things equal, catches should increase at the same rate I increase my effort

$C_t = qE_tB_t$

So the catch per unit effort is related to biomass or abundance:

$\frac{C_t}{E_t} = qB_t = \mathrm{CPUE}_t$

This is the Schaefer model; we now know this is a lot more complicated, eg q (catchability coefficient) is rarely constant, exploited population equilibrium is complicated

We can use the relationship between the catch and the catch per unit effor to know whether we are exceeding that MSY.

So far we have looked at the sustainability of a yield. But to be sustained, a fiserry needs also to be profitable and it must also not cause additional environmental or social impact. But they are so large, that we challenge the sustainability of resources the fisheries do not

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

exploit but interact with.

One dimension in isolation of others

- Bioeconomics of catches (efficiency, supply/demand, quality)
  - associated with fuel consumption (and hence C footprint)
  - Gordon-Schaefer model
- Biodiversity footprint
  - Incidental catches, habitat deterioration
  - Multi-criteria approach
- Can I find the effort which will be profitable, have acceptable biodiversity footprint, and yield sufficient catches?

In the fisheries, this problem is known as incidental catches. When for example a species is caught in the fishery, but is not a target of a fishery. Both incidental catches and profitability are directly associated with fishing effort. So we fall in a multicriteria question which is relatively simple:
Can I determine the fishing efforts which maintain my fisheries profitable, keep catches at MSY and does not cause a significant biodiversity footprint?
To do that, we need to understand the economics of my catch. In its simplest form, the income the fisheries will get are related to revenues from catches minus the cost of the effort to do that catch. Therefore, we can calculate the maximum economic yield (MEY) which corresponds to the effort point where the distance between cost and catch is maximised.
In most cases, MEY is below MSY (almost all) but external incentives can distort that relationship. That is particularly the case when fisheries are artificially maintained to effort with subsidies so if I add that extra cash, my cost is gonna decrease. And that's why subsidies can often lead to sustainable challenges for fisheries.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

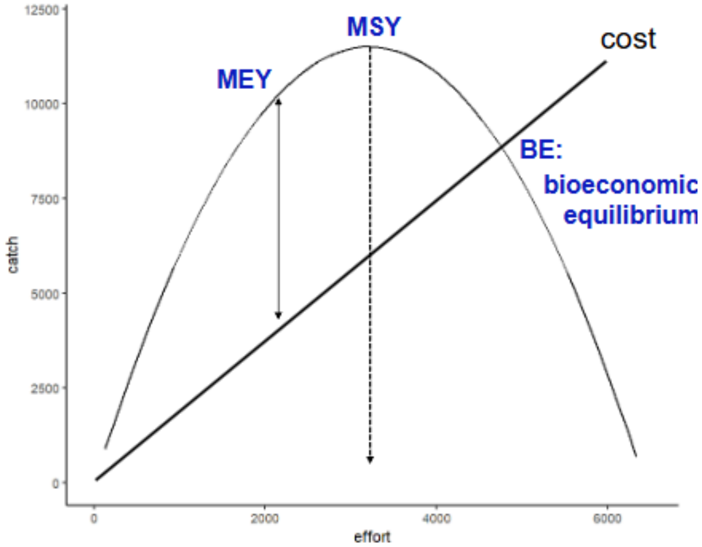
- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Gordon–Schaefer bioeconomic model

Revenue=aC-bE

Maximum Economic Yield < MSY

MEY can be > MSY
if there are external revenues
(subsidies)



So each effort unit has a probability of bycatch (incidental catch of non-target species that are sensitive but are there for a risk of extinction). We can therefore estimate the total bycatch by knowing the effort and the probability.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Biodiversity impact: bycatch

- There is a bycatch probability associated with fishing practices for varying sensitive and socially important species.
- Total bycatch is not optimised: an independent threshold is set to ensure conservation/restoration objectives are met
- Globally prevailing: Potential Biological Removal (PBR):
  – a la Schaefer model:
  – $PBR = N_{min} \times R_{\text{"MSY"}} \times F_r$

However, in this case, we don't face an optimization problem. We have a measure of how much bycatch is too much bycatch for a species. There are many ways to calculate this. In many cases this is calculated using the PBR: it is essentially the maximum catches that species can take without jeopardising the conservation objective we have for this species. It is estimated from the intrinsic rate of growth of a population of that species and its abundance (N), given a recovery factor (Fr), which is essentially a measure of how far from carrying capacity a population is.

So in this case we want for both species to be as close to this current capacity as possible under exploitation. So if we look at the complete decision graph it willlook like this:

Simple model for estimating Global Warming Potential

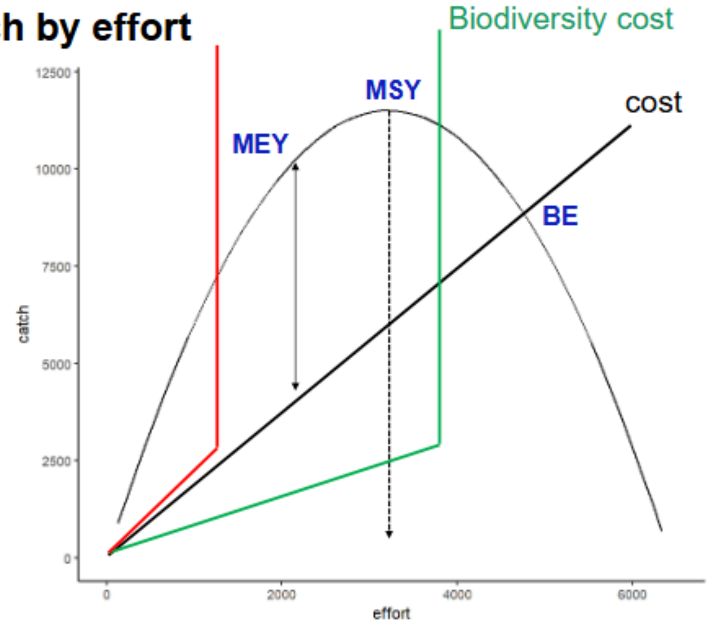
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Incorporating in catch by effort

- Biodiversity cost is independent of MEY and MSY
- Biodiversity cost can be reduced with mitigation
  - mitigations are species dependent
  - mitigations can affect MSY and MEY



If a Biodiversity cost as estimate throoigh PBR looks like the green line, then we are fine: Fisheries can operate MEY without trigging biodiversity issues. But if it looks like the red line, we are not fine. Various impacts needs to be addressed for our fisheries to operate sustainably. This can be done to trying to mitigate bycatch (reduce the probability of bycatch) or reducing fishing in bycatch hotspots.
Mitigation is not trivial and this changes can affect MSY and MEY.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Economic dimensions

Sustainability Tools for society

Here we will look at the economics and we look at the sustainability for society.

<u>Rationality for using Sustainability tools</u>

Companies have a central role in the transition towards more sustainable economic systems. There are various tools are available to support sustainability assessments and to make more sustainable decisions within a company or an institution.
Sustainability is not only about minimisinf the environmental impacts of goods and services, but also how we enhance the social and economic well-being of the people who use them.

<u>Deep-dive on the life-cycle economics for gasoline cars versus EVs for households</u>
– Quantitatively demonstrate economic cost of gasoline vs electric cars across their lifecourse
– Explore in context of different energy sources for electricity
– Explore different ownership models
– Discuss wider societal & equity issue

Why measure? If you can't measure it, you cannot manage it…

<u>Tools</u>
Despite there are many tools in the literature and their relatively easy to use in practice, companies dont use them to make good choices.

- multi-criteria decision analysis (MCDA),
- material flow analysis,
- life cycle assessment (LCA),
- input–output models,
- sustainability indicators and indices,
- cost–benefit analysis (CBA) and

DTU

Simple model for estimating Global Warming Potential DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

■ optimisation methods

Material flow analysis

■ Analysis of process, chains and quantifies the inputs and outputs of materials or substances related to those processes.

■ Represents a simple model of the interrelation between the economy and the environment. Here you would take one product for example, an electric vehicle, and think about the costs and the environmental impact of each component of the car.

  ■ economy is an embedded subsystem of the environment and dependent on a constant
  throughput of materials and energy

  ■ Most countries will provide material economy-wide material flow accoun

Important thing to remember about material flow analysis: is usually at one point in time. How much was, what is the cost and the environmental impact of actually making an electric vehicle. But they are more than just the production. We need to think about the costs to the households, to society and the environments andd as its used throughput its life course and also when it dies.

So material flow analysis can be seen as a precursor to something like life cycle analysis a on a much simpler level.

input–output models

From an economic perspective, this models dont just look at the impact of developing buying goods and services required to make an electric vehicle. Here we look at both direct and indirect impacts on the economy. And this offers a more holistic view.

■ Describes the interdependencies (not just a linear model) between different branches of the economy.

■ Important (economic) quantitative methodology

– Used to look at the impact of the production and consumption of different products and services on key economic parameters (employment, what is the profit that the industry will generate to the country), gross value added, etc.

DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

– Used extensively
– Environmentally extended IO (EEIO): analysis is a method for evaluating the linkages between economic consumption activities and environmental impact

Often the positive impacts completly outweigh the negative.

Like MFA, the Input output models, documents the flows of goods and services in terms of monetary value (underpinned by data on flows of goods and services). We are specifically interested in how monetary values changes between different goods and services.
For example, we can calculate for agriculture for example. If we increase expenditure in agriculture by 1 euro, what effect this would have in the wider economy? This expending will also impact in different sectors (indirect effect)

■ Calculate for Sector X both the:
■ Direct Effect: Impact of the expenditures for the sector on the wider economy
■ Indirect Effect: The impact a sector has on other industries and their subsequent activities to respond to the need for Sector X for the operations of the business.

This is what we are able to do in a very systematic way in an input-output model. It can also be used to used to calculate multipliers. Multipliers is what the impact for a change in output. For example, if output changes by one unit in agricultural sector, what impact will this have on something like profit in that sector or employment in that sector.

■ The impact that a change in output in a sector will have on the economy for key parameters GVA, employment

DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

■ For example, an 1kr increase in expenditure in Sector X and the potential impact it will have on employment

These are all really important pieces of information for policy makers to know. Everyone wants money in their sector. Policy makers have a certain budget, so by being able where the greatest amount of value can be derived, what sector creates the greatest amount of monetary values in terms of for example employment or profits, they can make an informed decision in what sector money should be put into. But we also need to look at the environmental and socual and this is what LCA does better.

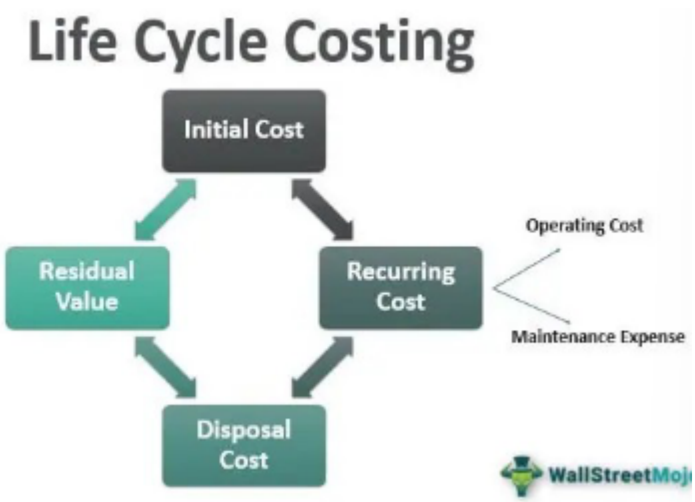
Example: every time government invest one krone in agriculture, there are 2.1 jobs created, but across other sectors, this change. So this is information the government can use. This is only monetary!!

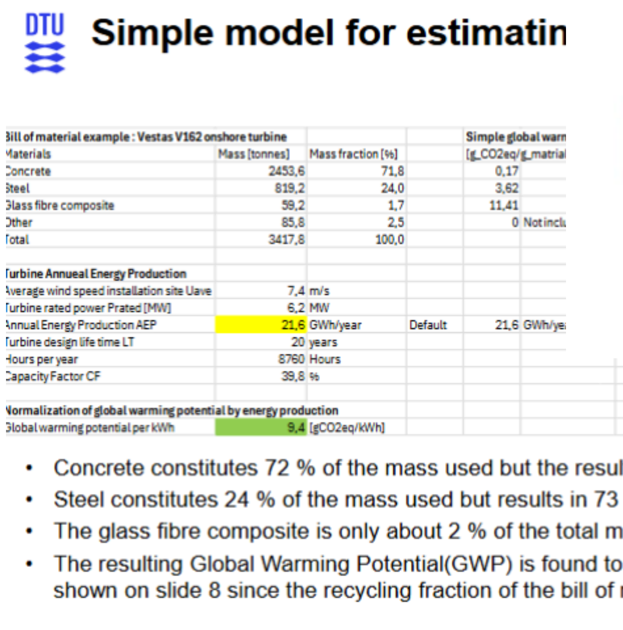
<u>cost–benefit analysis </u>(CBA)

It can be very complicated but a very basic cost benefit analysis would be use the outputs for an input-output model to make an informed decision of the costs vs the benefits of investing in different sectors of technology. You can also include the environmental impact and socual
■ … is an economic method that estimates the equivalent monetary value of the benefits and costs of a project.
■ Outputs from LCAs and IOs are regularly used within CBAs to quantify costs or benefit

<u>life cycle cost assessment (LCCA)</u>

■ Life cycle costing (LCC) is an approach that assesses the total cost of an asset over its life cycle, including initial capital costs, maintenance costs, operating costs and the asset's residual value at the end of its life





Bill of material example : Vestas V162 onshore turbine				Simple global warn	
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial	
Concrete	2453,6	71,8		0,17	
Steel	819,2	24,0		3,62	
Glass fibre composite	59,2	1,7		11,41	
Other	85,8	2,5		0	Not inclu
Total	3417,8	100,0			
Turbine Annueal Energy Production					
Average wind speed installation site Uave	7,4	m/s			
Turbine rated power Prated [MW]	6,2	MW			
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/ye
Turbine design life time LT	20	years			
Hours per year	8760	Hours			
Capacity Factor CF	39,8	%			
Normalization of global warming potential by energy production					
Global warming potential per kWh	9,4	[gCO2eq/kWh]			

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

■ Can be used within sustainability analysis to understand the economic cost of different goods or services
■ Moving from just environmental focus to an economic focus
■ Can be used to aid both producer (companies) or consumer decision-making

Scenario 1:
different prices of electricit
Social and Environmental
justice
■ EVs are cheaper for households across the lifecourse
■ Therefore, purchasing EVs are equally accessible to all households
■ Results should not be taken at face value
■ Upfront costs of purchasing an EV still means that despite long term savings, EVs will still be inaccessible for most low-income households
■ What about leasing

Scenario 2:
Leasing
■ Run a LCA to examine the economic cost of leasing an EV over its lifecourse.
■ Obtain information from various web resources (how else do you think we obtain data!!!)

Result
■ Sam Vimes "Boots" theory of socioeconomic unfairness
■ Theory that people in poverty must buy cheap and subpar products that need to be replaced repeatedly, proving more expensive in the long run

DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

than more expensive items.

Social - and health dimensions

7.1 - Social aspects

Sustainability in society. How do we make better sustainability baked decisions that benefits everybody in society?

Companies have a central role in making better sustainable decisions. Not only environmental aspects, but also from an economic and social perspective.

When we refer to social perspective we mean peoples welfare, peoples wellbeing, ensuring that the decisions we make to transition to a more sustainable society, to a more equitable society, is not compromised and that there is nobody left behind.

Social life cycle assessment (S-LCA)

■ As introduced in Module 5:
– Life cycle costing (LCC) is an approach that assesses the total cost of an asset over its life cycle, including initial capital costs, maintenance costs, operating costs and the asset's residual value at the end of its life

Here we look at:
– Social LCA (SLCA) is developed towards evaluating social impacts, such as employment, workplace health and equity

DTU Wind Energy

Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

– Assesses the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle
– Increasingly established
– UNDP - Social Life Cycle Assessment (2020): how to use it.

<u>s-LCA & impact assessment</u>

Social impact assessment is the phase in S-LCA aimed at calculating, understanding and evaluating the magnitude and significance of the potential social impacts of a product throughout the life cycle of the product.

What we do, within the framework of a social lifecycle analysis, the impact assessment component, which is the main part of it calculates what the social impact will be of whatever you are interested in calculating (product , service)

We have 2 approaches:
■ Reference Scale: looks at its performance measure. social performance or social risk of a product. You calculate it from a given set of data, and then use it. So its a reference to other product or services
■ Impact Assessment: consequential social impacts from a product by characterizing the cause-effect chai. It looks at the social impact of a product service across all aspects of that. “If you buy a product, how will this indirectly impact other aspects of society?” It is a pathway approach, where you look at different ways, paths, mechanisms in which a product or service will impact society.

Lets see an example

<u>S-LCA- Process</u>

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

S-LCA methodology present four main steps:

1. Objective and scope definition: think what the product or service is, the objective you want to measure
2. Determine stakeholders & Associated inventory indicators: you need to understand who is going to use and impacted y the product. Here we have to think: if we bring a product online, if we bring a service online, who are all the people/stakeholders that are going to be impacted.
3. Social Impacts Assessment and
4. Interpretation

■ Process:
– objects: products and services, and
– scope: the entire life cycle.
■ Social and socio- economic aspects assessed in S-LCA are those that may directly affect stakeholders positively or negatively during the life cycle of a product.
– indirect impacts on stakeholders may also be considered.
■ S-LCA does not have the goal nor pretends to provide information on the question of whether a product should be produced or not.
■ Lots of similarities with LCCA
– Not least it's data requirements

<u>Data & Databases</u>

The databases that we can use to calculate a SLCA, are being added to and broadened. But in terms of obtaining data, there is 2 main data bases:

S-LCA case studies,
– the Social Hotspot Database (SHDB) and
– the Product Social Impact Life Cycle Assessment (PSILCA) database remain the main sources for generic social
■ Both databases assume pathways exist across value chains and are commonly used to provide country- and sector- specific data on some of the social indicators specified in the

DTU **Simple model for estimating Global Warming Potential** DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

UNEP/SETAC

Impact pathway approaches

■ The main target within the IP S-LCIA is to assess and model relations between the cause (social activities or comercial activity /stressors) that arises from a company´s activity and their effect (in the population).
■ This is usually done by establishing what we call impact pathways.
■ Involves tracing the inventory data through the relevant social and socioeconomic mechanism to define the socioeconomic impact
– Can be established qualitatively and quantitatively.
– Focus is increasingly on effects on human health measured in terms of DALY's: Disability Adjusted Life Year

We will basically look at what the product, the service is, we think about how it will impact and we look at the different ways in which it can impact society.

Development of an IP S-LCIA method, just as for E-LCIA, usually consists of linking inventory data (data that are in data bases) that undergoes a characterization step, and which results in midpoint and/or endpoint impact indicators.

Example:

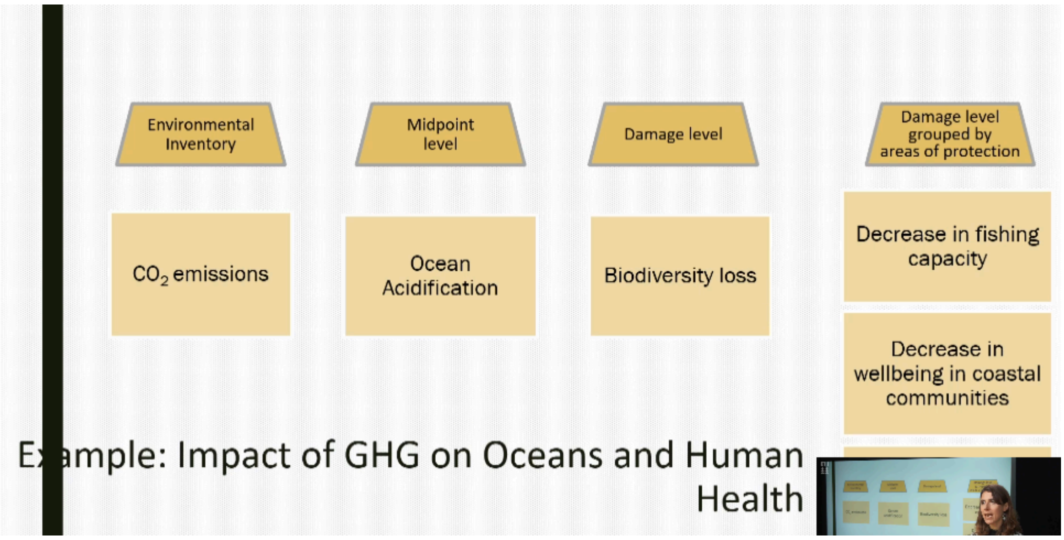
DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



Inventory data: CO2 emissions. Impact: within the context of oceans and then human health. So we get CO2 emisions, and then looking it from a pathways perspective, within the context of the oceans, CO2 emissions has an effect on ocean acidification, thats our midpoint (one point the mechanisms). Ocean acidification has an impact in biodiversity loss (this is our damage).Because ocean acidification in itself doesnt really impact human health, but how it does, is through biodiversity loss. So this is the pathway. So CO2 emissions within an oceans context doesn't really seem to impact human health. However, if we think about the mechanisms, the paths in which CO2 work through the environment, we know that C02 emissions are impacting ocean acidification. Ocean acidification is impacting biodiversity loss, this is where the damage it is done. Not only will impact on humans, but also ecosystems. And then we see the damage that this loss of biodiversity will have in terms of human activities: if biodiversity loss decrease, there is a decrease in fishing capacity, this will decrease well-being in coastal communities. And it also impacts greatly on ecosystems quality. If there is a loss of one specific fish or fish species, this goes on to have knock effects in ecosystems.

So the pathway model that social lifecycle analysis use, thinks very very carefully about each step in which society will be impacted. So its not CO2 emissions that are necessarily bad for humans, but in this instance it affects ocean acidification, which then damages biodiversity

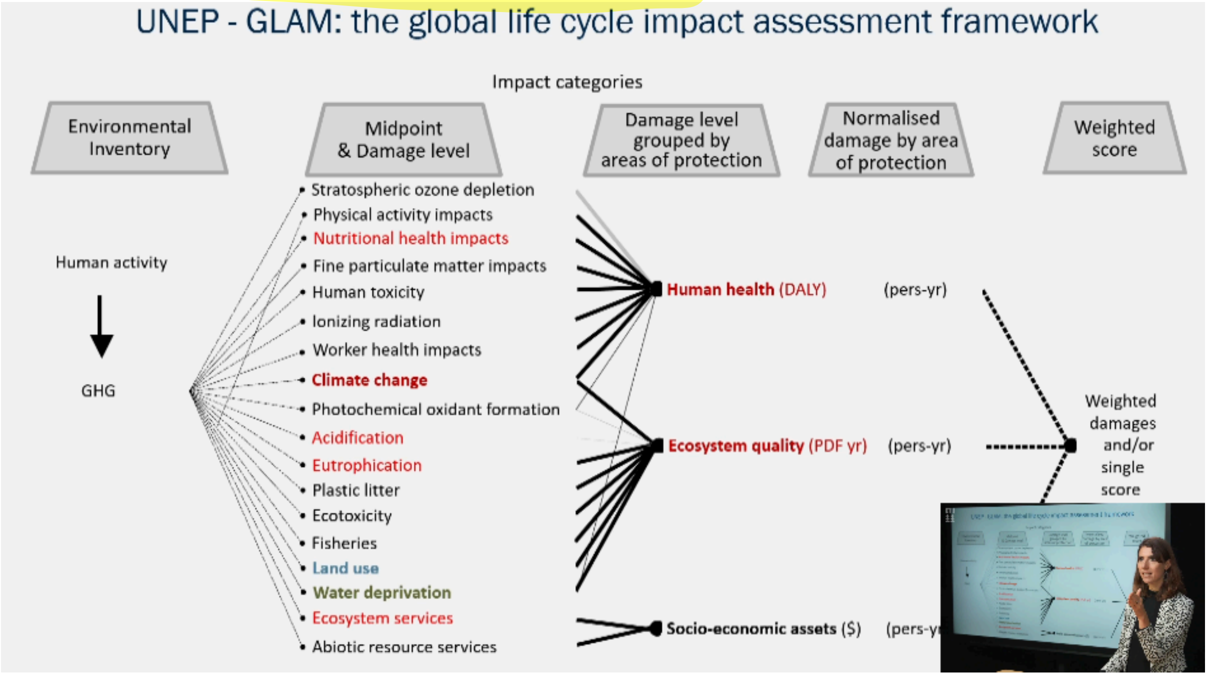
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

loss, that finally impacts people capacity for employment (social aspect) , people health and wellbeing through loss of nutrition and mental wellbeing, and knock on on ecosystem quality. So we see here that CO2 emissions within an ocean context, have a huge impact on each aspect of our 4 pillars: economic, society and ecosystems



This is how to look at everything.
You weight this up to get the social life cycle assessment to get the score for your product.

7.2 - Health assessment - tools and indicators

How could we quantify the impact on health considering we all have different activities in our lives and in the object or services that we are using in our world?

7.2.1 - The Global Burden of Disease (GBD)

Simple model for estimating Global Warming Potential DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Quantifying the burden of health in the world.

Global Burden of Disease

19 MAIN RISK FACTORS:

Air pollution 5H
Alcohol use
Childhood maltreatment
Dietary risks
Drug use 2H

High blood pressure
High body mass index 4H
High fasting plasma glucose 1H
High low density cholesterol (LDL)
Impaired kidney function
Intimate partner violence
Low bone mineral density

Low physical activity 3H
Malnutrition 8H
Occupational risks
Other environmental *(lead, radon)*
Tobacco smoking "H
Unsafe sex
Unsafe water & sanitation 2H

We would like to rank this main risk factors from the highest risk in terms og global deaths in the workd to the lowest factor and then we can compare to what the global burden of disease is displaying us.
How to measure this effect on health? GBD

Global burden of Disease: General Approach

The burden of disease can be thought of as a measurement of the gap between current health status and an ideal situation where everyone lives into old age (e.g. the average Japanese woman), free of disease and disability

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Measured in *"Disability Adjusted Life Years"*

1 DALY = 1 equivalent year of healthy life lost

DALYs are calculated by taking the sum of 'Years of Life Lost' (YLL) and 'Years Lived with Disability' (YLD)

DALY = YLL + YLD

Its not only living longer, but having a good quality of life. We measure that using DALYs, which are disability adjusted life years. So DALY is in equivalent years of healthy life lot. Is the sum of 2 factors:

- Shortening of life expectancy
- Years lived with disability.

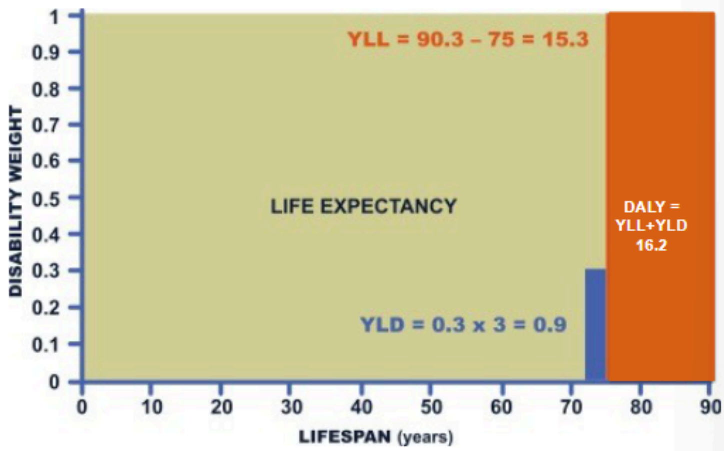
How do we get this 2 factors?
Lets take an example where a person gets cancer at 72 adn diest at 75. The life expectancy is 90.3 So this person in fact is losing 90.3-75=15.3 years of life lost.
And the weight is 1, we have lost 3 years of life.

Burden in Disability-Adjusted Life Years (DALY)

DALY = Years Life Disabled (**YLD**)
+ Years Life Lost (**YLL**)

Illustration: Person gets a cancer at 72 years old and dies at 75

At age 75: life expectancy is 90.3



Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

How impaired is certain disability: measured with different metrics. How people can eat by themselves, etc. Cancer: 0.3 of years life lost equivalent.

So total: DALY=16.2

GBD standard life expectancy tables

AGE	US LIFE EXPECTANCY	L-STANDARD LIFE EXPECTANCY	EXPECTED AGE AT DEATH
0	78.8	86.6	86.6
5	74.4	81.8	86.8
10	69.4	76.8	86.8
15	64.5	71.9	86.9
20	59.6	66.9	86.9
25	54.9	62.0	87.0
30	50.1	57.0	87.0
35	45.4	52.1	87.1
40	40.7	47.2	87.2
45	36.1	42.4	87.4
50	27.3	37.6	87.6
55	23.2	32.9	87.9
60	19.3	28.3	88.3
65	15.6	23.8	88.8
70	12.2	19.4	89.4
75	9.1	15.3	90.3
80	6.6	11.5	91.5
85	4.6	8.2	93.2
90	3.2	5.5	95.5
95	2.3	3.7	98.7
100		2.5	102.5
105		1.6	106.6
110		1.4	111.4

YLL = N x L

N = number of deaths

L = standard life expectancy at age of death in years DALY/death

Constructed based on the lowest estimated age-specific mortality rates from all locations with populations over 5 million in the 2013 iteration of GBD

As you get older, your expected age age of death is increasing, but your life expectancy is decreasing in that case.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Disability weights: Examples

$YDL = I \times DW \times L$

I = number of incident cases
DW = disability weight
L = average duration of the case until remission or death (years)

HEALTH STATE NAME	HEALTH STATE LAY DESCRIPTION	DISABILITY WEIGHT
CANCER controlled phase	has a chronic disease that requires medication every day and causes some worry but minimal interference with daily activities.	0.049 *(0.031 – 0.072)*
CANCER, diagnosis and primary therapy	has pain, nausea, fatigue, weight loss and high anxiety.	0.288 *(0.193 – 0.399)*
CANCER metastatic phase	has severe pain, extreme fatigue, weight loss and high anxiety.	0.451 *(0.307 – 0.600)*
CANCER, terminal phase, with medication	has lost a lot of weight and regularly uses strong medication to avoid constant pain. The person has no appetite, feels nauseous, and needs to spend most of the day in bed.	0.540 *(0.377 – 0.687)*
MILD PARKINSON DISEASE	has mild tremors and moves a little slowly, but is able to walk and do daily activities without assistance.	0.010 *(0.005 – 0.687)*
MODERATE PARKINSON DISEASE	has moderate tremors and moves slowly, which causes some difficulty in walking and daily activities. The person has some trouble swallowing, talking, sleeping, and remembering things.	0.267 *(0.181 – 0.372)*
SEVERE PARKINSON DISEASE	has severe tremors and moves very slowly, which causes great difficulty in walking and daily activities. The person falls easily and has a lot of difficulty talking, swallowing, sleeping and remembering things.	0.575 *(0.396 – 0.730)*

Example: parkinon you will have 1% years of life lost in the very early stage, but it can go to 50% in the severe

What is the main difference between death and DALYs ?
Malnutrition is ranked 8th risk factor of death, but becomes the first risk factor for DALYs, since each child death is associated with elevated YLL. Because malnutrition is mainly in children, and life expectancy of a child is much larger than cancer affecting 60 year older. And so here we have many more years of lige lost here per case in the case of malnutrition

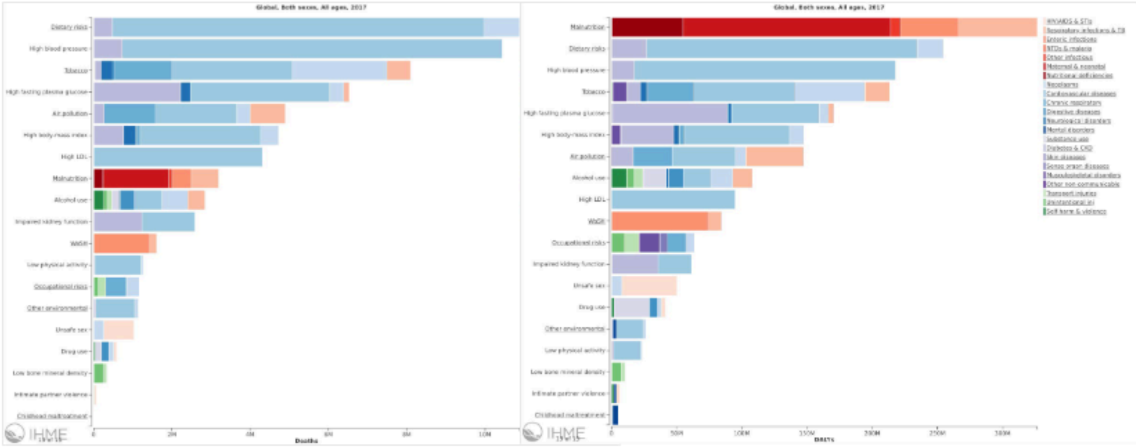
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Number of death in the World Number of DALYs



Institute for Health Metrics and Evaluation (IHME). GBD Compare. Seattle, WA: IHME, University of Washington, 2015. Available from http://vizhub.healthdata.org/gbd-compare. (Accessed 08/12/2020)

Number of deaths: the dietery tisk is the number one effect on human health and we see that worldwide and the dietry risk has 11 million deaths per year. And the type of disease: cardiovascular disease.
So improving the food in that case is very important

The other risks are in a similar rank
The GDB give you not only the risk factor but also the causes.

Causes define the illnesses or types of injuries to which DALYs are attributed to. On this map, areas are proportional to the magnitude of DALYs attributed to each cause
.
What are the dominant causes?
Risk factor are potentially modifiable causes of disease and injury

Summary
► DALYs – Disability Adjusted Life Years offer a more comprehensive metrics than death to account for both mortality and morbidity
► It measures the gap between current health status and an ideal reference situation of living a long and healthy life

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

► The Global Burden of Disease project provides worldwide comparison of health status, causes for death and risk factors for 153 countries
► The website is an amazing source of information, you can mine, relevant to many questions related to human healt

7.2.2 - Health assessment: Gasoline versus electric vehicles and bikes

7.2.3-4 - Impacts of product on health overview

How can we measure the impact of our activity and /or consumption of products on health? Weve seen that we can measure health impact in terms of DALYs. But when we think on individual food items for example , they dont create a daily, they just create microdaily. That doesnt really speak about the impact.

But if I think that in a year, I have 60 minute time, 24 hours time, 365 days, this is in fact 0.5M minutes a year. So micro daily is a minute of life gain or lost, which speaks much more than just DALYs

Inclusion of various impacts on human health:
- Climate change
- Fine particulate impacts
- Nutrition impacts
- Physical impacts
- Chemical in products

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Exposome definition (Wild 2012)

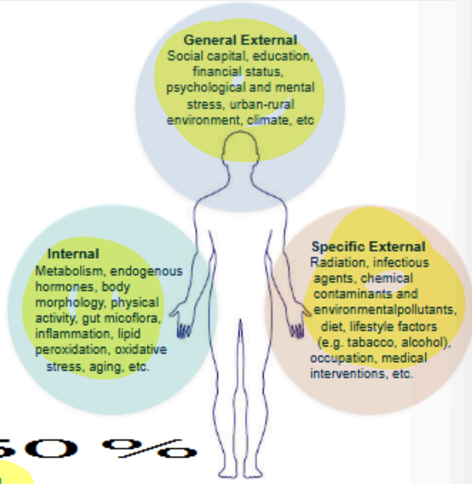
Published by Oxford University Press on behalf of the International Epidemiological Association
© The Author 2012; all rights reserved. Advance Access publication 31 January 2012
International Journal of Epidemiology 2012;41:24–32
doi:10.1093/ije/dyr236

REVIEW

The exposome: from concept to utility

Christopher Paul Wild

The exposome is composed of every exposure to which an individual is subjected from conception to death. Therefore, it requires consideration of both the nature of those exposures and their changes over time. For ease of description, three broad categories of non-genetic exposures may be considered: internal, specific external and general external.



¿ 50 %

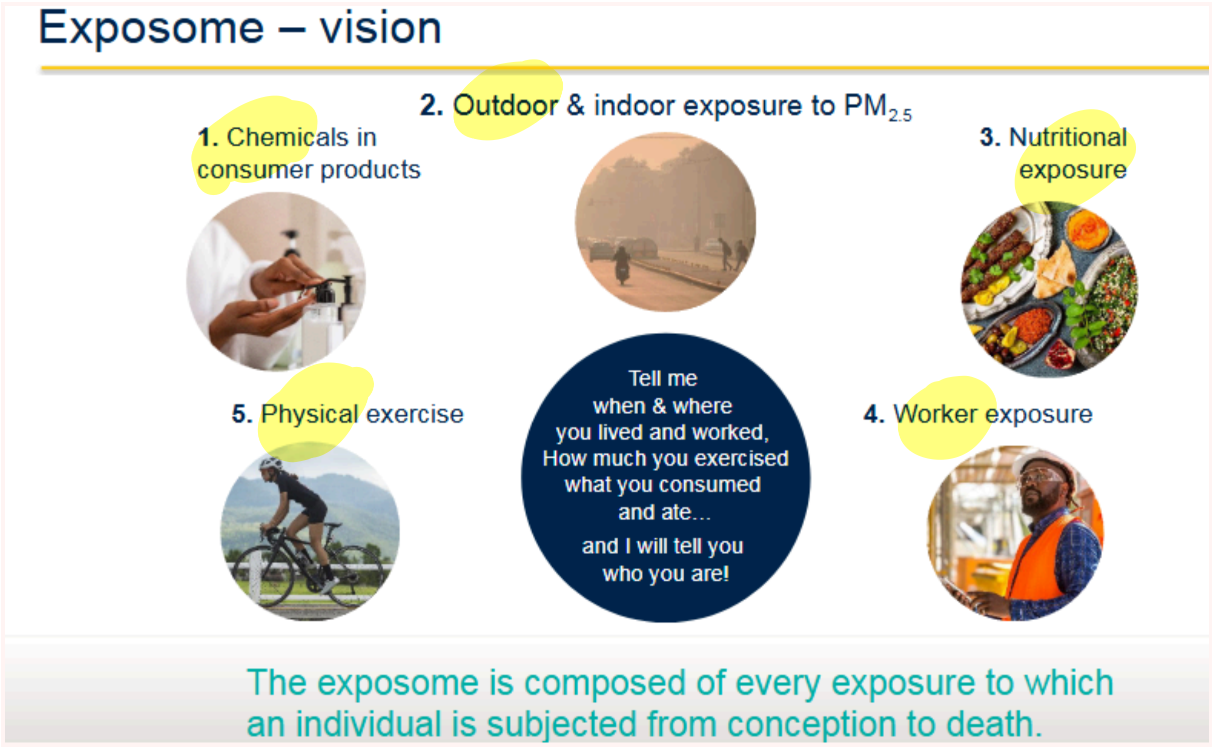
Phenotype = f (Genome, Exposome)   Variability: +

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



The vision here is that we are not exposed individually to all that, but to a mixture of these activities which are affecting our health.
We would like to say "tell me when and where you live and work, how much you experience exercise and you have consume and aid and I will tell you your life expectancy.
This is complementary to the genome. Here we can influence it by the way we live. We have now the data to quantify this

Simple model for estimating Global Warming Potential

DTU Wind Energy

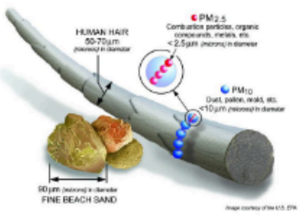
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Air pollution impacts on human health

6.5 mil deaths per year, **65% in Asia**, largely cardiovascular disease

17,800 deaths/day, equivalent to 60 Malaysian airplane crashes **per day**



A sunny day in Beijing!

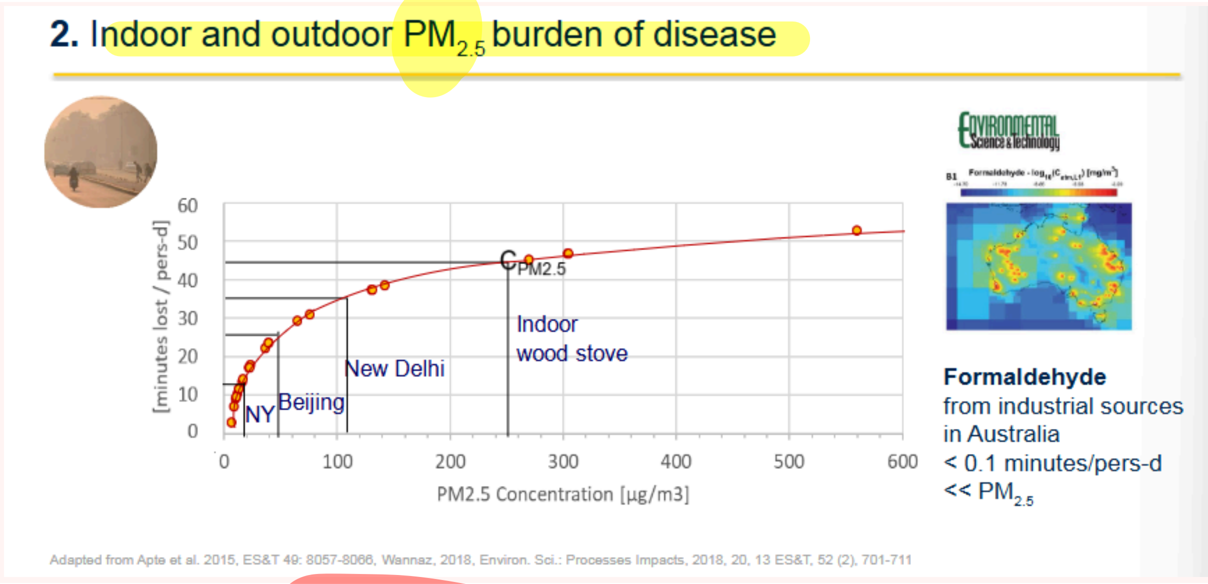
We are also responsible for this because many of our toys and products that we consume are produced here.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



We can measure the PM concentration in different cities . In NYC,we are losing up to 12 minutes life per day. In Beijing, we go up to 25 minutes per day, new Delhi you lose 35 minutes per day.
Indoor wood stove: 45 minutes per day.

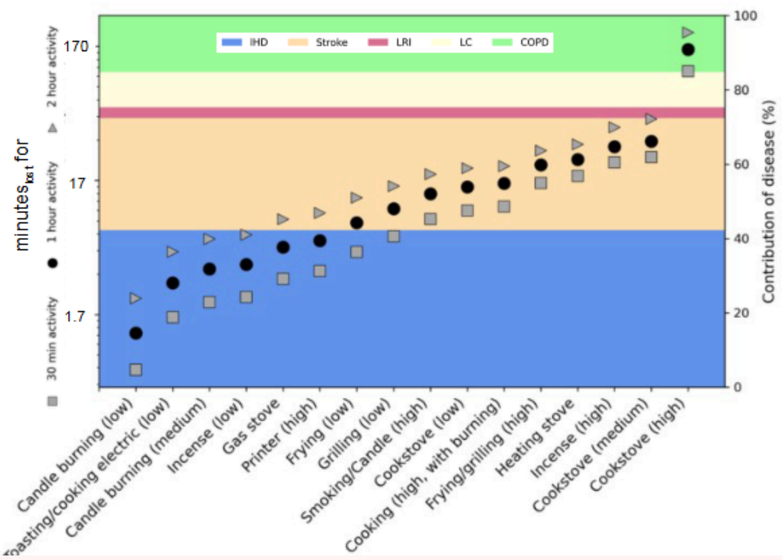
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Impact of indoor sources of fine particulates



1 – 17 min.(medium 3.5)
of healthy life lost
for 1 hour indoor
“huggely” candle,

Different activities reduce also the minutes per day. If you burn incense at high level, 20 minutes life lost per day.

And there are also methods to look at the impact of chemicals: we are exposed to many chemicals in toys, pesticides, building materials, personal care products

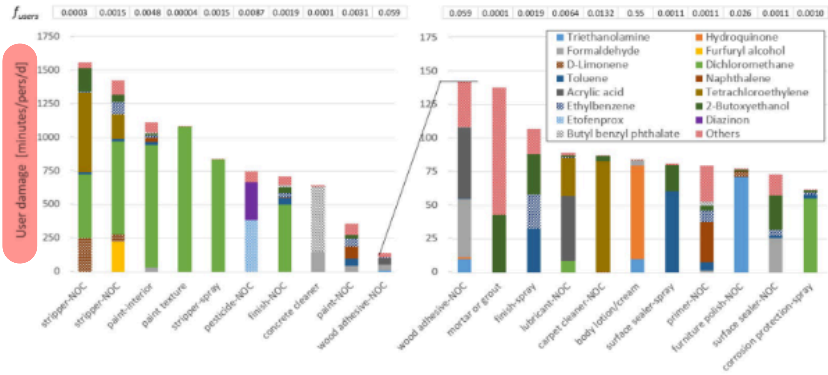
Simple model for estimating Global Warming Potential

DTU Wind Energy

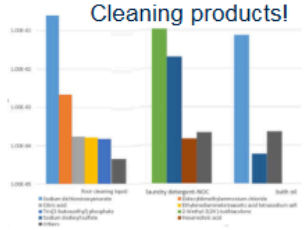
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Chemicals in household products: Human Health impacts on users



Impacts on freshwater ecosystems: Cleaning products!



Several home maintenance, cosmetics & cleaning product with substantial impacts on users, 20-1500 minutes lost per user per day ⇒ product-chemical combinations to further study or replace in priority

Nutrition: we look at different risk factors.

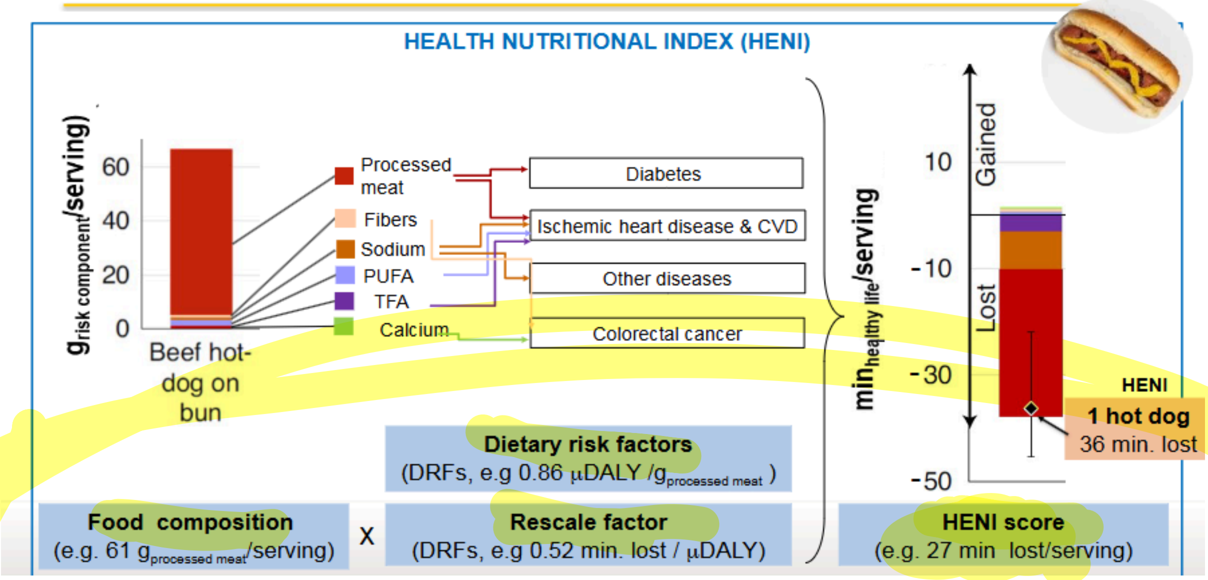
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Health Nutritional Index (HENI) for a beef hot dog (140g)



you gain with calcium, etc, but then some other are lost.

Physical exercise benefits. METS

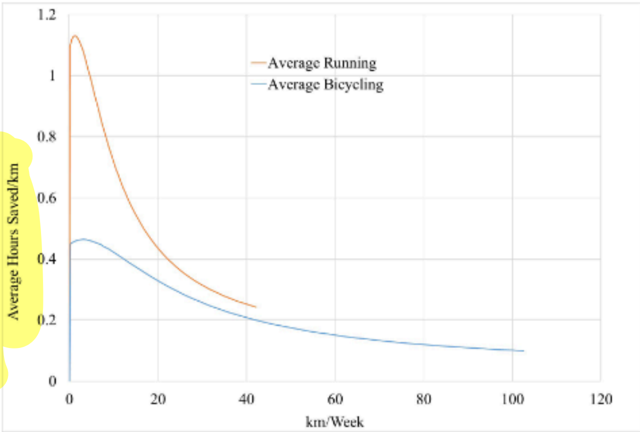
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Physical activity gains per km walking/running and cycling: hours of healthy life gained per km



2011 Compendium of Physical Activities

Duration of trip compensate for the MET
→ min_{gained} / $km_{activity}$ very comparable
Across walking or running, but depends on overall weekly physical activity

As long as not as not in New Delhi or forest fire area, much more beneficial to bike

Climate change impacts on heat cond cold on heath.

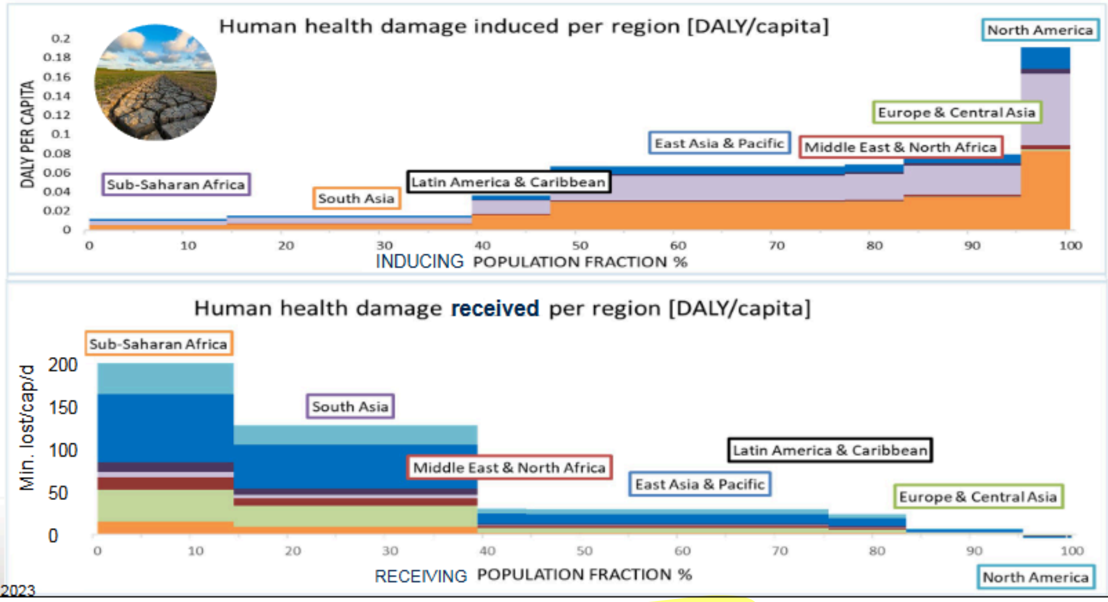
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Disparities: Climate change impacts of heat and cold on health



Rupcic, 2023

We are creating 200 minute lost per day per capita in healthy life.
We have global effeccts, unfair.

Summary:

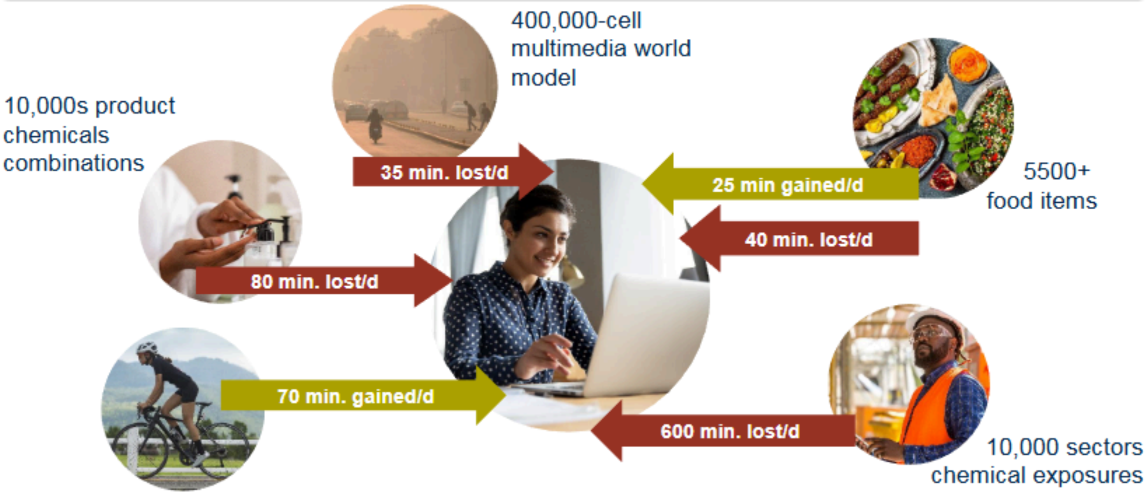
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Quantitative screening of impacts per pers per day



We can have different amount of life (gain or lost) according to the chemicals we are exposed to, food that we eat and activities we do.

Global TRADE

Part A- Using LCA to explore how our consumption impacts global health.
How much are we responsible in the western world of the impact on particular matter which is happening in Asia? Many thinks we are using are produced in Asia for example: computer, t-shirts,etc.
We have a displacement of the pollution from the user to the producer. We are inducing some impact. How is important this effect?

Clothing Imports: who is importing most of the clothing: US, western europe and Japan. Africa , south america not so much
Who is producing the clothing? China and India mainly.

DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

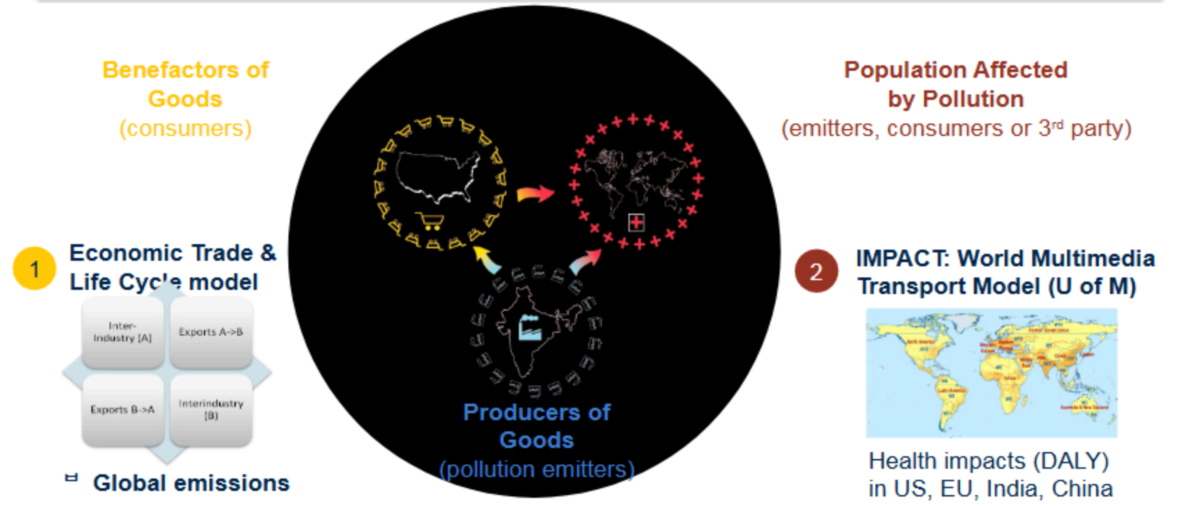
Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Global trade distances the consumer from the negative health impacts of production.. and displaces it on to other populations.

Lets think to what extent are we responsible fot the deaths due to the fine particulate matter in asia (PM)?
To study that we combine an economic trait and life cycle model which link the benefactor of the good to the emission and the production of the goods and the global emission that usually happens in the producer level. And then we couple that with the world multimedia model of transport of fine particulate (that are the substances to look how much the producer of the good are impacting people with transportation - pollution)

Combining models to calculate health impacts of global trade



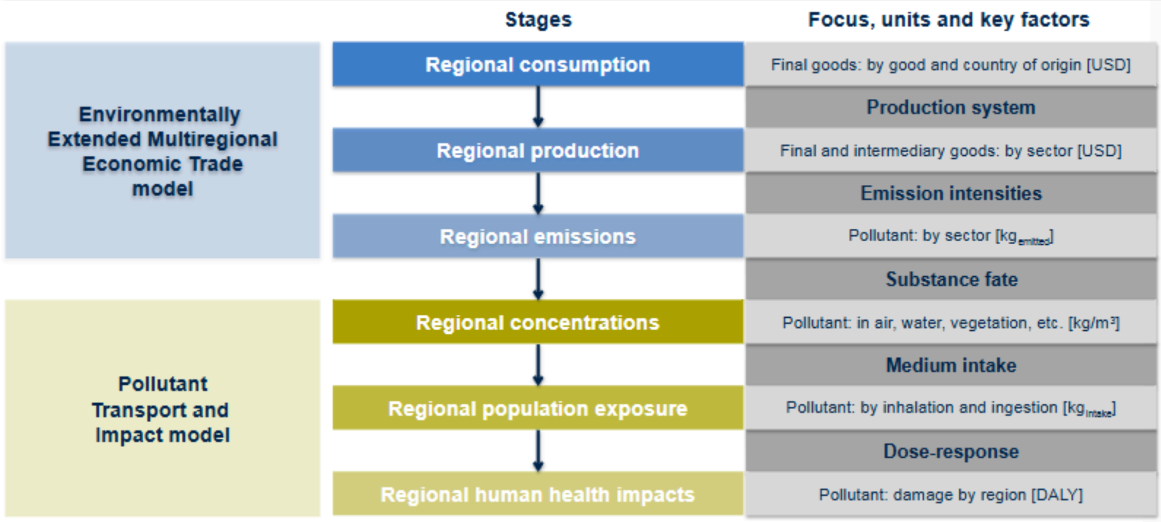
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Add global economic trade model



We go from the regional consumption. We look at where it is produced and this is multitrade and we see what is emitted,what is the increase in concentration in the region, density population in this region and finally get the guman health impact associated with this.

So what are the impact associated with ALL global trade? We have models that relate different country services and when we use this models, we can see the world production per capita
North american consumer: is inducing for 180k USD of consumption per year. But still, it generates production in Asia than an asian consumer is producing in this case. And when you look at the impact of Particulate matter: we get most of the impact in asia. Although asians are also inducing this, american consumers are also generating this.
So not all the impact is due to global trade, but there is still substantial impact which are linked to our consumption. It means that we not only need to reduce our impact locally here, but we need to think of limiting our imports or helping other countries to reduce the pollution to have a better quality of life.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

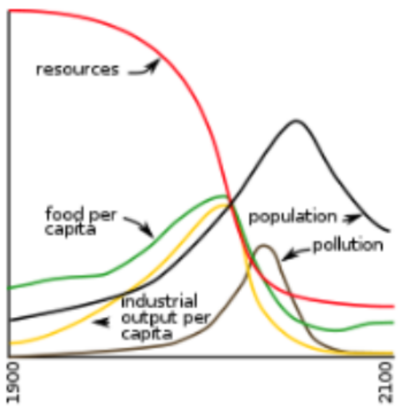
How can we do that? For particulate matter, we have the control technologies available. We can reduce and filter a lot

Part III –methods and strategies

Circular economy

What is the problem?

Urgent need for radically different measures to address anthropocentric sustainability. We have finite resources, we have growing population and industrial outputs, pollution, we need to take care of food.
Urgent needs to boost environmental sustainability: we have a climate challenge, temperatures are increasing around the globe.



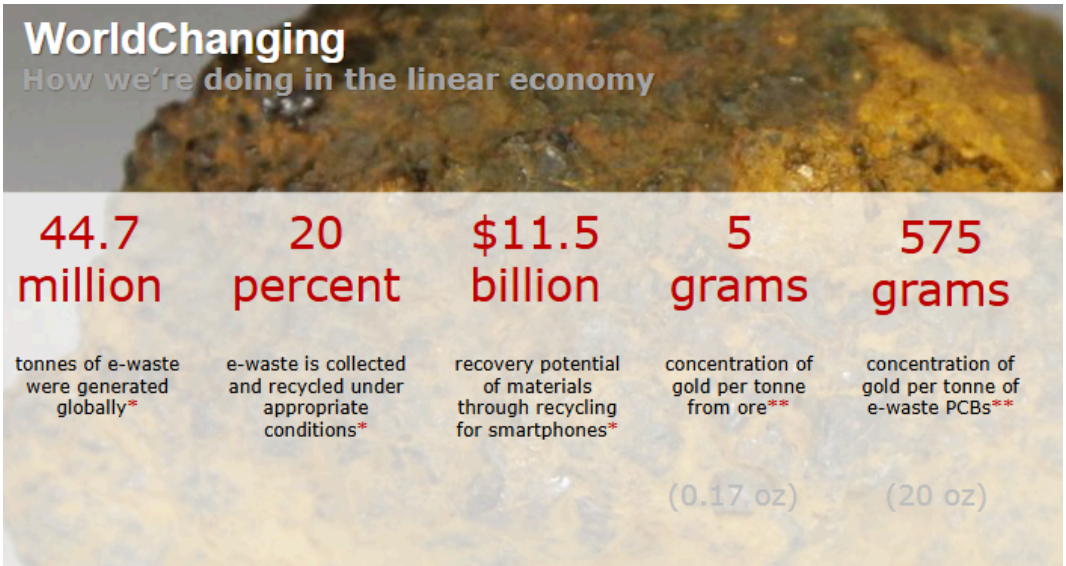
Simple model for estimating Glc

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Contamination and pollution, there are plastics that are affecting the fish and also that we eat.
Biodiversity crisis, and also resource crisis. Resources are finite.

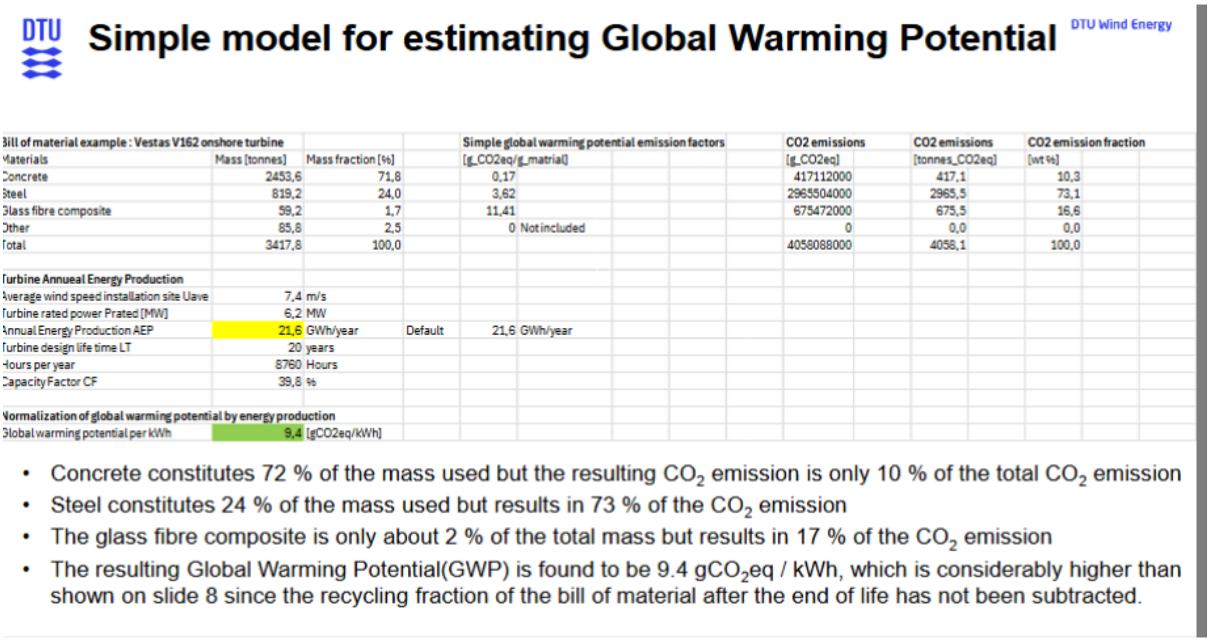
Here we are going to focus mostly on resource crisis.
Considering the Linear economy:
Electronic waste:



So 80% of the electronic waste we create is not recycled. In monetary values, we would recover 11.5 B only out of smartphones

Gold oil: gold is one of the precious materials that go in to our electronic. We can get 575 grams out of tonne of electronics waste. Then why are we digging material out of the ground if we can take it from our own waste?

The problem is that we are used to live in a linear economy. Where we take, make use and then dispose.
We created big challenges in terms of resources.

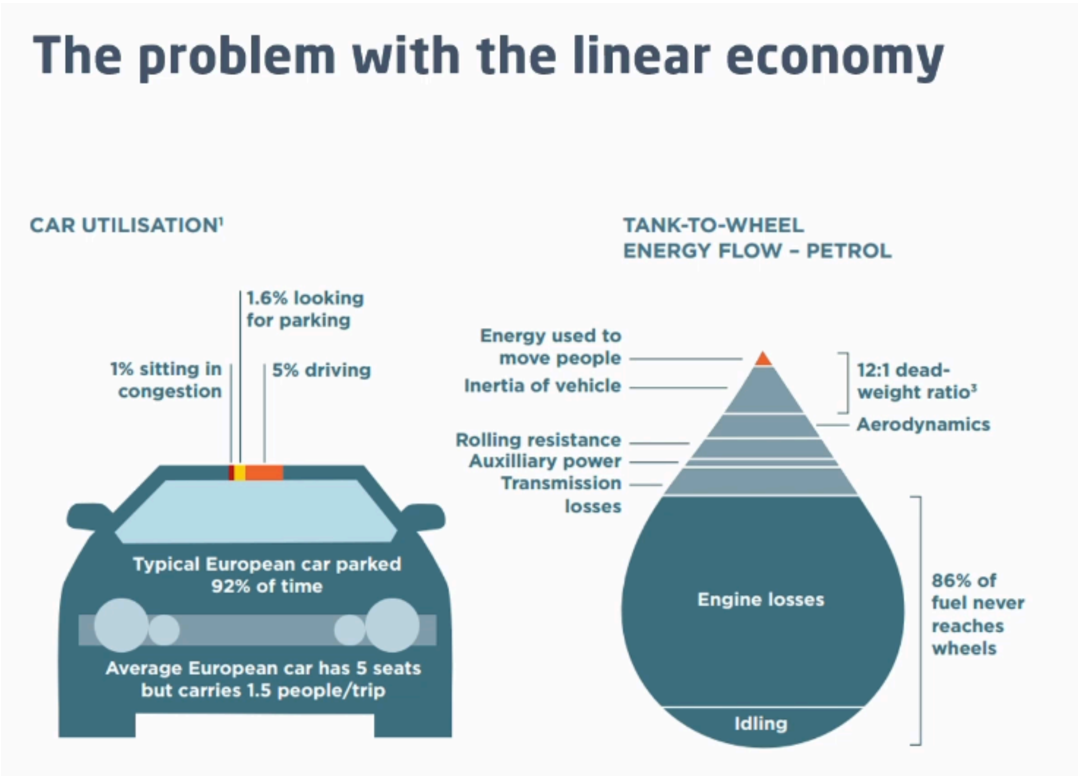


DTU Wind Energy

Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



Considering the car: structural waste.. Before we were looking at the materials, the direct waste. And then we can check the waste considering the energy. We need many engineering solutions. For example, we could make them lighter by building them from plastic rather than metal.

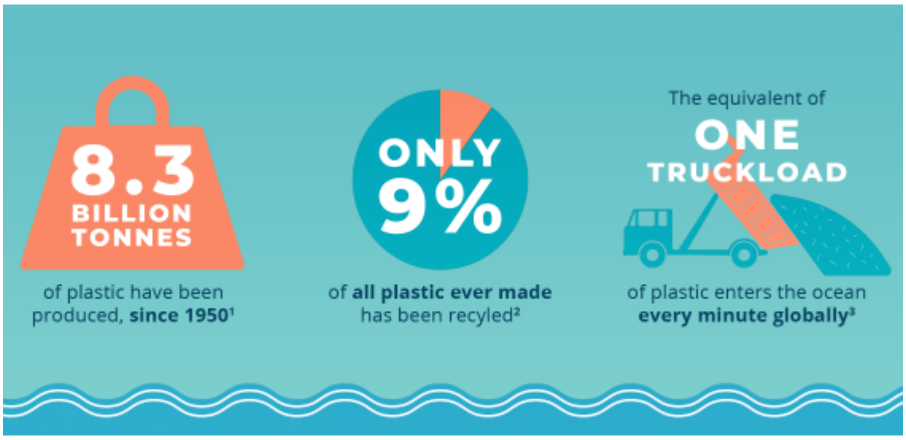
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Plastics can be seen as a proxy for our uncircularity. A lot of toxicity in the ocean are because of plastic. Rebound effect: some years ago for example, someone had the idea of putting waste tires in the ocean to create new corals reefs.Overtime, plastic and rubber decompose and so we are putting chemicals into the water. So the message is: there is not such thing as a way, we need to think how do we bend the circles.

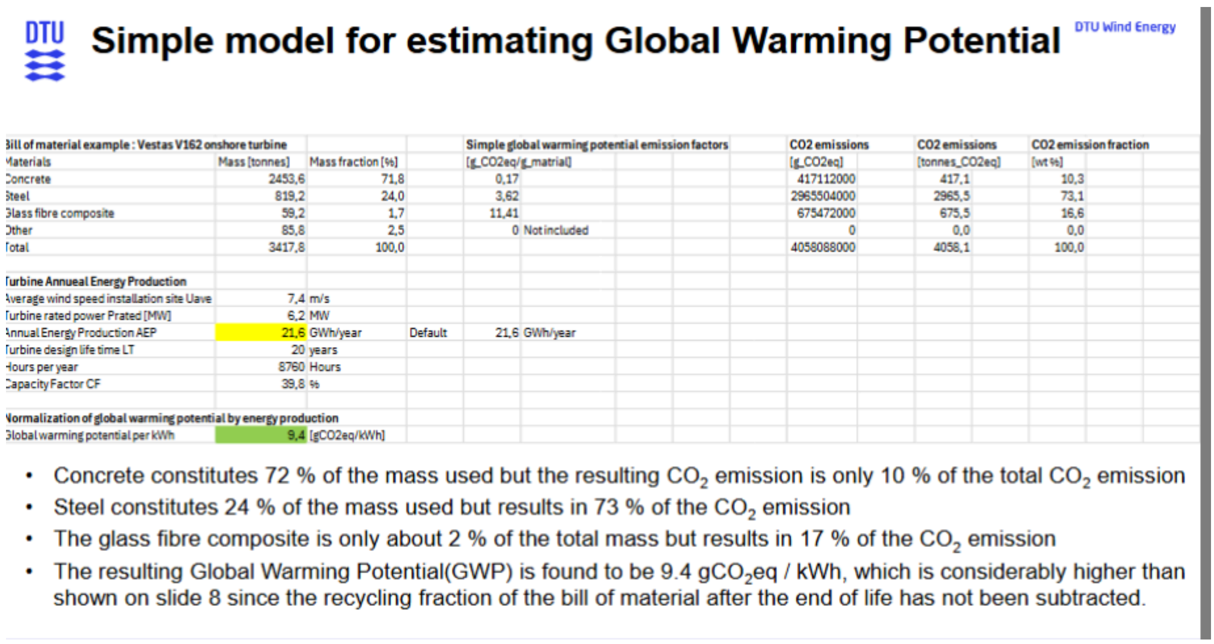


So whether is plastic, gold, oil, though it looks like we are only focussing on the resources, the challenge but also the opportunities to make a change, actually affects all the sustainability areas by doing better with out resource consumption, production and treatment, ownership. We can actually affect the climate change, diversity challgeny and toxicity.

<u>The promise of circularity</u>

What is Circular economy?
Is a concept which is growing in company interests, in political interest and in socual interest throughout the whole world.

- Fastest growing business strategy area in Europe
- Its about Closing the loops: how do we make sure that we close loops of those resources that we otherwise see as waste?



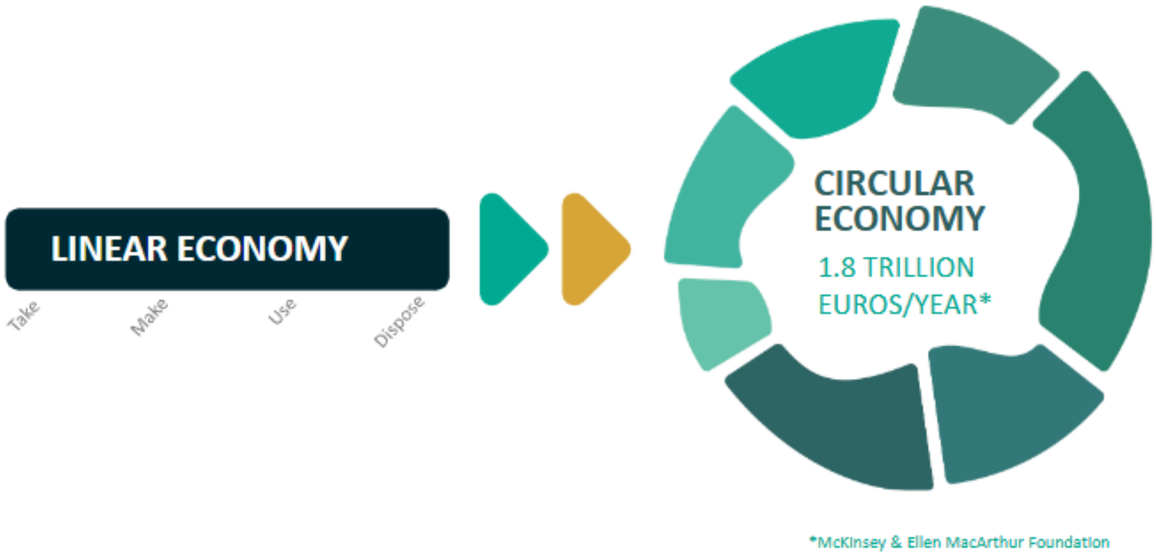
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

- Decoupling value creation from resource consumption: how do we kee providing value to a customer or company? How do we keep fulfilling our needs if we are a user? That is somehow not connected directly 1:1 with the consumption of some form of a resource.
- Requires a systemic approach



We are coming from linear economy and the circular economy is trying to bend into a circle to say that there is no such thing as dispose or waste anymore. How can we reuse it? How can we reuse the materials?

<u>Definition of a circular economy:</u>
"an economy that provides multiple value creation mechanisms, which are decoupled from consumption of finite resources"

If we map the linear economy:

Simple model for estimating Global Warming Potential

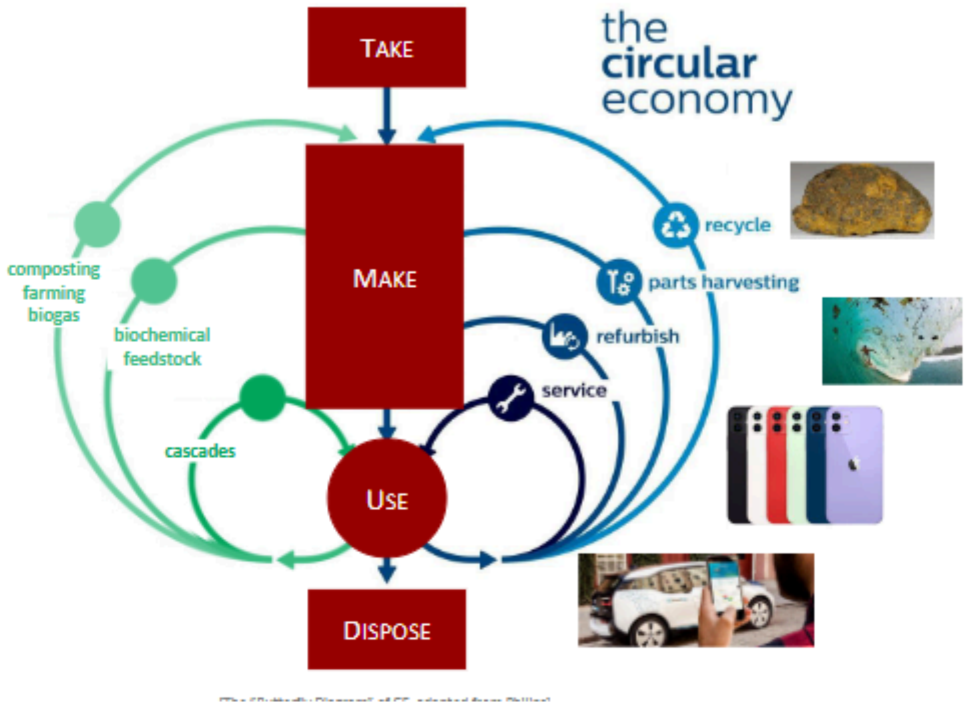
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Circular Economy

... decoupling value creation from resource consumption

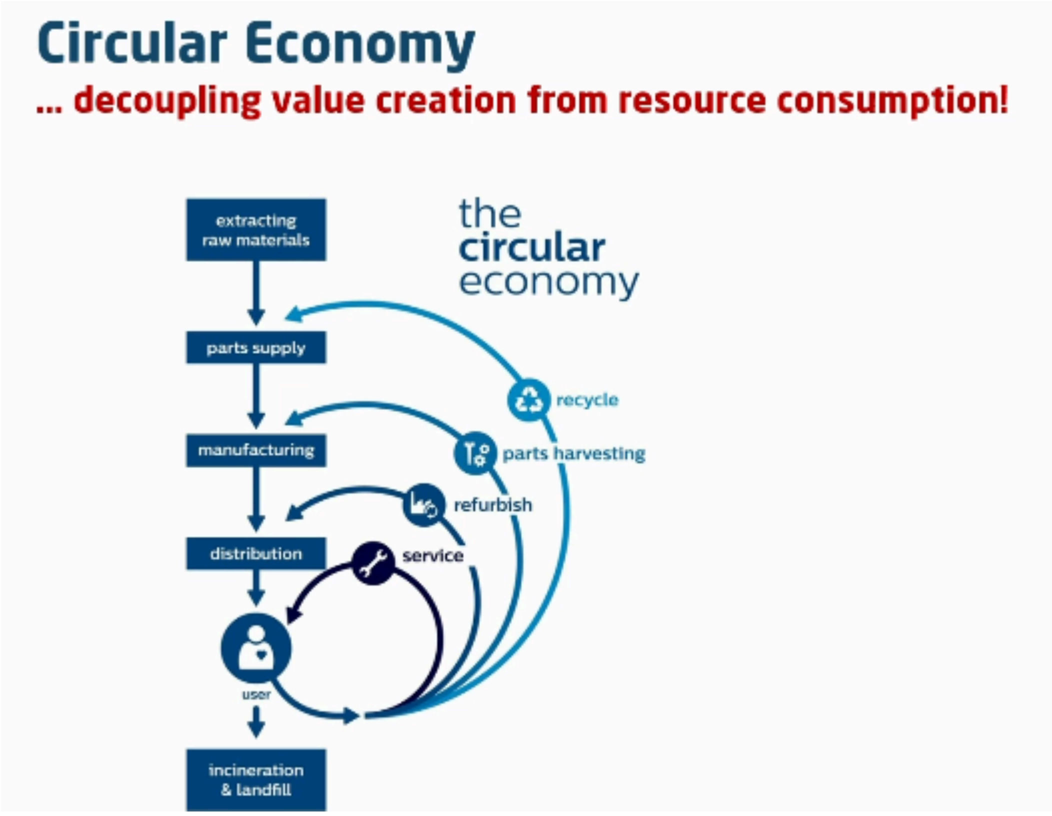


Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



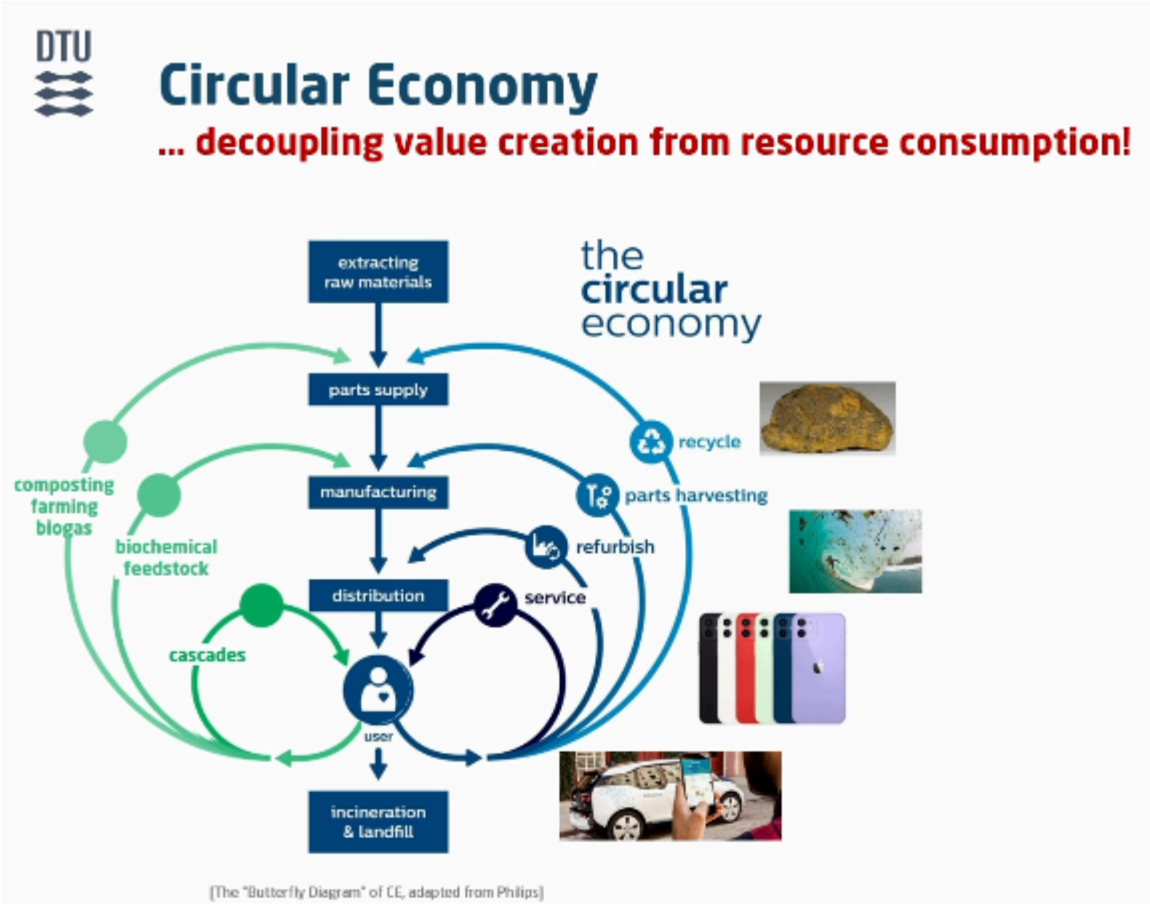
We see parts harvesting, refurbishing, recycling, services sharing systems, this are all opportunities to create a different way to continue to create value from the resources that we want to take out of the ground and hopefully can utilize again anf again
Butterfly diagram: right part is technical and left side is nature

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



We should as much as possible mimic nature, how can we learn that and do the same in technical cycle.
Cascading ways: the smallest the circle the better it is: so recycling is better than incinerating.
There is basically 4 main principles of circularity:

VALUE Creation
Inner Circle – Minimising comparative materials use, through re-use. The tighter the circle, the less it has to be

Simple model for estimating Global Warming Potential

DTU Wind Energy

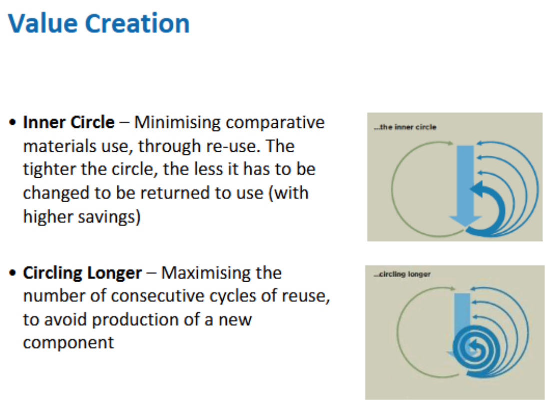
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

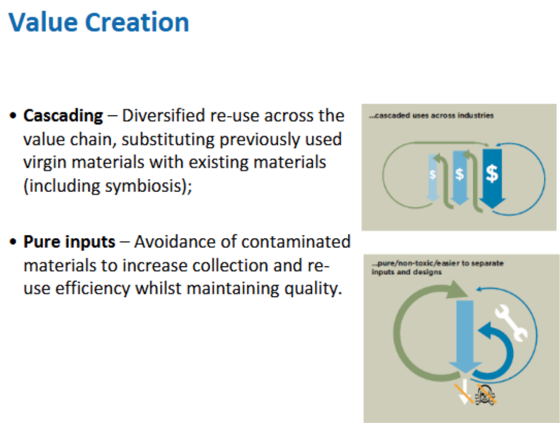
- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

changed to be returned to use (with higher savings)

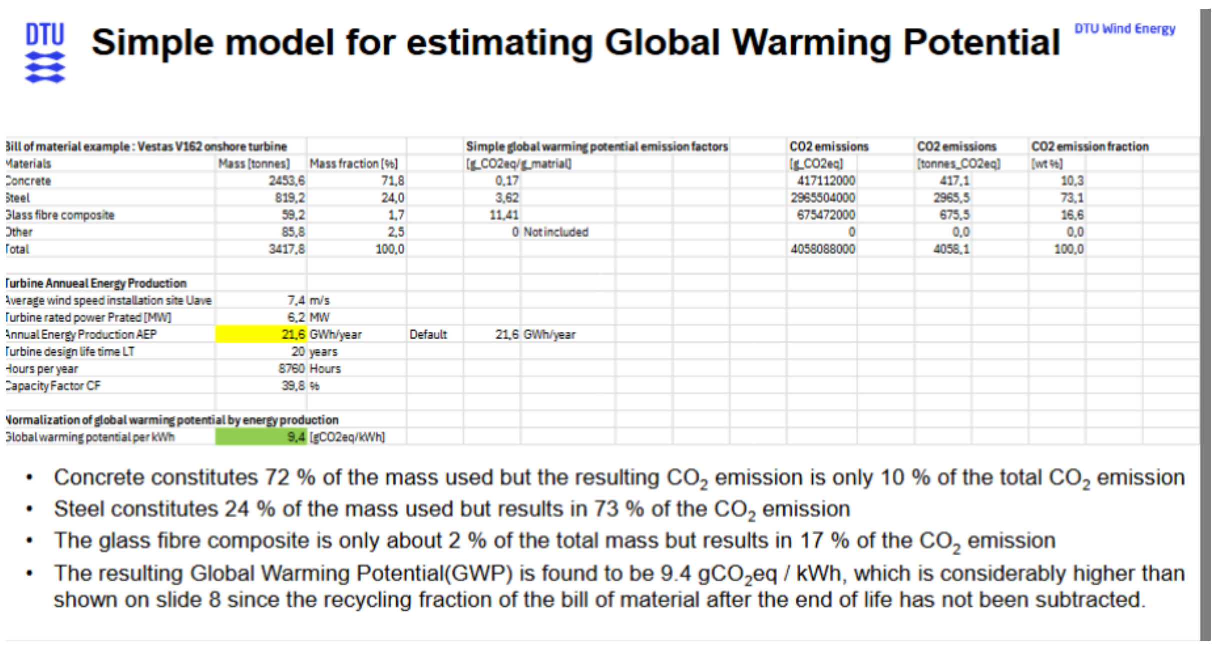
• Circling Longer – Maximising the number of consecutive cycles of reuse, to avoid production of a new componen

Cascading – Diversified re-use across the value chain, substituting previously used virgin materials with existing materials (including symbiosis); – Can we use it somewhere else?
• Pure inputs – Avoidance of contaminated materials to increase collection and re- use efficiency whilst maintaining quality. Trying to design product so they are not toxic in the end.



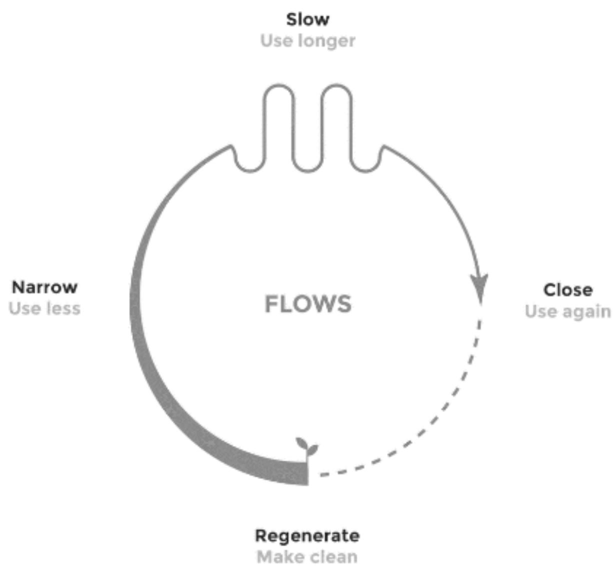


Another 4 philosophies around how we can see circularity as a strategy in the way in which we see our material flows.



Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



* Narrow material flows: using less. Example: share based vehicles, using minimum amount of materials
* Slowing materials flows: using them longer. Example: car sharing : can we make sure instead of structural waste where 90% the time the vehicle is parked, how we can use it the most of possible.
* Closing material flows: using again. Example: Clothes renew
* Regenerating: making things clean. Example: bottles that can regenerate

We need to design and develop products and systems that can close the loop.

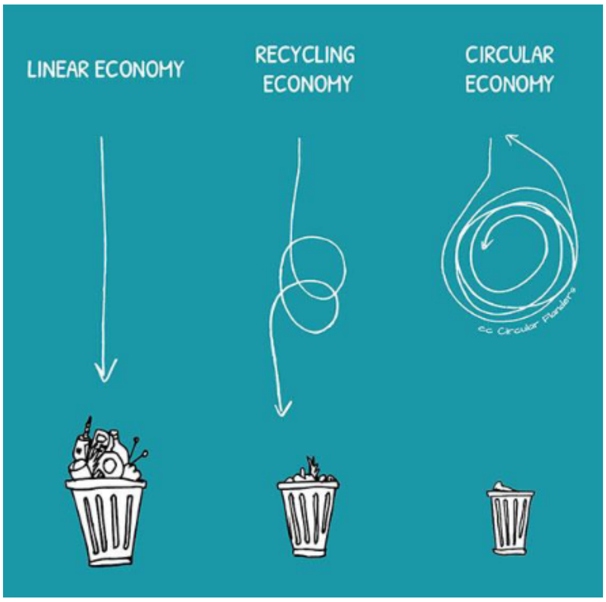
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

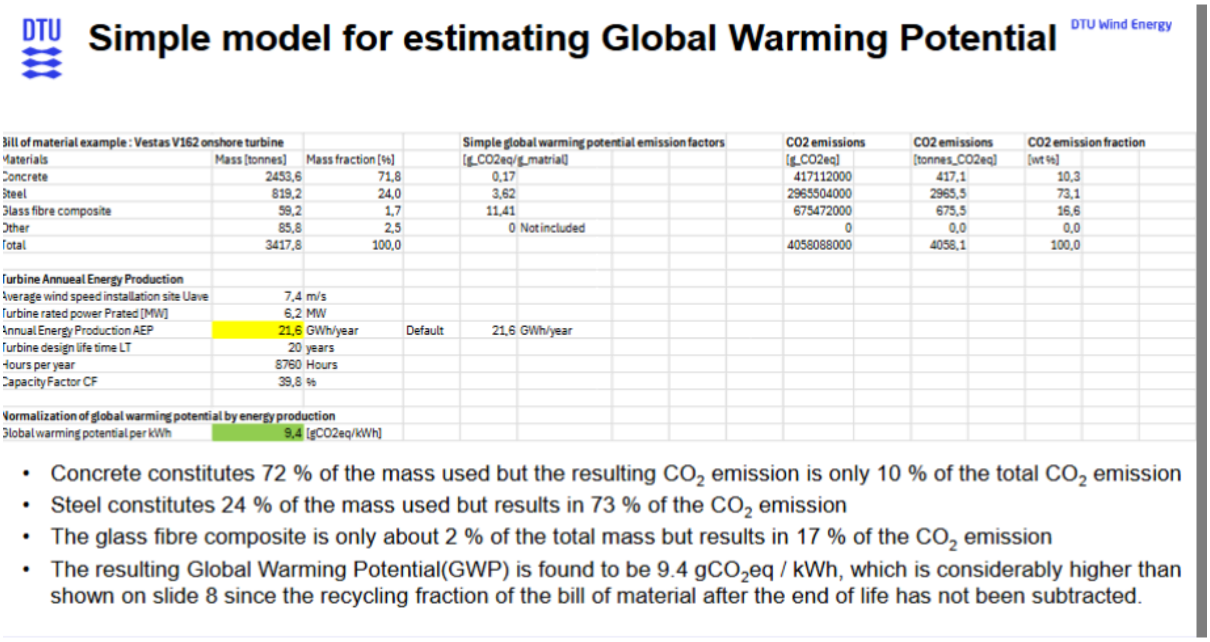
- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Deploying circular economy strategies



3 paradigms. Waste creation is decreasing and also we ee that recycling is not the only thing of circular economy, we need to do more things.

Different strategies that can contribute to go circular. There are some grey areas: material level. Blue: components and products level. Green: what can we do from the company. Orange: doing business in a different way.Yellos: whole new paradigms

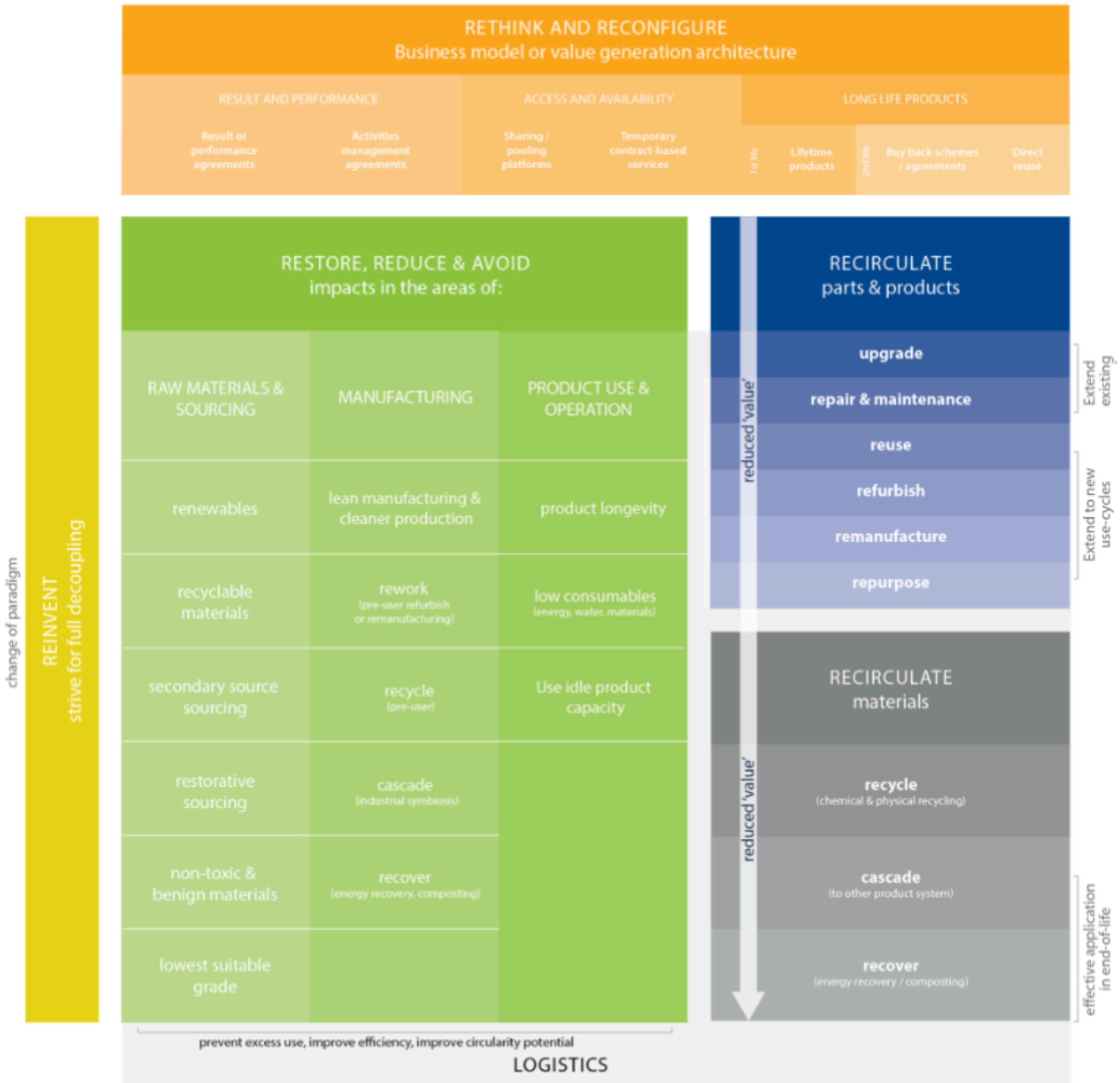


DTU Wind Energy

Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



Examples:

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

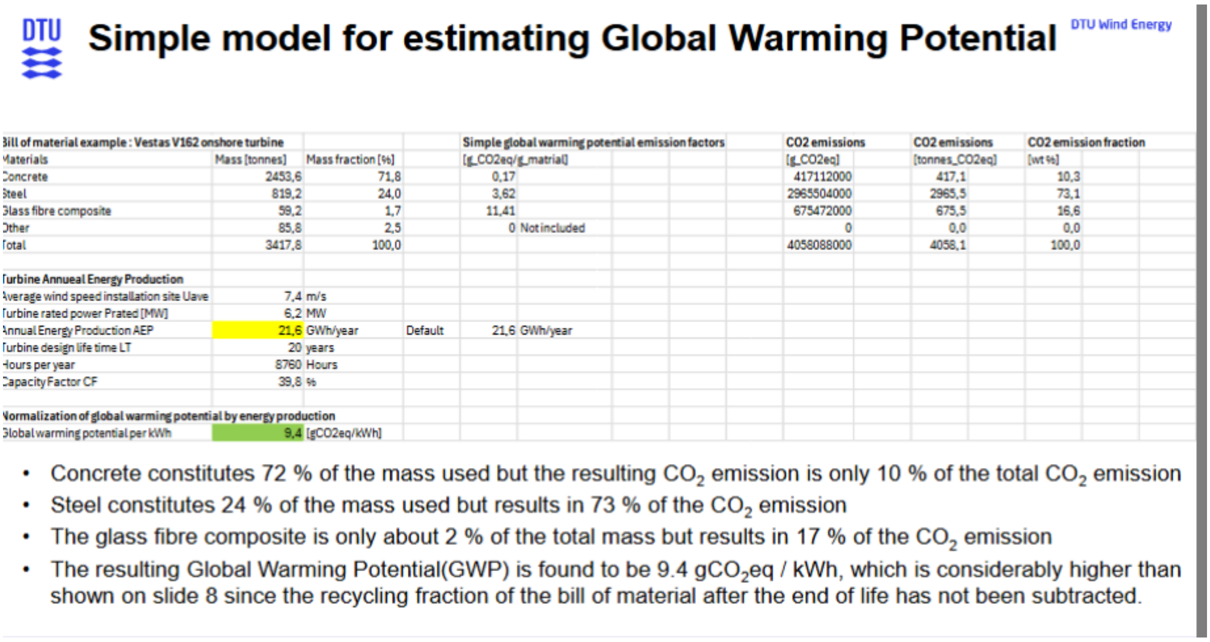
- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

grey: making products out of materials which were formerly used with higher mechanical propeprties and higher demands on them. We can use the cascade mindset to mix materials and get something else with different mechanical properties
Recycling: 83% plastic material in their products and 100% recycle . Printers: companies has changed the way they see and use the materials. The return cartridges in an envelope
Parts and components level: reuse shampoo or creams
Collect materials and use them ofr something else
Materials as aservice: plastic from ocean and then recirculate it

Circular economy readiness

How ready are companies to make transition from linear to circular economies?

Realising a circular economy needs a systemic approach, we need to look at this holistic shift to circular economy. Its extremely important to look not just at our own business, but the



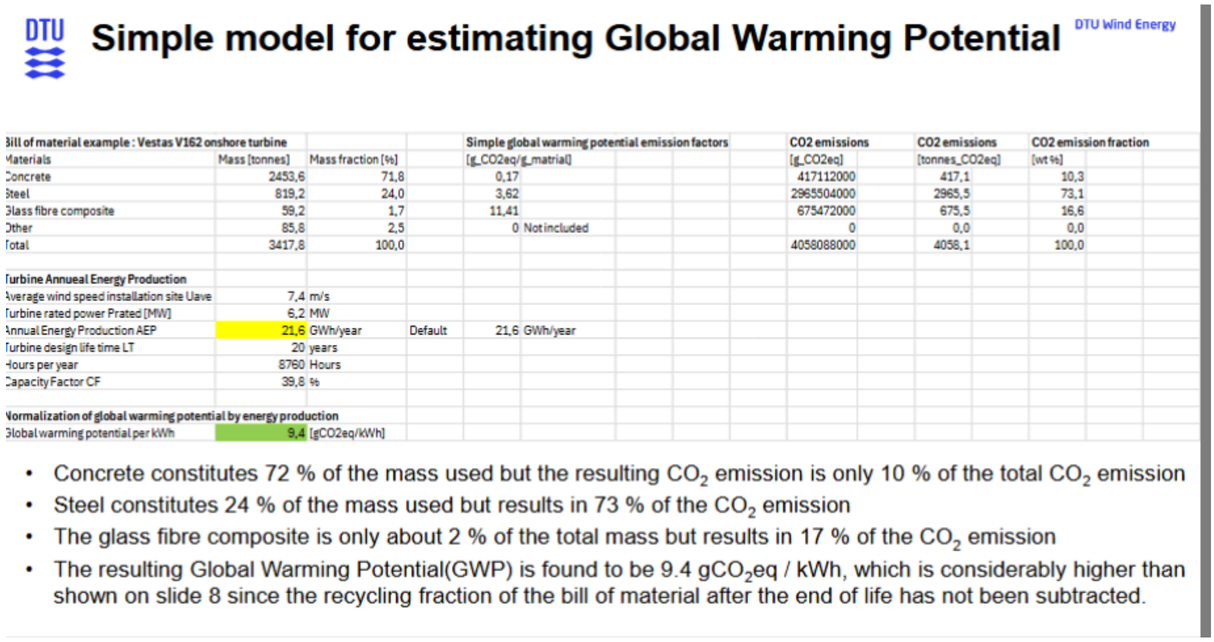
Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

whole product and the whole value chain and the whole needs delivery to the user. Circular economy only arises if we cooperate in the value chain.

Ready to loop: research project. 3 out of 4 companies hadnt even started to collaborate in the value chain. So we need to put focus on all the value chain activities. To really chive a circular economy, we need to think about the materials: materials become componentes, so components manufacturers have a very large role to play: they use the components and also sell the products to the system at the end of the day. Packaging manufacturers have a very big responsibility. Different delivery of products, a great deal. We also have the logistics providers. They actually flue all of the steps together. Then we have the products retailers, the maintenance and the value recovery components. And hopefully we can close the value completely.
Ready to loop: readiness assessment for companies in all these value chain layers to asses how ready are we to transition to circular economy.
How to do this? Lets take for example product manufacturers. Then, we look and try to understand what are the different dimensions of circular economy that a company typically



Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

needs to be aware of. We have 8 when looking to product manufacturer

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Business opportunities from a circular economy. How ready are we to look at the more long term activities in the organization, to be able to provide a business offering. To understand how to develop those business offerings to our customers and to be able to deliver it in a way which is actually sustainable. Sustainable both environmentally but also from a income perspective.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Product & Service Innovation

Product & Service Innovation

Readiness of 'Product & Service Innovation' measures the capabilities necessary to develop new solutions (incl. products and services) that are suitable in a Circular Economy context.

To what extent is the company actually designing and developing its products to be part of a circular economy system? Example: reusable packaging for e commerce.

Manufacturing & Value Chain

Manufacturing & Value Chain

Readiness of 'Manufacturing & Value Chain' measures the capabilities that will help you to create new value chain engagements and partnerships, aimed at maximum value creation from finite resources.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

To what extent are the companies actually able to manufacture their products in a more circular manner? Also to communicate and collaborate in the value chain.For this you need to have many areas collaborating, not just the manufacturing but all the whole value chain considerations are extremely important to be aware of to achieve a circular economy.

To what extent do we see opportunities to use technology and data to facilitate the circular economy. Example: App, internet of things, data , how to see how the company is doing. You can do better if you collect the right data and use it in the right way.

DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Use, Support & Maintenance

Use, Support & Maintenance

Readiness of 'Use, Support & Maintenance' measures the capabilities need to provide enhanced maintenance and repair services, aiming at an extended value creation from the provided solutions.

How do we make product last as much as possible. To make the product end of use, not end of life. How can we reutilize that. How can we extend it as much as possible. Companies: how ready are to enhance repair and maintaining activities to create preventive maintenance, to offer different service packages or maybe even different spare part packages

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Takeback & End-of-Life Strategies

Takeback & End-of-Life Strategies

Readiness of 'Takeback and End-of-Life Strategies' measures the capabilities that will ensure maximised value of end-of-life products.

What are companies doing to ensure that we dont just let the products fall off the cliff into the waste pile? Refurbishing, remanufacturing, looking at the different opportunities we have from a product component and materials perspective.

Policy & Market

Policy & Market

Readiness of 'Policy & Market' measures the external readiness of the legislative frameworks and markets for the development and provision of circular solutions.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

This is very big. Companies need to think if they are ready to understand the policy instruments and that give market opportunities as well. You can follow policy but also push for some change.

Organisation

Organisation

Readiness of 'Organisation' measures the internal business capabilities of your company to be able to implement new concepts, such as the Circular Economy.

Nothing gets changed if the organization isnt behind it. So how ready is the company? If the organizaiton is not behind, it will not last. If it is , then everyone collaborate

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

REALISING CIRCULAR ECONOMY

REQUIRES A SYSTEMIC APPROACH

Simple model for estimating Global Warming Potential

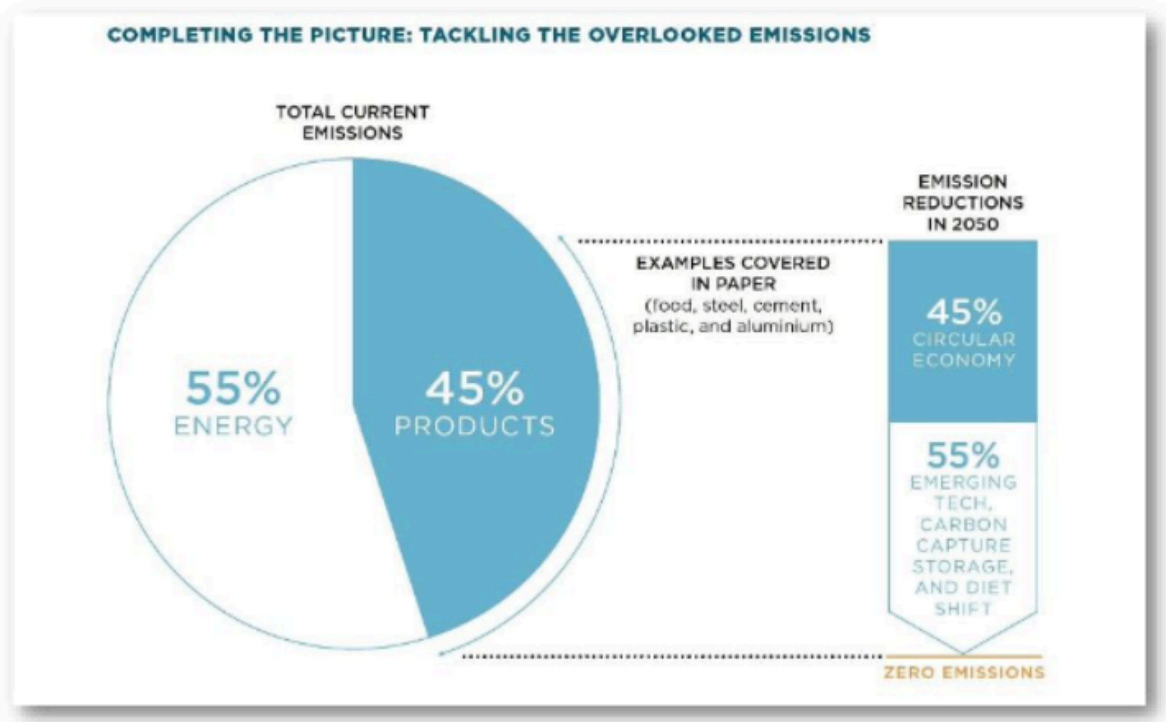
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Different questions to each of the different companies, we just saw product manufacturers

Circularity increasingly recognised as a means to net-zero



What does circular economy actually means from the sustainability perspective?
It has been estimated recently that actually around a half of the climate challenge that we have from the CO2 perspective, can be aided/helped by companies in society, generally taking a circular economy stance. So if we were to transition to a circular economy, we can actually manage to achieve around half of the savings.
So doing well in a circularity perspective, is not just good from a resource perspective but also for the climate challenge.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

In summary

- Consider what type of circularity pattern(s) your project might best be suited to follow: narrowing, slowing, closing, regenerating..?
- Which of the 32 circular strategies could/should you follow? Make a consideration and find a workbook to aid you!
  www.circitnord.com
- How ready do you think you/your case company is to transition to a circular economy? Try it out!
  www.ready2loop.org
- Read the appended articles for deeper theoretical understanding and guidance

Summary:

Planetary boundaries and absolute sustainability

From relative to absolute sustainability

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Why we need to move from a relative to absolute sustainability perspective or at least enhance the relative perspective with an absolute perspective.

The sustainability challenge

$$I = P \cdot A \cdot T = Pop \cdot \frac{GDP}{person} \cdot \frac{I}{GDP}$$

Ehrlich P, Holdren J (1971) Impact of population growth. Science 171, pp. 1212–1217
Commoner B (1972) The environmental cost of economic growth. In Ridker RG (ed.) Population, Resources and the Environment, pp. 339- 63. U.S. Government Printing Office, Washington, DC.
Graedel and Allenby (1995) Industrial ecology. Prentice Hall, New Jersey.

- I is the environmental impact
- Pop is the **global population**
- $\frac{GDP}{person}$ is the **Affluence**, the material standard of living
- $\frac{I}{GDP}$ is the **Technology factor** – environmental impact per created value

IPAT= a way of analysing the environmental impact I as a function of population, affluence of population and the technology factor (that is the environmental intensity of the technology by which we achieve the affluence that we have)
GDP/person is the gross domestic product per person. If you measure affluence like that, technology becomes the impact of GDP.

o if you increase the population by 50%, then the impact will increase by 50%. If you increase the affluence by 20% keeping the rest constant, it will increase 20%. So this is a way to look at the environmental impact

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

The sustainability challenge

$$I = Pop \cdot \frac{GDP}{person} \cdot \frac{I}{GDP}$$

- The global population may level off around 10 billion
- Material standard of living will grow strongly in newly industrialised countries
- The environmental impact already exceeds sustainable levels in many areas
- So what is the challenge?

Global population is growing, GPD per person is going up. We are losing species, climate change, etc. We are impacting too much: I needs to go down, population goes up, GDP per person goes up and that means that the technology factor needs to be reduced. The impact for created value needs to be reduced quite strongly in the decade to come.
To talk about this we use the Eco efficiency term. I defined as the ratio between what we get out of the technology and which environmental impacts it causes.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Eco-efficiency

Eco-efficiency can be defined as the ratio between the functional output and the environmental impacts caused by an activity

$$\textit{Eco-efficiency} = \frac{\textit{Delivered service}}{\textit{Environmental impact}} = 1/T$$

Eco-efficiency is the reciprocal of the technology factor in the IPAT equation

Eco-efficiency is determined with Life cycle assessment, LCA

Eco-efficiency has to grow strongly to achieve the needed reduction in impact with growing population and affluence

M. Hauschild
12100
4

The ecco efficiency is the inverse of the T factor in the IPAT equation. So the Ecoefficiency needs to grow strongly in order to achieve these reductions that we need to see in our environmental impact.
Is that realistic at all?

Simple model for estimating Global Warming Potential

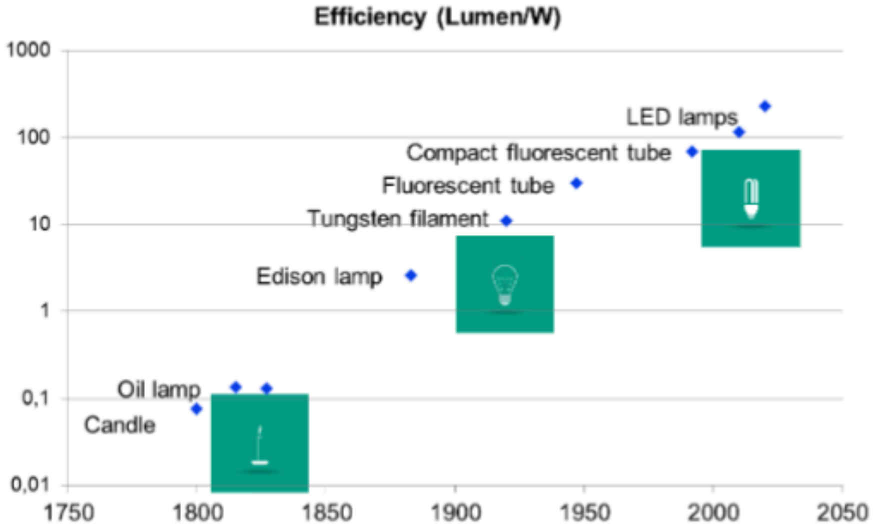
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Developments in efficiency

The example of lighting technology



Franceschini, S (2015) Eco-innovation dynamics and sustainability – new perspectives in innovation studies illuminated through the case of lighting and its energy consumption. PhD thesis DTU Management Engineering, Technical University of Denmark, Lyngby

We had an exponential development in the energy efficiency of a different lighting sources.
Increase in energy efficiency (not ecoefficiency - but they are strongly correlated) of more than 3 orders in magnitude.}
Good potential. Moore's Law: alos related to energy efficience.
But if we check the development in consumption of light:

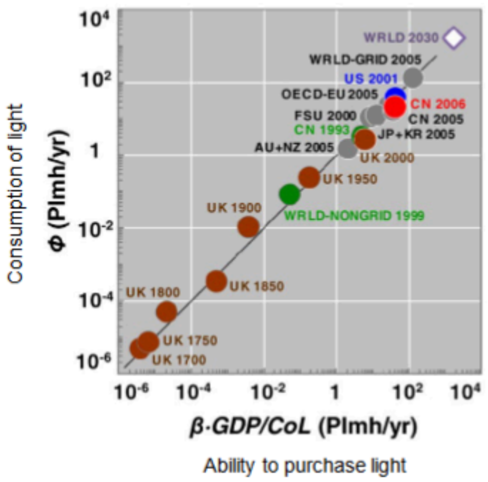
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Development in consumption



"Over the past three centuries, and even now, the world spends about **0.72%** of its GDP on light and **0.54%** of its GDP on the consumption of energy associated with light"

Tsao JY, Saunders HD, Creighton JR, Coltrin ME, Simmons JA (2010) Solid-state lighting: an energy-economics perspective. J. Phys.D: Appl. Phys. 43, 354001 (17p)

This is strange: efficiency in lightning sources had gone up by 3 orders of magnitude in the same period..so we would have expected that this would lead to a reduced spending on light. But we see that it grows dramatically out use of light. So the increase of ecoefficiency, so the efficiency in terms of environmental impact by which we achieve our services, our functions, does not translate into the overall picture. This is the rebound effect: increased efficiency in the technology, may actually translate into more consumption.
The problem is that when technology goes down, it may actually trigger the affluence to go up, so you need further reductions in the T factor. So E and T in the IPAT equation are not necessarily independent (they may debut in many cases not).
So it is insufficient to take the perspective that life cycle assessment gives us. The LCA supports the relative assessments of renewables sustainability. " Is it more sustainable to go

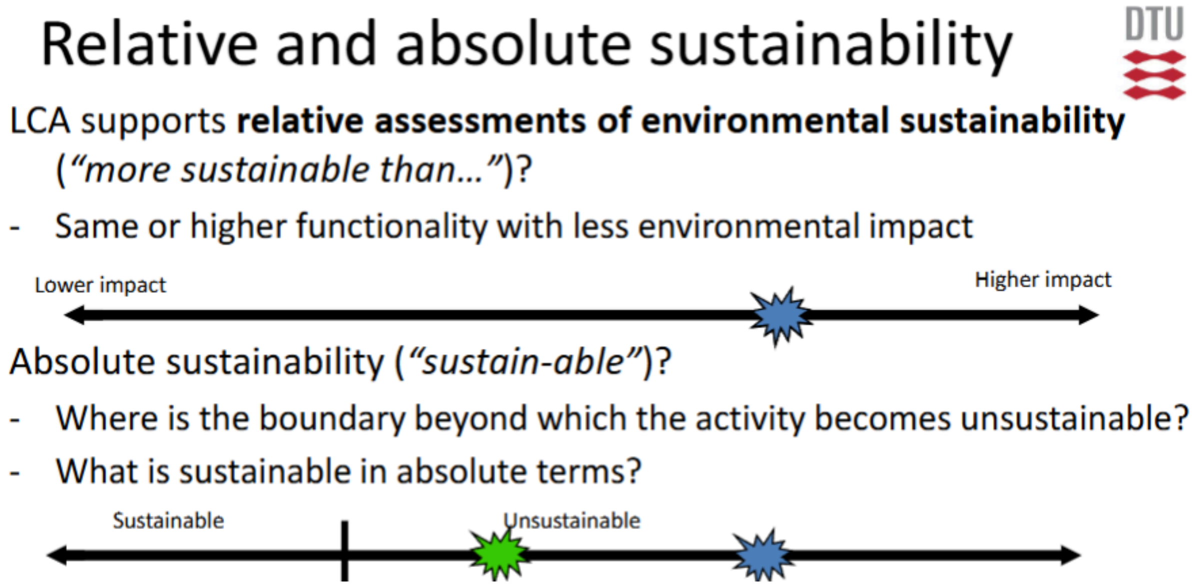
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

by a bike or a car? But it doesnt tell where it is sustainable!



Where is the boundary to say its sustainable or not? We need to talk in absolute terms!! We need to know where is the limit beyond which it becomes unsustainable. How can we find

Simple model for estimating Global Warming Potential

DTU Wind Energy

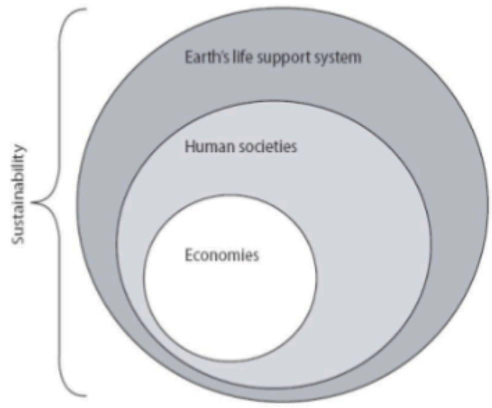
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

that limit?

A sustainable level of impact?

- Sustainability: Fulfilment of needs
  - Today and in the future
  - Which needs?
  - How to fulfil them?
  - For how many?
- Planetary boundaries
  - Top-down prescription of sustainable level of impact



M. Hauschild
12100
8

When we often talk about sustainability: meeting the needs of the present without compromising the ability of future generations to meet their own needs. But what is not very clear is what needs are needed? Maslow needs: nutrition, water, shelter, etc. But then there are more higher levels of needs: love, self fulfilment, etc. So what needs are we talking about when we talk about meeting the needs of the present and the future and at what levels should this be met? Is a very clear concept, but a very imprecise definition of what is sustainable.

So if we want something more concrete, we should look into biophysical limits of the ecosystem, of the climate system on which our well-functioning society depends. So this is a view on the 3 dimensions of sustainability that looks like this:

- Economy: is not a goal in itself when you are a society, the economy is a means. If you have a strong economy, you can achieve things, you can do things.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

- Human dimension: is encapsulated inside earths' life support system: we need it in order to support our lives and this is why we want to protect it. Humans need to respect the limits of the planet!

And this is the idea of absolute sustainability: lets take a top down approach- NOT the bottom up approach. Dont say which needs do I have and which are reasonable to feel, etc. Instead: what are the limits that whatever level of needs fulfilment we aim for, we neeed to stay inside!

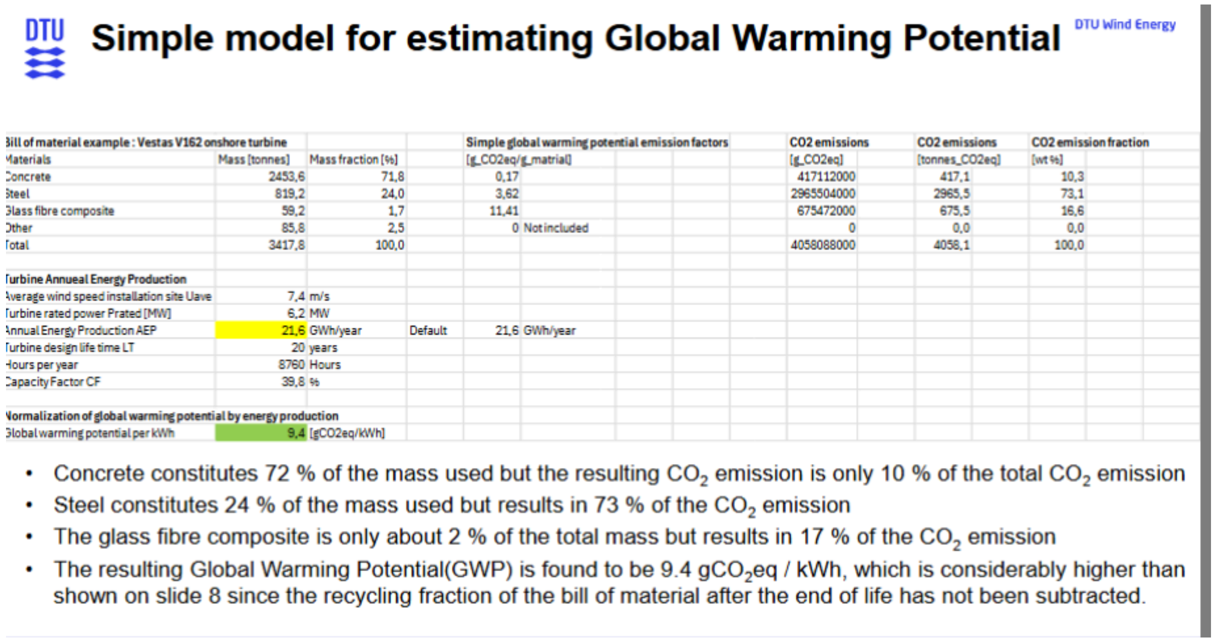
Summarizing
• Eco-efficiency is the ratio between created value and caused environmental impact
• Sustainability requires strong improvements in eco-efficiency
• Our current focus on eco-efficiency must be informed by an absolute sustainability perspective to ensure that solutions are also eco-effectiv

We need to inform it by an absolute sustainability perspective to know not just that we are doing things better, but also how far we need to move before we can call it sustainable. And this is something we can call eco effectiveness. So we need to have the absolute sustainability perspective to ensure that the solutions that we develop are also eccoeffective or have the potential to become so.

How can we do the absolute sustainability: one approach: Planetary Bounderies approach.

Planetary boundaries and absolute sustainability

So we already see that we need to take a top down approach based on the tolerance levels or carrying capacity of our natural capacity or of our climate system when we want to define what is sustainable in absolute terms.
One approach: planetary boundaries approach,



DTU Wind Energy

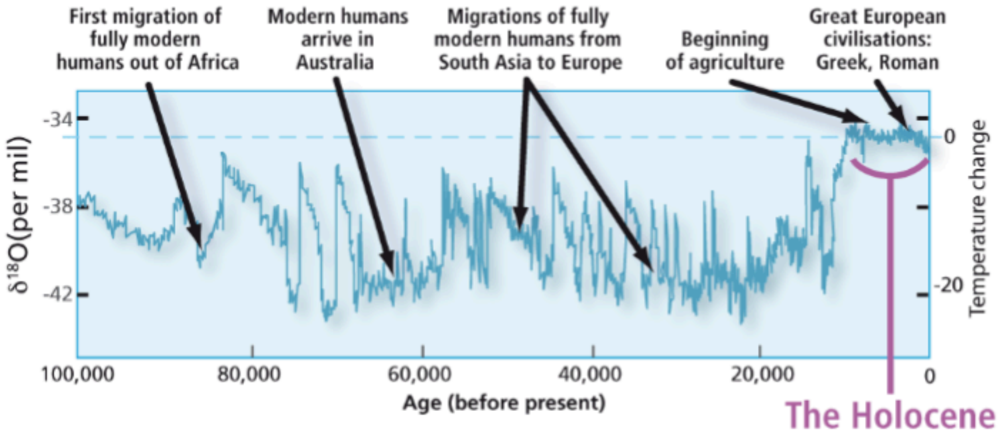
Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

The sustainability challenge

Keeping the planet in the holocene



International Geosphere Biosphere Programme
http://www.igbp.net/globalchange/anthropocene.4.1b8ae20512db692f2a680009238.html

M. Hauschild
12100
2

The planetary boundaries approach starts by taking a point in the curve, The curve shows the development in the average temperature of the atmosphere from 100k years compared to the present. Present is 0. So if we see are below the zero, we see that its been colder than it is today.
On the left y axis, we can see the fraction of oxygen 18 isotope. This is how temperature has been measured across time (ice cores). So we know how
We can see that it is a very strongly fluctuating graph, the temperature of the atmosphere has changed up to 15, nearly 20 degrees within a century. Thisis very dramatic. Particularly, the holocene (after ice age), it has been remarkably stable. Above the graph, we see different spots in evolution and modern human across the planet.
After the beginning of agriculture: is able to produce a surplus that allows you to develop civilisation so people become residential, they stay the same place. Now is easier to survive. Huge growth in human population.
The outlier period is the holocene, is very unusual that the temperature is so stable. And this is what allowed us to grow as species in numbers.

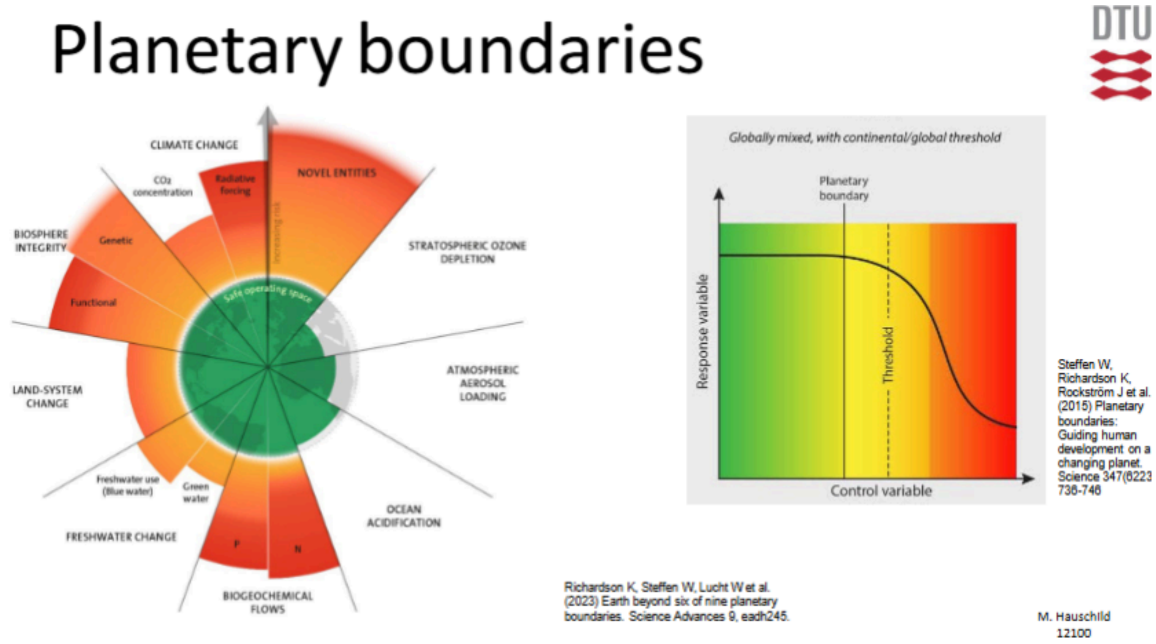
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Researchers ask: what are these processes that ensure the stability of the climate that we are experiencing now? Whys is so stable?
They identifies 9 different earth system processes that they think are influential here.



* Climate change
* Biosphere integrity: species, ecosystems, etc
* Use land
* Use water

9 process in total. And for each of them, they hypothesis a model that could look like that. X axis: control variable, which reflects the pressure that we put on that earth system process at the moment, measured by some appropriate indicator. And on the Y axis, you have the response, the environmental response of what happens to this process.
Resilience is in the beginning: green zone: if you increase your pressure, if you increase your control variable, nothing really happens. Until you pass a threshold (yellow zone), after there is a dramatic response.
If we are talking about climate change, the control variable that they suggest could be the concentration of carbon dioxide in the atmosphere. You can increase the concentration of

DTU

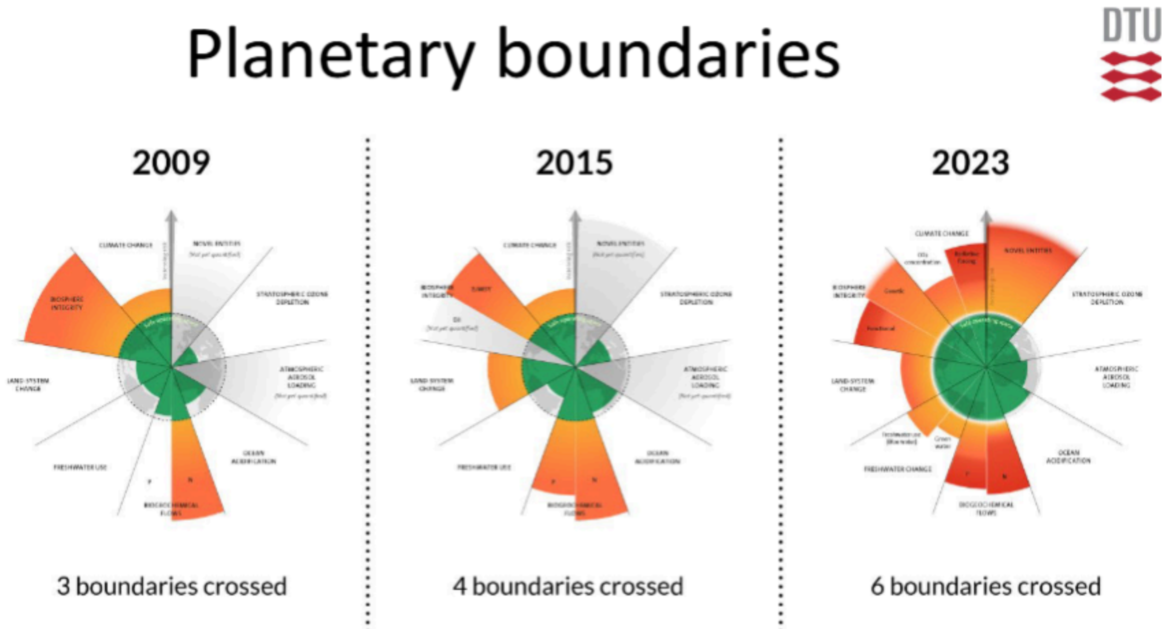
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

CO2 in the atmosphere, but there are tipping points, if we exceed them, we will see feedback loops to have more stronger impacts
The problem is we dont know exactly where the threshold is. The yellow zone around the threshold is the The uncertainty zone.
This group, also defined the planetary boundary for this impact, at the lower bond of the uncertainty range around the threshold. So if we are below the planetary boundary, if the control variable is below the planetary boundary, we are pretty sure that we have not crossed it. But the moment we move across the planetary boundary into the yellow zone, there is an increasing risk that we pass the threshold. And when we are in the red we know we have passed it.



Some of them are crossed severely, some of them are orange. It doesnt mean that the climate system collapses but that we haven a larger ristk that we will see dramatic and irreversible changes in the functioning of the climate regulation system (which is the focus of the planetary boundaries).

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

And it is also important to remember that these are earth system processes that are represented in the boudndaries, influence each other. So the more of them we exceed, the bigger the risk that we will see and instability of climate system and have a very unstable climate.

Now based on this kind of thinking and the arguments around a need for an absolute perspective on sustainability, we define absolute sustainability, paraphrasing the Brunland comissions definition as :

Absolute sustainability: Meeting the needs of present and future generations within the biophysical boundaries of our climate and ecosystems – within the safe operating space

safe operating space(green zone: as long as we are below the boundary, we are within the safe operating space)

This was all about environmental sustainability. But what about the social and economic dimension?

Absolute boundaries for social sustainability?
• Social science and natural science
• What is for negotiation

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Donut model: green ring and on the outer ring you have the planetary boundaries or other measures of biophysical limits that we need our pressure in the environment to respect. So they are the outer boundary - we should not exceed the ecological ceiling in the way we meet human needs.
So in order to be abstolute sustainable environmentally speaking, we have to be inside the outer rim of the donut.On the other hand, we have a lot of different social needs (fundamental, higher levels, etc). There is a minimum level that is acceptable at least for this, for the physiological needs, is quite clear what it is for some of the other needs is more of a negotiation. So the question is , where is the social foundation, the inner ring for the social? And this is for negotiation.
So the tipping points for the planet are there, is not a negotiation. But for the social, then there is a negotiation

Summarizing

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

• Planetary boundaries are limits for our pressure on earth system processes that ensure climate stability
• They cover many types of environmental impact but at the core are climate change and biosphere integrity
• Absolute sustainability is meeting the needs of present and future generations while respecting the Planet's biophysical boundaries

We have defined the meaning of absolute sustainability… but now how we measure it?

Absolute environmental sustainability assessment (AESA) for assessing absolute environmental sustainability

AESA: is absolute sustainability assessment

Performing AESA

• 1st step: Identify biophysical boundaries and determine safe operating spaces. " If this are the limits, what is the safe operating space? What is the current level of impact" How much can we exceed or how much we need to reduce?
To do so: we can use PBs or LCIA

In life cycle impact assessment (left) we model the product system and processes and get the emissions that go out and then we translate them to a range of different impact categories.
On the right: planetary boundaries: processes that are considered for stability of the climate and ufnctioning of the earth system processes. So how we do it?

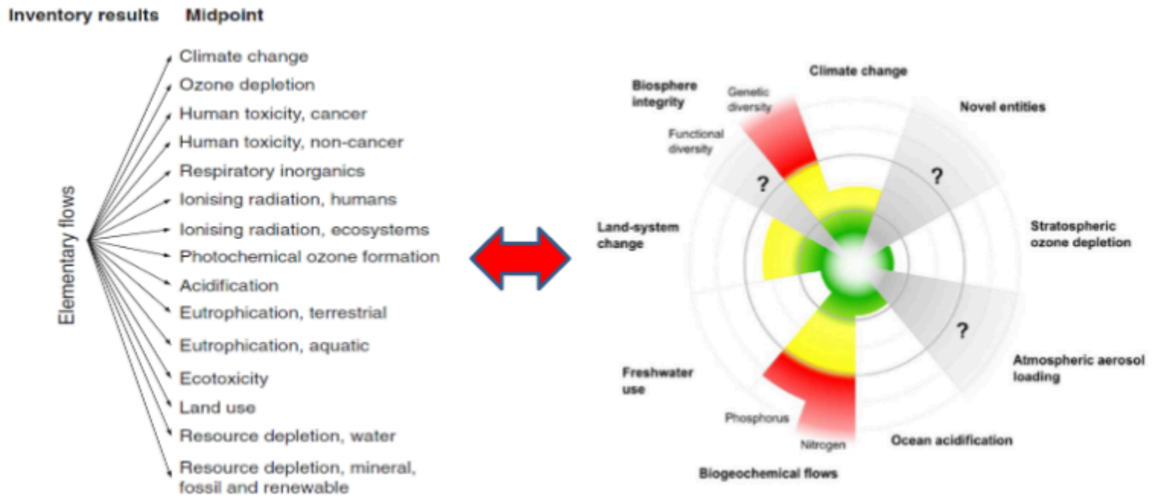
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Where is the boundary?



ILCD recommended characterization models (Hauschild et al. 2013)

Basically, LCA: we have the midpoints that have been identified with environmental concerns, problems, potentially contributing the areas of protection (human health, natural resources, etc)
If we do the same for planet boundaries, is a less systematic approach. But we see yellow boxes: define control variables.

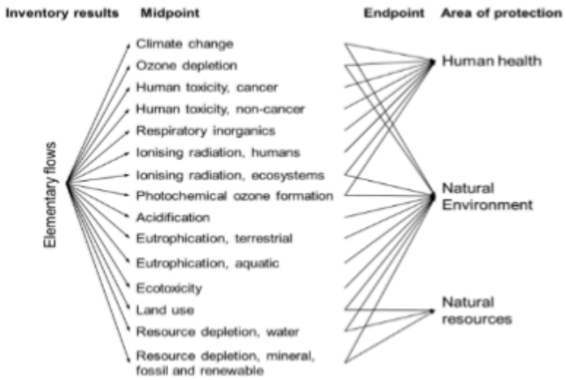
Simple model for estimating Global Warming Potential

DTU Wind Energy

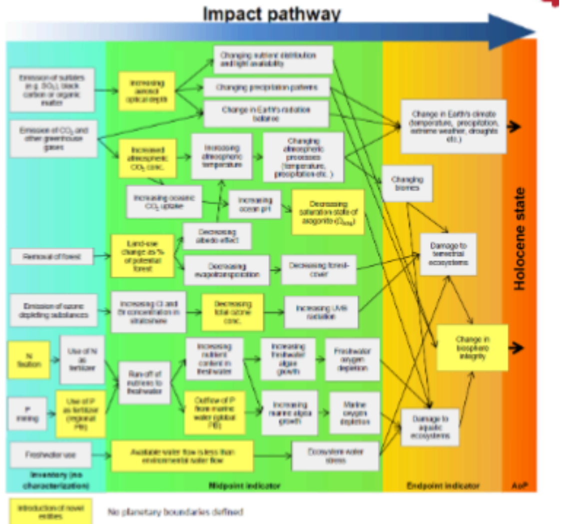
Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Planetary Boundaries and LCIA



Hauschild MZ, Goedkoop M, Guinée J, Heijungs R, Huijbregts M, Jolliet O, Margni M, De Schryver A, Humbert S, Laurent A, Sala S, Pant, R (2014) Identifying best existing practice for characterization modelling in Life Cycle Impact Assessment. Int J Life Cycle Assess 18(3), 683-697



Ryberg M, Owsianiak M, Richardson K, Hauschild MZ (2016) Challenges in implementing a Planetary Boundaries based Life-Cycle Impact Assessment Methodology. Journal of Cleaner Production 139, 450-459.

M. Hauschild
12100

Performing AESA
• Identify biophysical boundaries and determine safe operating spaces
– PBs or LCIA
Now we know what our total impacts have to respect. If we want to be sustainable in absolute terms, we need to respect the biophysical limits. How do we share this safe operating space between the activities we have for everybotdy (healthm food, transport, etc for everybody)

• Allocate the safe operating space to different activities

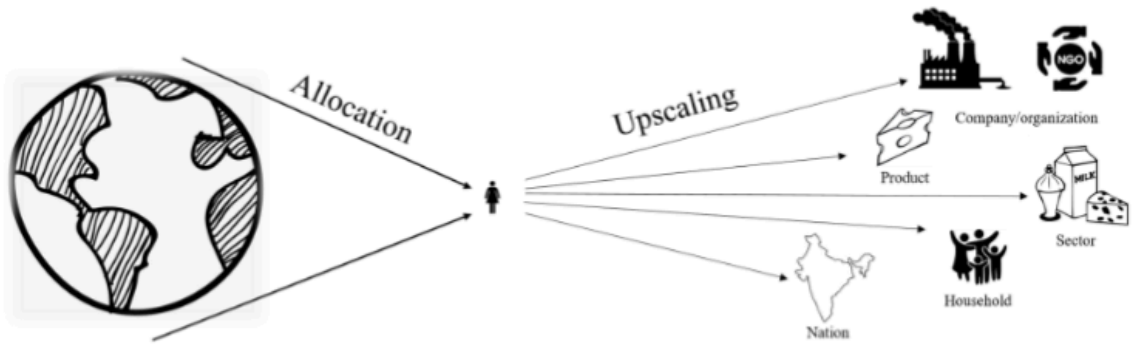
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Allocating the operating space



Hjalsted AW, Laurent A, Andersen MM, Olsen KH, Ryberg M, Hauschild MZ (2021) Sharing the safe operating space: Exploring ethical allocation principles to operationalize the planetary boundaries and assess absolute sustainability at individual and industrial sector levels. Journal of Industrial Ecology 25(1) 6-19, https://doi.org/10.1111/jiec.13050.

We have a global perspective that gives us a safe operating space. And we need to allocate that to an individual, so we share between us. And then we can upscale it again to different levels: industries, countries, products, etc

There are different principles for doing this allocation.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Allocating the operating space

Name	Description	Ethical norm (tentative)
Equal per capita (EPC)	Assigned share is the same for all individuals	Egalitarian
Capability to reduce (CR)	Assigned share is negatively correlated with a region's gross domestic product per capita	Prioritarian
Historical debt (HD)	Assigned share is negatively correlated with a region's cumulative environmental impact per capita	Prioritarian

* EPC: take the global safe operating space and divide it between the people in the planet (people that need to share it). We are all equal, we get the same share. But there are parts that needs are being met at a very high level, and other parts where infrastructure has not yet been developed. So maybe we need to divide the space unequally if we want to be fair.

CR: some countries have a better possibility, are more prepared than others. Some sectors in society and can reduce more. You assign a share that is negatively correlated with your GDP. So the wealthy nations have a higher capability to reduce, and therefore they have to reduce more.
Historical debt: you assign a share that is negatively correlated with what you have caused.

The most frequently used is grandfathering:

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Allocating the operating space

Name	Description	Ethical norm (tentative)
Grandfathering (GF)	Assigned share is proportional with environmental impact in a reference year	Inegalitarian
Economic value added (EVA)	Assigned share is proportional to economic value added	Utilitarian
Cost efficiency (CE)	Assigned share is inversely proportional with the cost of reducing environmental impact of production	Utilitarian
Final consumption expenditure (FCE)	Assigned share is proportional with final consumption expenditure	Utilitarian

Bjørn A, Chandrakumar C, Boulay A-M, Doka G, Fang K, Gondran N, Hauschild MZ, Kerkhof A, King H, Margni M, Mclaren S, Mueller C, Owsianiak M, Peters G, Roos S, Sala S, Sandin G, Sim S, Vargas-Gonzalez M, Ryberg M (2020) Review of life-cycle based methods for absolute environmental sustainability assessment. Environ. Res. Lett. 15, 083001

M. Hauschild
12100
8

ey get smaller space per capita. You prioritize some sectors.

GF: if we have to reduce global impacts by 50% for climate change, everyone has to reduce it by 50%. We are not treated equally. New activities that dont have a print today, they wont get it in the futer

Economically based criterias: FCE: we assign share to different activities proportionally to what we expend on them. Expensive goods get a higher operating space than less expensive goods in this case. Problem: you might expend less money in things that are very important

FCE and GF are the mostly used because they are simple yo apply and have some relevance. But they also have some problems.

Performing AESA

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

• Identify biophysical boundaries and determine
safe operating spaces
– PBs or LCIA
• Allocate the safe operating space to different activities
• Calculate the impact profile of the activity using LCA: what are the impacts of doing this
• Compare impact and allocated space: if impact of the activity is less than the allocated space, then the activity iss done in an absolute sustainable way. If it is larger, then is not sustainable. And the ratio between the impact and the allocated space is what we call the absolute environmental sustainability ratio.

Planetary Boundaries-based LCI

Science of the Total Environment
journal homepage: www.elsevier.com/locate/scitotenv

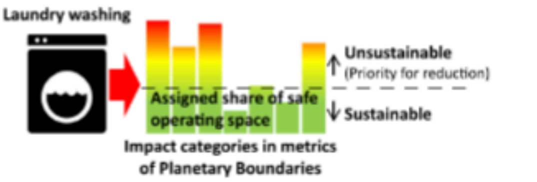
How to bring absolute sustainability into decision-making: An industry case study using a Planetary Boundary-based methodology

Morten W. Ryberg[a,*], Mikołaj Owsianiak[a], Julie Clavreul[b], Carina Mueller[b], Sarah Sim[b], Henry King[b], Michael Z. Hauschild[a]

HIGHLIGHTS

• Applied novel Planetary Boundaries based LCIA methodology in case study
• Characterized impacts in metrics of the Planetary Boundaries
• Assessed absolute sustainability of activity relative to Planetary Boundaries
• Assignment of safe operating space found to be largest source of uncertainty
• Allowed for quantifying impact reductions required to be absolutely sustainable

GRAPHICAL ABSTRACT



Laundry washing in europe: is it sustainable?

Summarizing
• Absolute environmental sustainability assessment, AESA,

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

• Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
• Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
• The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
• The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

builds on LCA
• AESA relates environmental impacts to the assigned operating space to measure whether an activity is sustainable or not
• AESA covers all relevant environmental impacts

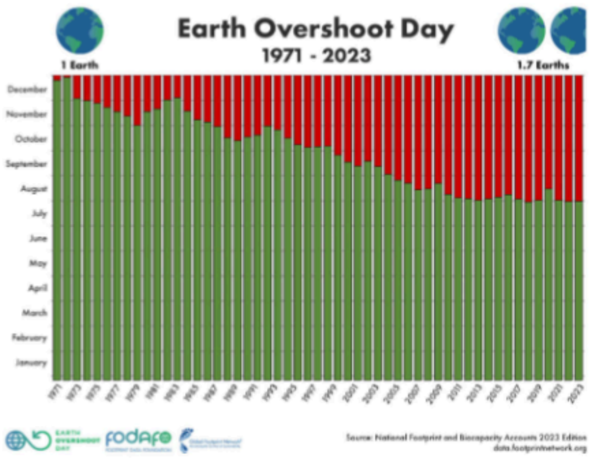
Examples of other absolute sustainability metrics

Ecological footprint: if we think of the day where our accumulated impact or use of resources exceeds the total annual impact that we can have, total annual resource use that is the Global Earth Overshoot Day.

DTU

Ecological footprint

- Focus on land use and CO_2 emissions
- Life cycle perspective
- Product footprints and national footprints
- Earth overshoot day
  - 2015: 7 August
  - 2016: 9 August
  - 2017: 5 August
  - 2018: 1 August
  - 2019: 3 August
  - 2020: 16 August!
  - 2021: 3 August
  - 2022: 1 August
  - 2023: 2 August



M. Hauschild
12100

It represents ofr a nation, the area of land that is used to meet the consumption needs of that country. For producing everything needed to meet the consumption of the country. The other part of the ecological footprint is the area of land that would have to be planted with forests in order to sequester and bind the carbon dioxide emissions that are caused to the atmosphere as a consequence of the consumption of that country.

DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

So this is real landuse and hypothetical land use (that we would need to plant in order to keep the CO2 emissions stable).

The ecological footprint allow as to define the earth overshoot day: it is the day of the year where our accumulate ecological footprint day by day, where we sum that up.
Earth overshoot day is the day of the year where the accumulated ecological footprint exceeds the area that i there (everything that we have).

Country overshoot day: day in which the total area would be used if everyone lived as the inhabitants do in that country.

Another method: The Science Based Targets Initiative (SBTi)
• organization SBTi established in 2015
• "…in line with what the latest climate science says is necessary to meet the goals of the Paris Agreement—to limit global warming to well-below 2°C above pre-industrial levels and pursue efforts to limit warming to 1.5°C.

A company needs to set this to be allowed to claim that is following the science based targets initiative. Is for companies to go in and take their share of the reductions that what we need to undertake in order to comply with the goals of the paris agreement to limit global warming

there are 5 steps that a company needs to do in order to join the science based targets initiative:

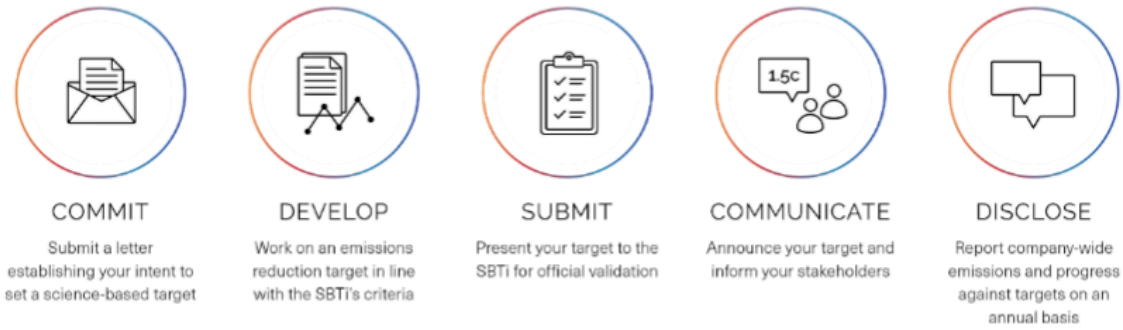
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Five steps



Develop targets for your company. You quantify what are your impacts

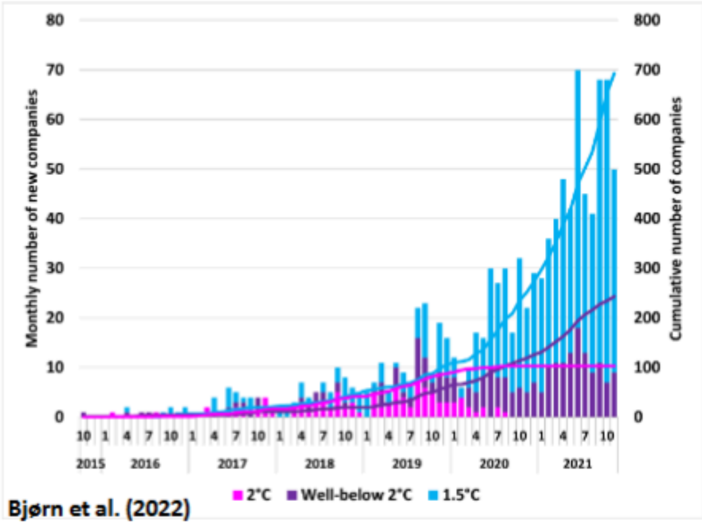
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Rapidly growing



It is growing

What is important when we are talking about this kind of target setting is to identify the scopes. So the science based targets is building on the greenhouse gas protocol. Where they operate with 3 scores:
1- Your own greenhouse gas emissions (emissions that are caused at your facility)
2- specifically focused on the energy that you buy. If you buy electricity, that electricity may have caused emission of greenhouse gases and then that is your scope to emissions. The green house gases that have been caused by the electricity or heat or whatever you have bought from external suppliers
3- Basically the rest of the life cycle: stuff that you buy, the commodities you buy as company, and also the products that you sell and what impact they have in the rest of their life cycle.

Simple model for estimating Global Warming Potential

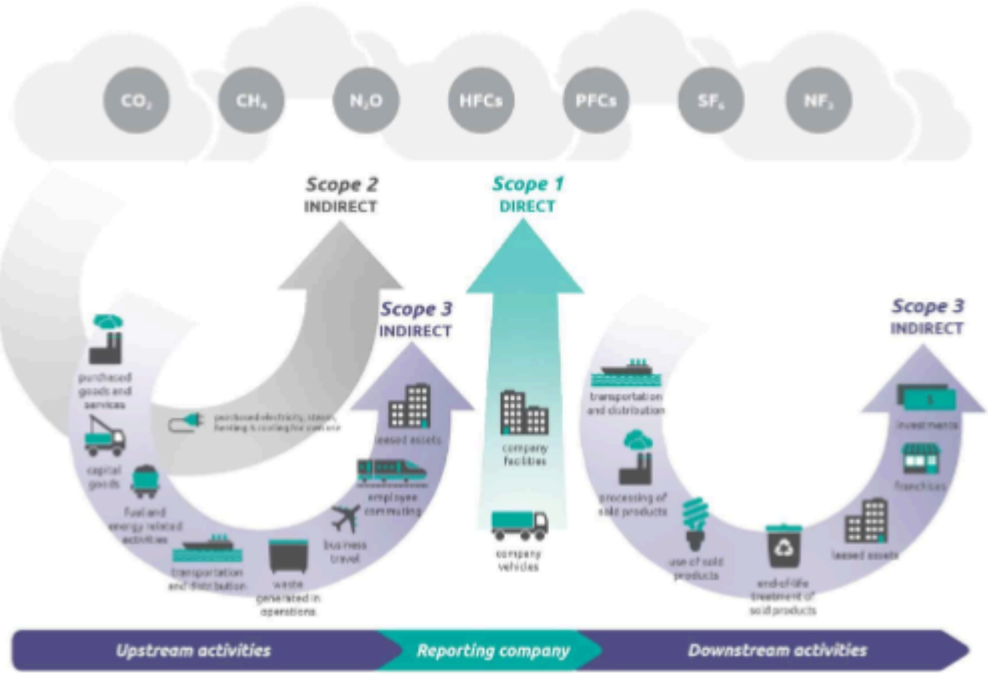
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

So together, they the 3 scopes are the full life cycle of the products that you as a company produce., but with the specific focus that is relevant for climate change

The three scopes



Simple model for estimating Global Warming Potential

DTU

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Setting targets

- Science-based, i.e. in accordance with the Paris agreement's 1.5 or well below 2.0 degree scenario
  - Sectoral approach
  - Absolute contraction approach (grandfathering)
  - 95% of scope 1 and 2
  - Min. 67% of scope 3 (if it is more than 40% of total emissions)
- Absolute or intensity depending on sector
- Short term (5-10 years)
  - Min. 4.2% linear annual contraction
- and long term (2050 or sooner)
  - 90% reduction

When setting targets, what is on your scope?
How do we allocate the total space that is within the emission allowances that are in accordance with the paris agreement as we move ahead. There are sectoral approaches. scopes 1 and 2 are easy to determine for the company, but 3 is more difficult because they depend more on the external suppliers.
Are we looking to absolute impacts or intensities? Intensity is what is represented by the eco efficiency.Intensity is emissions per product per delivered service. Whereas absolute is total emissions. This difference is important because if as a company grows, you sell more and more, if you have an intensity approach, then your products need to get better, but overall your impact may go up, because your growth in sales volumes exceeds your reduction in impact per product
but if you have an absolute approach: is you have a space or allowance as a company, then you need in total not to emit more than this. And then is very challenging if you have growth in your sales, because it does not increase your space. You have same space, so the more you grow the more you have to reduce the emission per product.

It is not enough to reduce intensity if you dont have the sales volume perspective in

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Two examples

Coca-Cola European Partners commits to reduce absolute scope 1, 2 and 3 GHG emissions 30% by 2030 from a 2019 base year. Within that target, Coca-Cola European Partners commits to reduce absolute scope 1 and 2 GHG emissions 47% by 2030 from a 2019 base year and reduce absolute scope 3 GHG emissions 29% by 2030 from a 2019 base year.

HeidelbergCement commits to reduce scope 1 GHG emissions 22% per ton of cementitious materials by 2030 from a 2016 base year. HeidelbergCement also commits to reduce scope 2 GHG emissions 65% per ton of cementitious materials within the same timeframe.* *The target boundary includes biogenic emissions and removals associated with the use of bioenergy.

Differences in:

- Base year
- Target year
- Targeted reduction
- Absolute/intensity
- Emission scope

Companies have liberties to define their targets.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Summarizing

Absolute sustainability metrics

- relate performance to a target that is based on environmental limits
  - stability of the climate system
  - available area of land
- inform about the size of improvements that are needed to achieve the target
- shift the focus from efficiency to effectiveness
  - from ”better” in the relative assessments
  - … to ”good enough” in the absolute assessments

M. Hauschild
12100
10

Absolute sustainability metrics
• relate performance to a target that is based on environmental
limits. Examples:
– stability of the climate system
– available area of land
• inform the company and user about the size of improvements that are needed to achieve the target. Not just if some practice is better, but if its sufficiently much better.
• shift the focus from efficiency to effectivenes. From doing the hings right, to doing the right things. So from the better in the relative assessments to the good enough in the absolute assessments.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

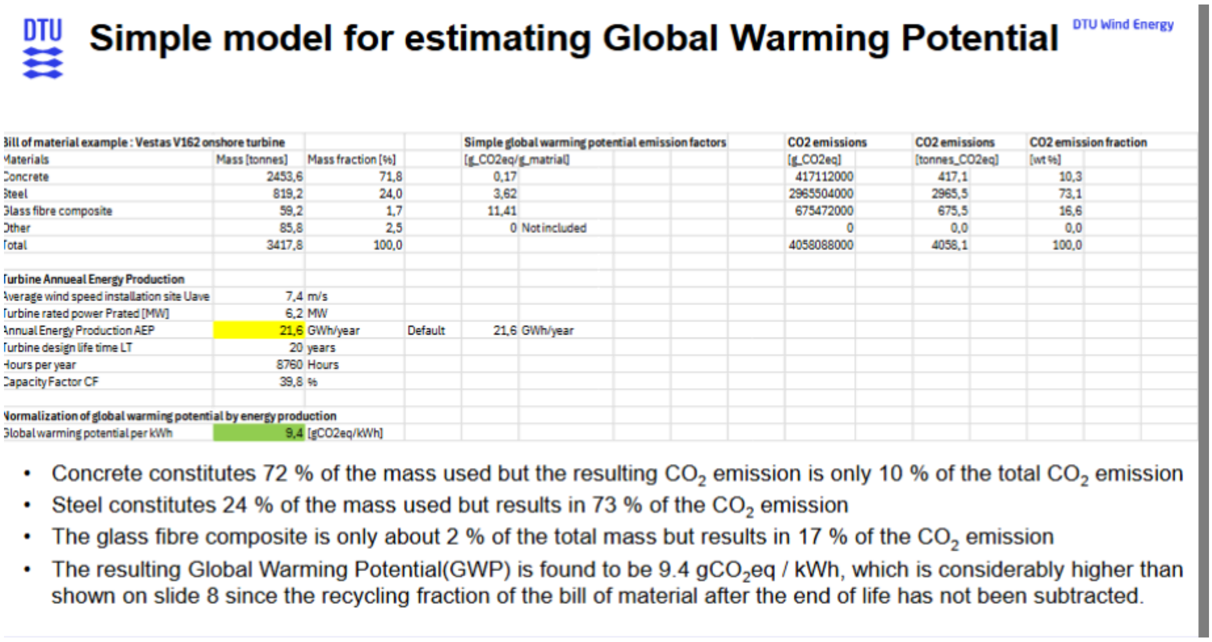
Energy systems and transition/decarbonisation

This module will focus on the impact of electricity production on the world emissions by reviewing the life cycle assessment (LCA) emissions reported by the United Nations (UN) on electricity producing technologies in the report [Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources (2022)].

These emissions should be considered as reference levels and one can determine the resulting emission from a country or a region by the electricity producing technology mix and the energy consumption of the county or region. A method for estimating the resulting global emission is proposed and ["Planetary CO2 boundary - Electricity Technology Mix"] is provided to apply the method. The Global Warming Potential (gCO_2e/kWh) estimated by the electricity technology mix is compared to the planetary boundary as specified by the UN global warming scenario of a 1.5 or 2.0 degree global temperature increase by end of 2100.

Finally Decarbonization strategies of changes to the electricity technology mix of the world and Denmark scaled to global production are evaluated and discussed. You are encouraged to propose your own decarbonizing strategies and investigate if the planetary boundary of Global Warming Potential is violated.

[Decarbonizing energy systems]



Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

How do we investigate the consequence that a technology makes in the electricity system in terms of CO2 emissions and climate change.

DTU

Outline of Decarbonizing energy systems

The intention of the module "Decarbonizing the energy systems" in the course Quantitative Sustainability is to enable the student to calculate the resulting Global Warming Potential emission from electricity production given a specific technology mix of a country or region. By scaling up the emission to the equivalent global emission one can compare the CO_2 emission to the global planetary boundary as dictated by the Paris agreement of a 1.5 degree global warming limit. The students will then be able to determine if a future electricity mix will violate the global planetary boundary of the Global Warming Potential.

Since there is a trend towards electrification of the energy system, then the focus of the module is on the electricity part of the energy system and especially the renewable energy technologies.

The following lectures are provided as part of the module

- Lecture 1 Decarbonizing the energy system
- Lecture 2 Wind Energy as case
- Lecture 3 Violation of planetary boundary of Global Warming Potential due to electricity mix

Electricity fraction of energy consumption
As we move along the years, we expect that a larger part of the energy consumption of the planet is covered by electricity and we also expect that a larger fraction of the technologies used for making electricity will be of low emission types.
About 50% of all energy will be covered by electricity. Above 100% this electricity should be generated by a low emission technology.

The different technologies for electricity production are various:
Fuel based
• Coal
• Gas
• Biomass
• Nuclear

DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

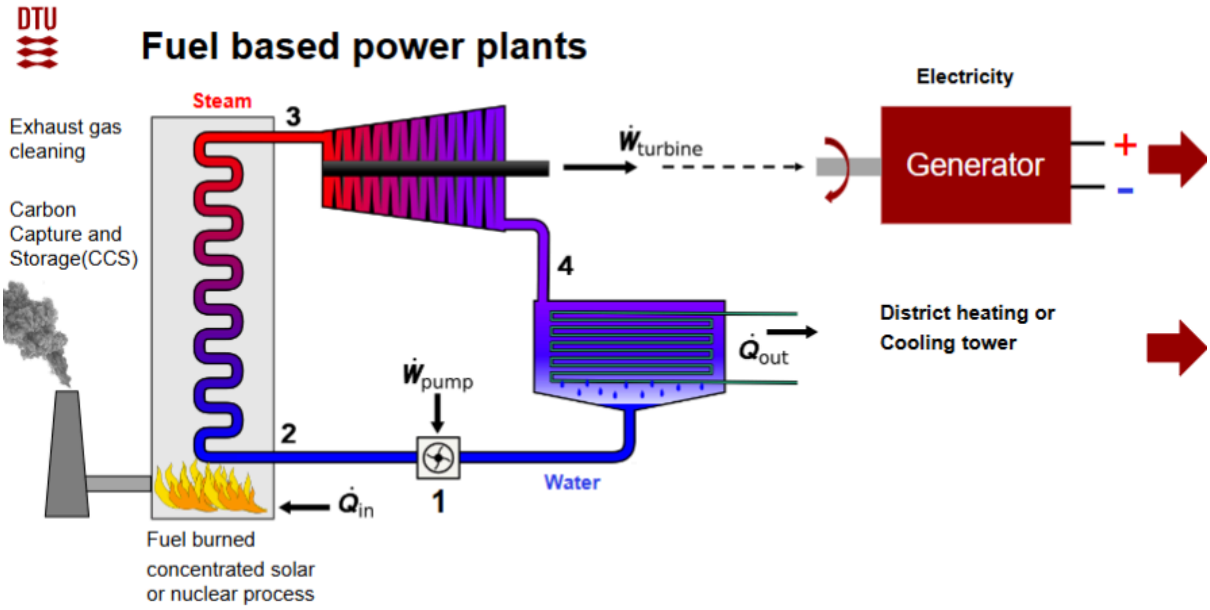
Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Renewables

- Wind
- Solar
- Hydro
- Tidal
- Geotherma

This is a very general schematic on how fuel based powe plant works:



1: Pump **2**: Boiler **3**: turbine **4**: condenser

Source: Rankine cycle (Wikimedia.org)

Some water is circulating, the water is heated up by burning some sort of fuel. The water gets hot and converts to steem, the steem can then move a generator and the generator can convert kinetic energy into electric energy. The water is cooled down and the steem is turned back into water, and we can use this as cooling or heating to other systems. But this is basically how they fuel plants operate. Nuclear processes can also be used to heat up the water.

DTU Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Burning fuels causes CO_2 emissions

Coal	C	$+ O_2$	$\rightarrow$	CO_2		+ Heat +
Methane	CH_4	$+ O_2$	$\rightarrow$	CO_2	$+ H_2O$	+ Heat +
Oil	C_xH_y	$+ O_2$	$\rightarrow$	CO_2	$+ H_2O$	+ Heat +
Wood	$C_6H_{12}O_6$	$+ O_2$	$\rightarrow$	CO_2	$+ H_2O$	+ Heat +
Plastic (PET)	$C_{10}H_8O_4$	$+ O_2$	$\rightarrow$	CO_2	$+ H_2O$	+ Heat +
Hydrogen	H_2	$+ O_2$	$\rightarrow$		H_2O	+ Heat +
Ammonia	NH_3	$+ O_2$	$\rightarrow$	NO_x	$+ H_2O$	+ Heat +
Fission	^{238}U		$\rightarrow$	$^{234}U + \ldots$	+ Neutrons	+ Heat
Fusion	${}^2_1D + {}^3_1T$		$\rightarrow$	${}^4_2He$	+ Neutron	+ Heat

Remember that burning fuels in air will also include nitrogen and some sulfer, whereby NO_X and SOx can result

$$C + O_2 + N_2 \rightarrow CO_2 + NO_X$$
$$C + S_2 + O_2 \rightarrow CO_2 + SO_X$$

Note : Chemical formula not balanced for simplicity

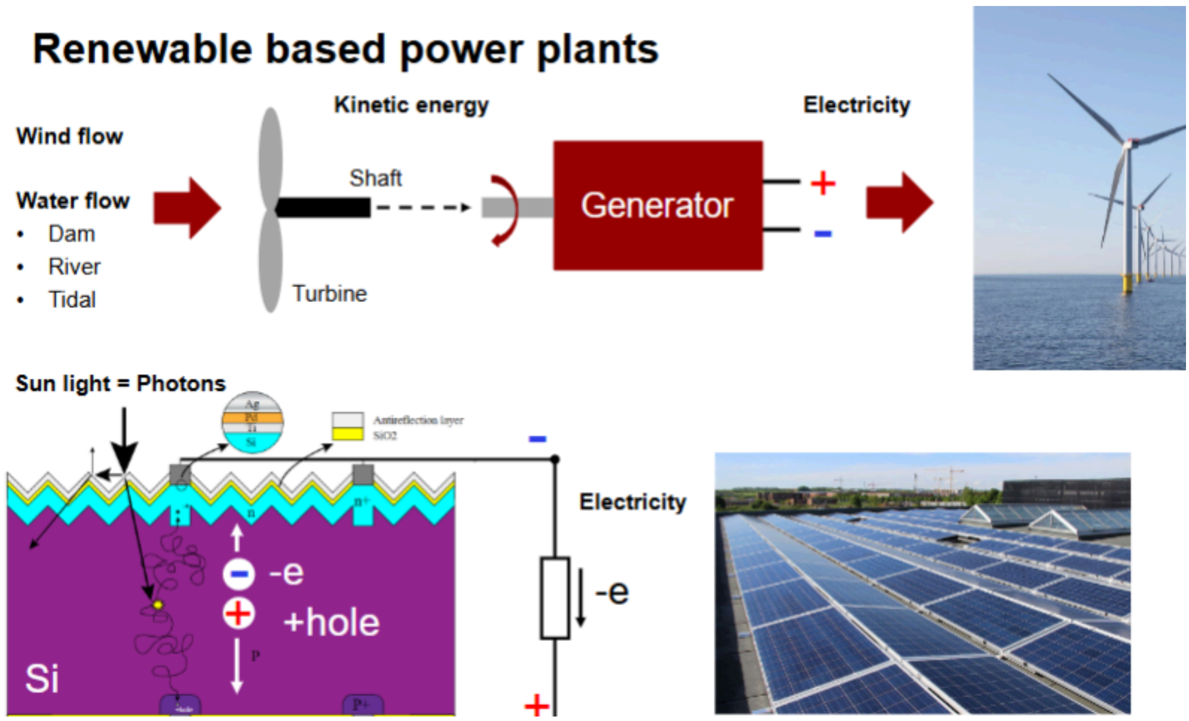
We can take the fuel and the burning process makes this to react with O2. We end up generating CO2 in many of the cases.
H2 as fuel: not CO2, Ammonia as well (probelm: nitrogens as well), etc
All of these processes could be use in the fuel plant that we saw but the problem is that we usually have co2, no oxides and sulfur oxides that are pollutants.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



Most of them are either based on wind or flow or water. Kinetic energy into electric energy that can then go into the grid

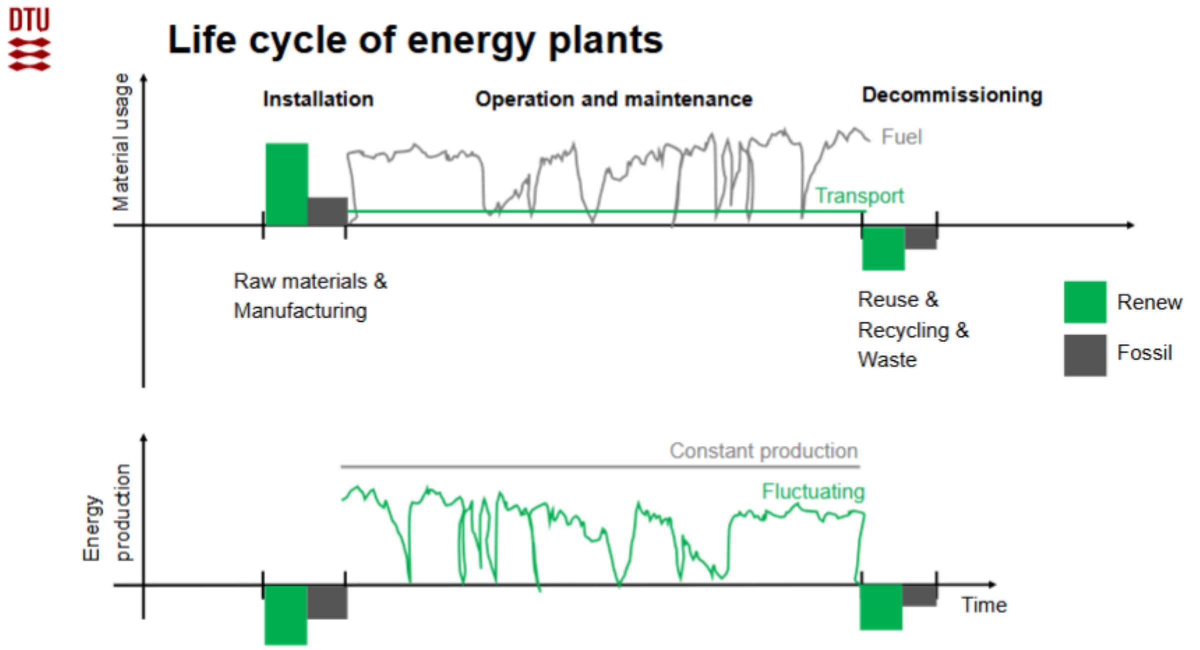
Solar panels: silicon as waver: if photon goes through top layer, it can create electron inside the silicon. The electron can move to one side and hole to another side, so we will get a current flow and if we put a resistor: we can convert light into electricity.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



The material usage vs time. For renewable we install a lot of equipment at the beginning, and then we staart operating the system. The fossil fuel plant is not using that many materials in the beginning because they are relying in feeding in fuel to the plant when it operates.
For the renewable, for the maintenance and operational phase, we may have uses and materials for transport, but for the fuel based power plant,we will be feeding up material we want to keep the production. When we go to energy production:

- Use quite a lot of energy to produce the renewable sources
- For the fossil fuell sources, we will not be using a lot of energy resources.

The advantage of the fossil fuel powerplants is that they have a constant production, and the renewable sources will rather have a very fluctuating production (only when wind is blowing or sun is heating).
When it comes to the decommisinioning phase, since we installed a lot of materials for the renewable, we are also taking a lot of materials.
For the same reason, we might use more energy, than it would take to decommission fuel fossils.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

We have to look and analyze everything to compare which one is better (LCA). We need to look how many materials are going in an out of these powerplants and how much energy is produced by this powerplants.
If we have these 2 things, we can normalize the emissions by the energy produced by the power plant. So we want to determine now is to ge the materials that went into the power plant, the lige time fuel consumptions, etc

Normalization of emissions [emission / kWh]

- The bill of material (BOM) of an energy plant accounts for the usage of the different materials m_i used to manufacture the energy plant
- The life time fuel consumption m_f is the sum of the annual fuel consumptions *AFC* used during the life time *LT* of the energy plant
- The recycling masses $m_{r,i}$ are the masses of the original bill of material recovered during the decommissioning phase, which can replace raw materials for the production of new energy plants. This means that emissions can be subtracted.
- The life time energy production *E* is then sum of the annual energy production *AEP* of the energy plant over the life time *LT* of the plant
- Total emission factors of the technology EF_j are now calculated from the specific emission factors $\varepsilon_{i,j}$ of the materials and normalized by the life time energy produced

Example:

Gram CO_2 / kWh

$$EF_j = \frac{\sum_{i=1}^{N} m_i \varepsilon_{i,j} + m_f \varepsilon_{f,j} + \sum_{i=1}^{N} m_{r,i} \varepsilon_{r,i,j}}{E}$$

We can try to calculate this. In order to check this: UN LCA analysis of electricity producing technologies. They ranked them in terms of what is the greenhouse emission.

We can see that coal fuel powerplants have large numbers of co2 per kw, while natural gas is less .
If we are putting get carbon captute and storage the CCS, we can reduce that into levels in between the natural gas
If we see the other ones, are low in emissions

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Material manufacturing causes CO_2 emissions

Materials	**Chemical process**	**Impact**
Mining Iron ore and making metal	$Fe_2O_3 + 3\,CO \rightarrow 2\,Fe + 3\,CO_2$	1.9 ton CO_2e /ton_{Fe}
Remelting recycled steel (NLMK Dansteel)	Fe + heat/electricity + $\rightarrow$ Fe	0.7 ton CO_2e /ton_{Fe}
Refining Iron ore using hydrogen ("Green steel")	$Fe_2O_3 + 3\,H_2 \rightarrow 2\,Fe + 3\,H_2O$	? (Demo at Salzgitter)
Concrete (turning limestone to CaO)	$CaCO_3$ + Heat $\rightarrow$ CaO + CO_2	0.1- 0.2 ton CO_2e /$ton_{Concrete}$
Green cement (Aalborg Portland)	As above but use minerals and heating with less CO_2 foot-print	30 % lower than cement ~ 0.6 ton CO_2e /ton_{Cement}
Making sand into silicon for PV wafers	$SiO_2 + 2\,C \rightarrow Si + 2\,CO$	5-16 ton CO_2e /ton_{Copper}
Making Copper ore into copper for wires	$2\,Cu_2S + 3\,O_2 \rightarrow 2\,Cu_2O + 2\,SO_2$ $2\,Cu_2O + Cu_2S \rightarrow 6\,Cu + 2\,SO_2$	3-4 ton CO_2e /ton_{Copper} SO_2 causes acid rain

Simple model for estimating Global Warming Potential

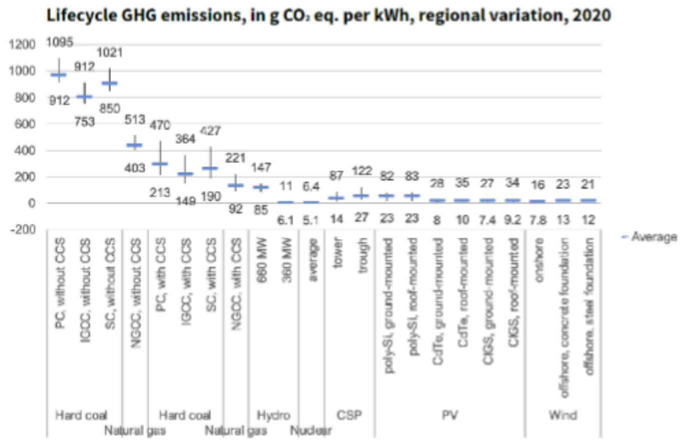
DTU Wind Energy

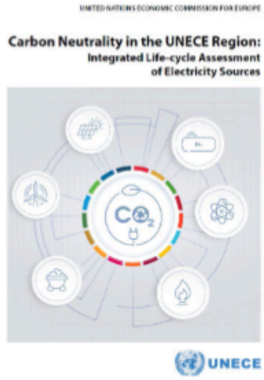
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

LCA overview of electricity producing technologies

Figure 1 Lifecycle greenhouse gas emission ranges for the assessed technologies





Source : UN: "Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources" (2022)

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Energy technologies

ble 1 Summary of life cycle inventories' scopes, per type of technology

Recycling of materials in UN report is absent !

ECHNOLOGY		INCLUDED	EXCLUDED
oal power	without CCS	Energy carrier supply chain, from extraction to combustion, including methane leakage Infrastructure construction, operation, and dismantling (energy inputs and waste production) Connection to grid	Potential recycling of dismantled equipment
	with CCS	Same as above, plus capture equipment and chemicals, transportation of captured CO_2 and storage infrastructure (well)	Same as above, plus Potential emissions (leakage) from captured CO_2 transportation or from the storage site
atural gas ower	without CCS	Energy carrier supply chain, from extraction to combustion, including methane leakage Infrastructure construction, operation, and dismantling (energy inputs and waste production) Connection to grid	Potential recycling of dismantled equipment
	with CCS	Same as above, plus capture equipment and chemicals, transportation of captured CO_2 and storage infrastructure (well)	Same as above, plus Potential emissions (leakage) from captured CO_2 transportation or from the storage site
ydropower		Construction, site preparation, transportation of materials Connection to grid	Potential recycling of dismantled equipment Site-specific biogenic emissions of CO_2 and CH_4
uclear power		Fuel element supply chain (from extraction to fuel fabrication) Core processes (construction and decommissioning of power plant, as well as operation) Back-end processes: spent fuel management, storage, and final repository	Potential recycling of dismantled equipment Reprocessing of spent fuel (conservative assumption that all fuel is primary)
Concentrated solar power		Infrastructure, site preparation and occupation, operation and maintenance (including 6-hour storage) Decommissioning (energy inputs and waste production) Connection to grid	Potential recycling of dismantled equipment
Photovoltaics		Infrastructure, site preparation and occupation, operation and maintenance Decommissioning (energy inputs and waste production) Connection to grid	Potential recycling of dismantled equipment
Wind power		Infrastructure, site preparation and occupation, operation and maintenance Decommissioning (energy inputs and waste production) Connection to grid	Potential recycling of dismantled equipment

The impact of these technologies are also defined in the UN report

Simple model for estimating Global Warming Potential

DTU Wind Energy

ill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
aterials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
oncrete	2453,6	71,8		0,17		417112000	417,1	10,3
teel	819,2	24,0		3,62		2965504000	2965,5	73,1
lass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
ther	85,8	2,5		0	Not included	0	0,0	0,0
otal	3417,8	100,0				4058088000	4058,1	100,0
urbine Annueal Energy Production								
verage wind speed installation site Uave	7,4	m/s						
urbine rated power Prated [MW]	6,2	MW						
nnual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
urbine design life time LT	20	years						
ours per year	8760	Hours						
apacity Factor CF	39,8	%						
ormalization of global warming potential by energy production								
lobal warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Table 3 Selected environmental indicators for Life Cycle Impact Assessment

CATEGORY	UNIT	REFERENCE	DESCRIPTION
Climate change	kg CO_2 eq.	IPCC (2013)	Radiative forcing as global warming potential, integrated over 100 years (GWP100), based on IPCC baseline model.
Freshwater eutrophication	kg P eq.	EUTREND, Struijs, Beusen [16]	Expression of the degree to which the emitted nutrients reach the freshwater end compartment. As the limiting nutrient in freshwater aquatic ecosystems, a surplus of phosphorus will lead to eutrophication.
Ionising radiation	kBq ^{235}U eq	Frischknecht, Braunschweig [17]	Human exposure efficiency relative to ^{235}U radiation. The original model is Dreicer, Tort [18] and follows the linear no-threshold paradigm to account for low dose radiation (details in Box 5).
Human toxicity	CTUh (comparative toxic units)	USEtox 2.1. model Rosenbaum, Bachmann [19]	The characterization factor for human toxicity impacts (human toxicity potential) is expressed in comparative toxic units (CTUh), the estimated increase in morbidity in the total human population, per unit mass of a chemical emitted, assuming equal weighting between cancer and non-cancer due to a lack of more precise insights into this issue. Unit: [CTUh per kg emitted] = [disease cases per kg emitted]1

eq kw/H
there are other impact factors
ionization: how many radiations is resulting from operating . Whenever you are operating a mine, you are taking minerals from ground, which releases ratton or uranium

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

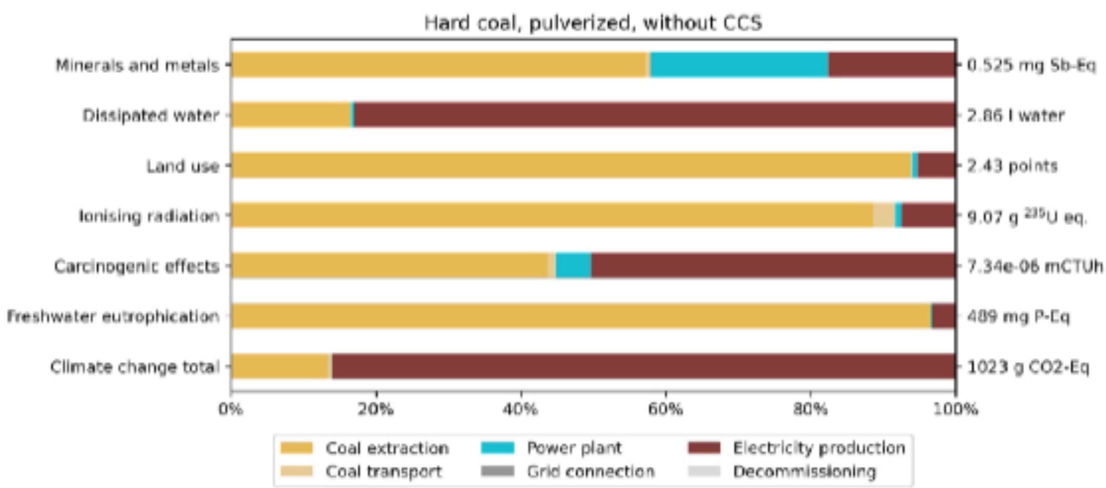
- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Land use	points	LANCA model, Bos, Horn [20]	The LANCA model provides five indicators for assessing the impacts due to the use of soil: 1. erosion resistance; 2. mechanical filtration; 3. physicochemical filtration; 4. groundwater regeneration and 5. biotic production.
Water resource depletion	m³	Swiss Ecoscarcity Frischknecht, Steiner [21]	Water use related to local consumption of water. Note: only air emissions are accounted for. *In this method, all flows have an identical characterisation factor of 42.95 m³/m³ – we therefore choose to account for these flows uncharacterised, i.e. 1 m³/m³.*
Mineral, fossil and renewable re-source depletion	kg Sb eq.	Van Oers, De Koning [22]	Scarcity of resource in relation to that of antimony. Scarcity is calculated as « reserve base ».

In the report you can find chartres for technologies. There are indicators wher each process is contributing to the climate change

Technology examples : coal

Figure 4 Life cycle impacts from 1 kWh of coal power production, pulverised coal, Europe, 2020



Simple model for estimating Global Warming Potential

DTU Wind Energy

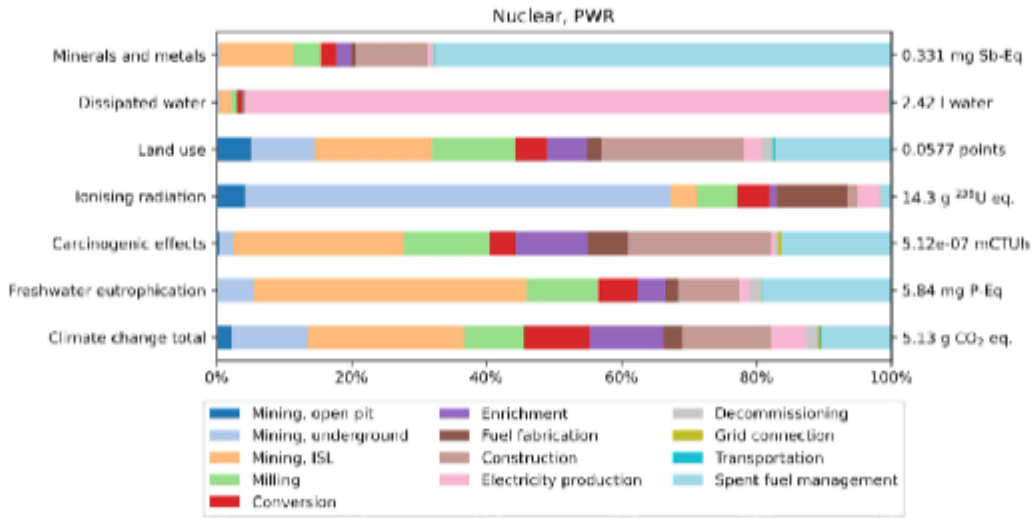
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Natural gas: we can see that climate c
Nuclear:climate change drops more

Technology examples : Nuclear

Figure 35 Lifecycle impacts of nuclear power, global average reactor, per kWh and activity



So decomissioning starts to play a role. Cooling water still is a lot
Solar PV: 36 g co2 per horut. 95% of the CO2 emissions is resulting from the silicon production and manufacturing of the panels.
Finally: onshore wind: 12.4 CO2. we can see the contributions to this. Again 95 % of the emeissions come from the manufacturing

To summarize: As we go along, CO2 emissions are dropping. Water eutrophication si high for cole, but more or less the same for other sources. Almost the same orderof magnitude for carcinofenic. Interesting more ionizaiton, some even more than nuclear.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

LCA impact summary based on main technologies

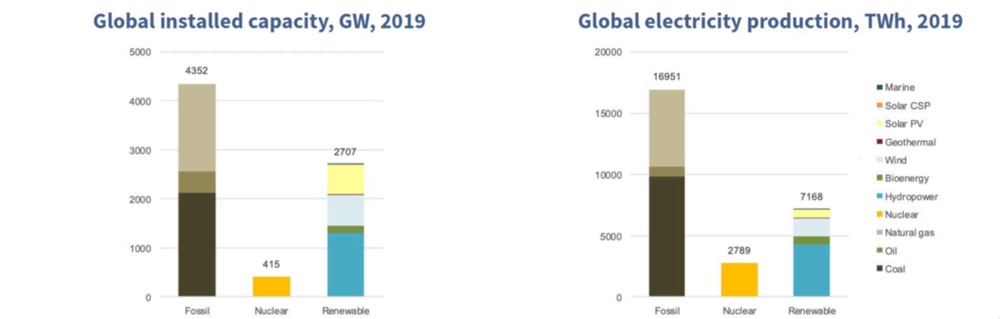
Technology and LCA impact	Climate change total [g CO_2 / kWh]	Freshwater eutrophication [mg P-Eq/kWh]	Carcinogenic effects [mCTUh/kWh]	Ionizing radiation [g ^{235}U Eq/kWh]	Land use [points/kWh]	Dissipated water [Liter/kWh]	Minerals and metals [mg Sb-Eq / kWh]	Source
coal	1023	489	7,34E-06	9,07	2,43	2,86	0,525	Fig 4
Natural gas	434	19,7	1,33E-06	9,24	0,195	1,17	0,243	Fig 9
Nuclear	5,13	5,84	5,12E-07	14,3	0,0577	2,42	0,331	Fig 35
Solar PV	36,7	28,4	4,12E-06	9,14	1,87	0,579	4,45	Fig 25
Onshore wind	12,4	6,62	6,55E-06	1,03	0,107	0,175	0,658	Fig 12
Source :	Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources, UN (2022)							

Table 13 UN summarizes this and table 14 gives even more detail.

Estimating the consequence of an electricity mix

If we know the mix of electricity producing technologies and the total production then we can estimate the impact and compare this with a defined limit

Figure 2 Global installed capacity, and production, of electricity-generating plants in 2019



Source: International Energy Agency [4].

Total production in 2019 : 26908 TWh

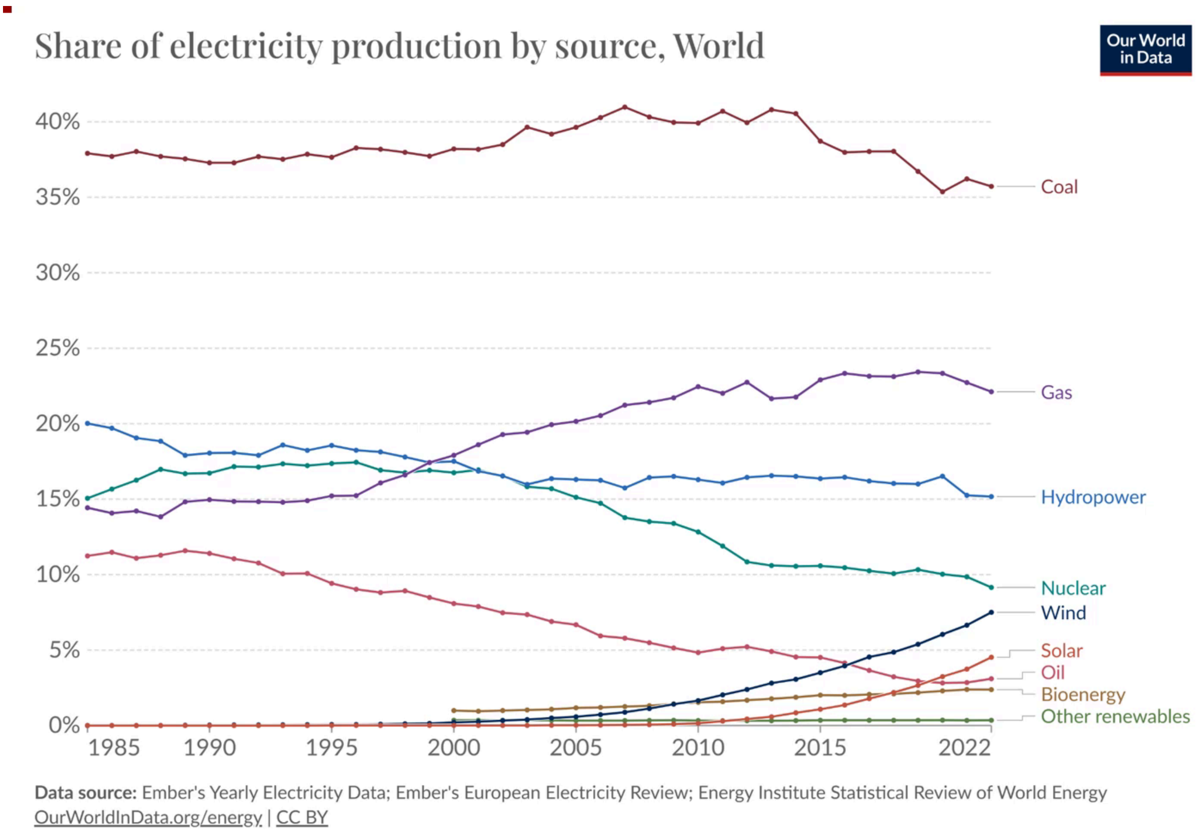
Consequence of havinge electricity mix: the total global electricity production of 26k terawats hour. The fraction of sources use to produce the worlds energy: major is coal

Simple model for estimating Global Warming Potential

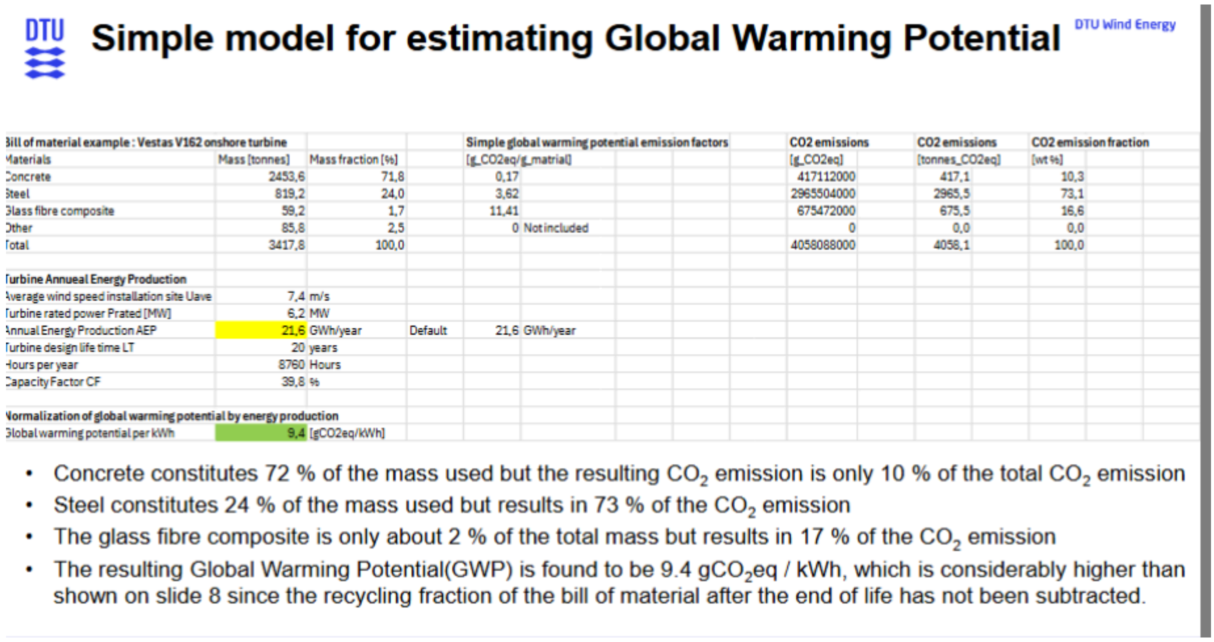
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



Oil has gone down, gas up.



Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Example of calculating world CO_2 emission from coal, gas, nuclear and hydro power

- The electricity production from coal, gas, nuclear and hydro power in 2019 is
  - E_{Coal} ~ 9500 TWh, E_{Gas} ~ 6500 TWh, $E_{Nuclear}$ ~ 2800 TWh & E_{Hydro} ~ 4000 TWh (Fig 2 in slide 24)
- And the climate change total emission factors for coal with no Carbon Capture and Storage are
  - $EF_{Climate\ change,\ Coal}$ ~ 1.02 kg CO_2e / kWh
  - $EF_{Climate\ change,\ Gas}$ ~ 0.434 kg CO_2e / kWh
  - $EF_{Climate\ change,\ Nuclear}$ ~ $5.29 \cdot 10^{-3}$ kg CO_2e / kWh
  - $EF_{Climate\ change,\ Hydro}$ ~ $1.07 \cdot 10^{-2}$ kg CO_2e / kWh (Table 14 in slide 22)
- The resulting Climate Change (CO_2e) emission then becomes
  - $EM_{Climate\ change,\ Coal} = EF_{Climate\ change,\ Coal} \times E_{coal}$ = 1.02 kg CO_2e / kWh x $9500 \cdot 10^{9}$ kWh = $9.7 \cdot 10^{12}$ kg CO_2e = 9.7 Gt CO_2e
  - $EM_{CC,\ Gas} = EF_{CC,\ Gas} \times E_{gas}$ = 0.434 kg CO_2e / kWh x $6500 \cdot 10^{9}$ kWh = $2.8 \cdot 10^{12}$ kg CO_2e = 2.8 Gt CO_2e
  - $EM_{CC,\ Nuclear} = EF_{CC,\ Nuclear} \times E_{Nuclear}$ = $5.29 \cdot 10^{-3}$ kg CO_2e / kWh x $2800 \cdot 10^{9}$ kWh = $1.5 \cdot 10^{10}$ kg CO_2e = 0.02 Gt CO_2e
  - $EM_{CC,\ Hydro} = EF_{CC,\ Hydro} \times E_{Hydro}$ = $1.07 \cdot 10^{-2}$ kg CO_2e / kWh x $4000 \cdot 10^{9}$ kWh = $4.3 \cdot 10^{10}$ kg CO_2e = 0.04 Gt CO_2e
- Thus the CO_2 emission from nuclear and hydro is only about 0.6 % of the coal emission.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

DTU Global boundary on green house gas

- The UN Emission Gap Report 2022 provides an estimate of the difference between the global emissions and the needed trajectory to fulfill the Paris agreement of a 1.5 °C, 1.8 °C and 2.0 °C global temperature increase by 2100. It is the accumulation of green house gasses in the atmosphere that dictates the future allowed emission levels.
- Currently the global emissions are approximately 53 Gt CO_2e per year.
- Given the global electricity mix and resulting emissions one can estimate the fraction of the total permitted emission that is provided by electricity generation.

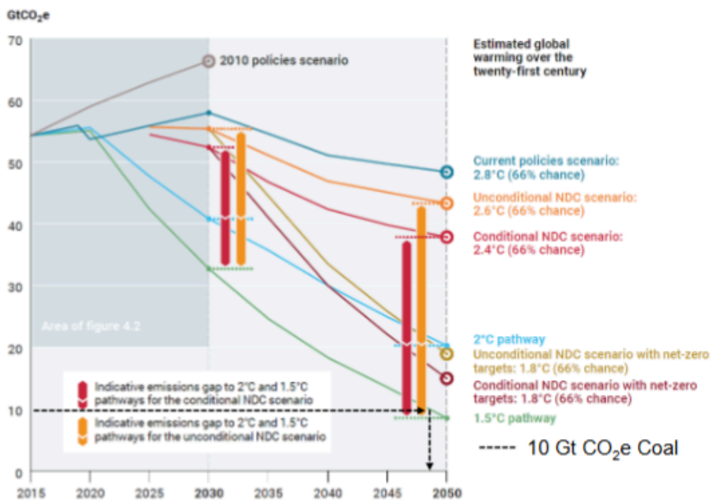


Figure 4.3 in the UN Report "The closing window – Emission gap report 2022"

Source: UN Emission Gap Report 2022

The plot shows how many gigatons of CO2 per year should be emitted in the future. The CO2 are already 20Gt, so just the electricity production coming from coal, is enough to put as there. How much will the CO2 be for different electricity productions compared to the chart

DTU Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Country specific development trends and targets

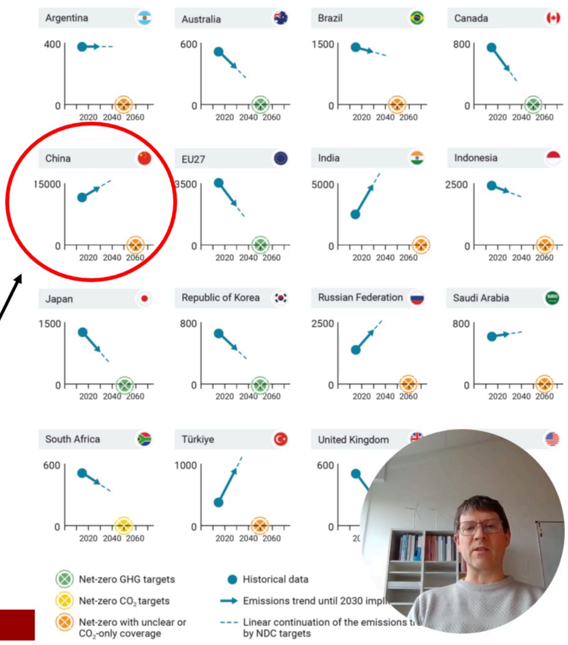
The electricity climate change emission from coal and gas is comparable to the current total climate change emission of China !

$$EM_{\text{Climate change, Coal}} + EM_{\text{Climate change, gas}} = 12.5 \quad \text{Gt } CO_2e$$

Source : UN Emission Gap Report 2022
https://www.unep.org/resources/emissions-gap-report-2022

Date DTU

Figure ES.4 Emissions trajectories implied by NDC and net-zero targets of G20 members. National emissions in $MtCO_2e$/year over time.



if we want to compare emissions of coal:

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Comparison of electricity climate change emission to total global climate change emission limit

- The Coal climate change emission was found to be $EM_{CC,Coal}$ = 9.7 Gt CO_2e in 2019
- The global emission limit was around $EM_{CC,\ Global}$ = 53 Gt CO_2e (Fig ES.3 on slide 27)

Thus the fraction of the planetary limit from the electricity production based on coal is

$$f_{Coal} = \frac{EM_{CC,Coal}}{EM_{CC,Global}} = \frac{9.7\ Gt\ CO_2e}{53\ Gt\ CO_2e} = 18\ \%$$

And if the emission from electricity production from natural gas is also included then one gets

$$f_{Coal+Gas} = \frac{EM_{CC,Coal} + EM_{CC,Gas}}{EM_{CC,Global}} = \frac{9.7\ Gt\ CO_2e + 2.8\ Gt\ CO_2e}{53\ Gt\ CO_2e} = 24\ \%$$

If the 2030 climate emission target of 1.5 ºC is used $EM_{CC,\ Global}$ = 33 Gt CO_2e then $f_{coal\ +\ gas}$ = 38 %, which shows that the electricity production has a large impact on the climate change emissions. Unchanged coal and gas will violate limit around 2045.

Date DTU 30

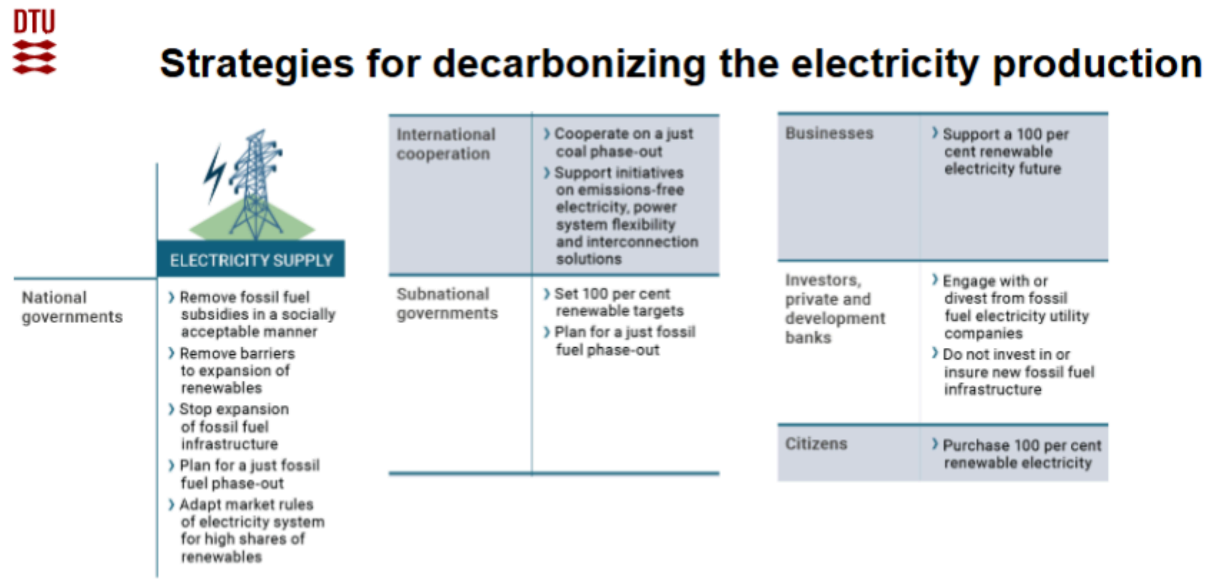
We are reaching 24% of the planetary boundary alone, from just the emission coming from the electricity production based on coal and natural gas. If we look at the future, if you unchange the coal and gas it will violate the boundary limit in 2045

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



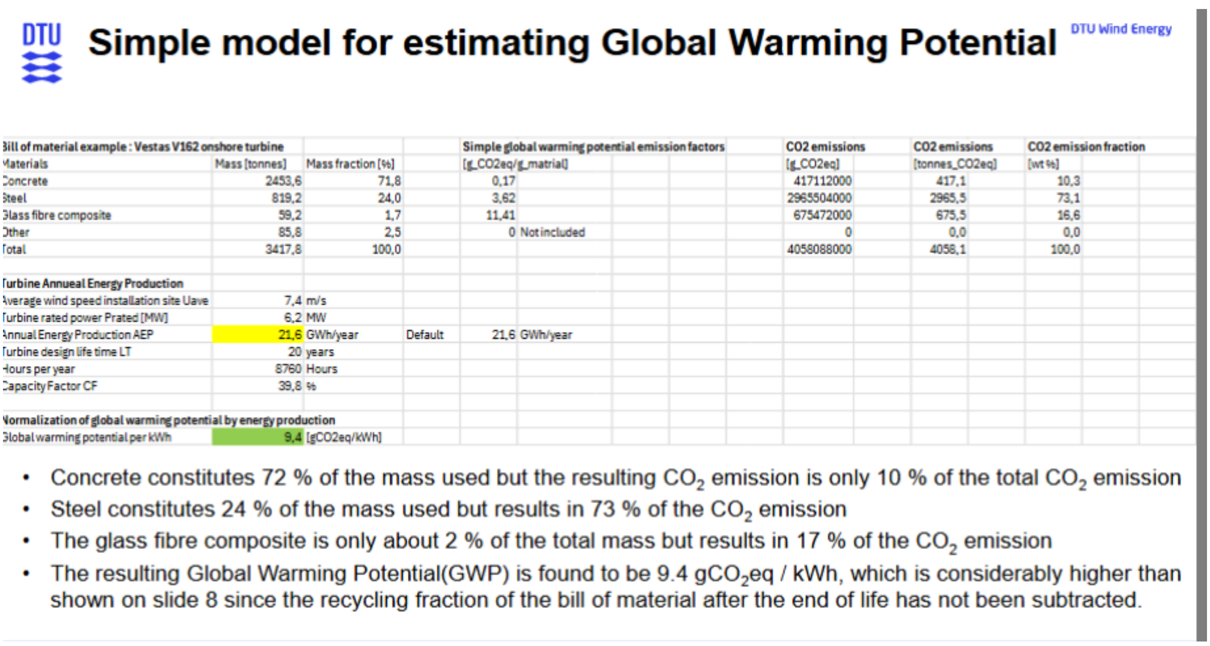
How to formulate strategies in decorbanizing electricity production: get rid of the fossil fuels.

Conclusion

• The United National report “Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources “ (2022) provides a baseline reference on the emission expected from the technologies of the electricity mix of countries and regions. This cna be used to look into how can we evaluate the consequences.

• The electricity mix of different countries and regions can be found from statistical sources (Hannah Ritchie and Pablo Rosado (2020) - “Electricity Mix” Published online at OurWorldInData.org.)

• Impacts from the electricity mix can then be estimated using the reference values and compared to the UN emission gap report in order to understand how close the planetary climate change emission is to the planetary boundary.



Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

Wind energy as example

Wind energy : by definition: green. Is ma

DTU Wind Energy

How sustainable is Wind Energy?

"Wind Energy is by definition green and once it supplies all production processed then the world will become purely green"

Just a matter of

- Producing plenty of green energy
- Getting emission to the environment low enough (examples CO_2 emission, water pollution, toxic emissions, ….)
- Ensure circularity of the turbine technology production (Old turbines → New turbines .. Blades?) – Zero waste

- Life Cycle Analysis (LCA) is a method to quantify the impact on the environment (example CO_2 emission per kWh produced energy, but 17 others)

There are many other impact categories, but here we focus in co2 emissions.

DTU Wind Energy

Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

DTU Wind Energy

How sustainable is Wind Energy?

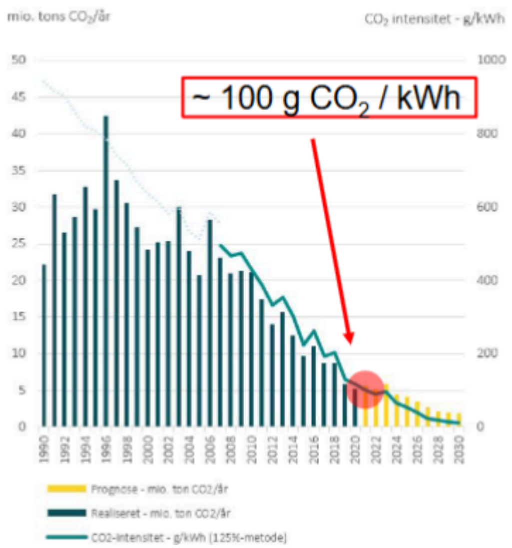
"Wind Energy is by definition green and once it supplies all production processed then the world will become purely green" (Wind sector around 2010)

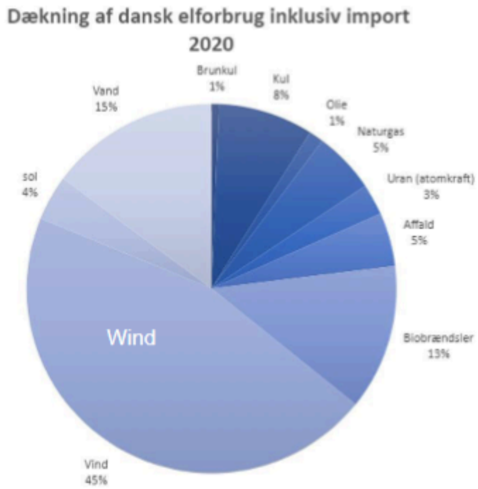
There are however some challenges related to this point of view:

- The production of the materials will need energy that might not be green
- The production of materials might result in direct chemical emissions
- The installation and Operation and Maintenance might be fossil-based
- There are many emissions to the environment and how to define limits?
- Is the turbine fleet operated in a circular manner with zero waste, or are new materials needed to compensate for the waste?

• Life Cycle Analysis (LCA) is a method to quantify the impact on the environment (CO_2 emission per kWh produced energy as example, but 17 others exist).

CO_2 emission from electricity of Denmark





DTU Wind Energy

Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

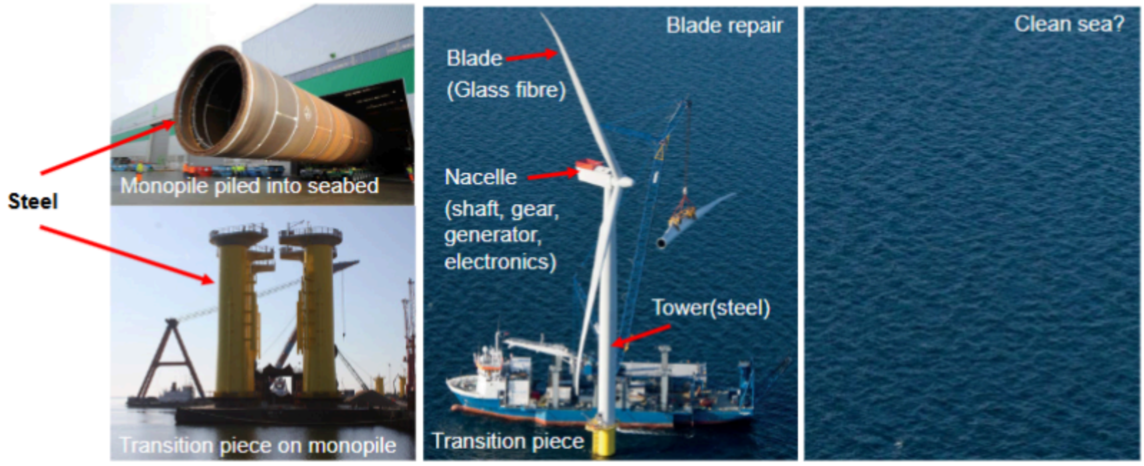
CO2 in denmark has been decreasing over time. most of the electricity production is from wind.

DTU

The life cycle of offshore wind farms

DTU W

Manufacturing & Installation | **Operation & Maintenance** | **Decommissioning after 25 year design life time**



In order to construct it, we need the monopile. On top of it we put the transition piece to hold the turbine. Generator converts energy of rotor into electricity. After 25 years, need to decommissioning , are we leaving a clean sea? by using this LC, we can try to illustrate this: how much steel do we need to do it

DTU

Simple model for estimating Global Warming Potential

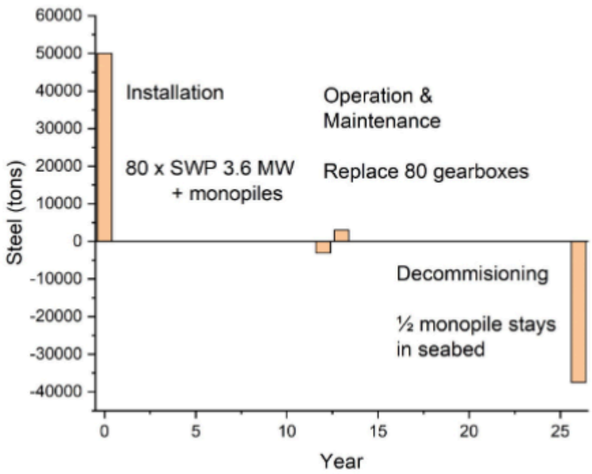
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

DTU Wind Energ

The steel life cycle balance of an offshore wind farm



CO_2 emission =

Bill of Material x **emission per material +**

Energy consumption x emision from energy

Transport x **emission per length +**

- Recycled material (?)

Normalization:

Total energy produced in operational lifetime of the wind farm [kWh]

if we leave half ot the monopile in the sea, not all steel goes out. If we calculate the co2.
Why do we have CO2 emission from a wind turbine? One reason: when manufacturing steel or iron: get CO2 as byproduct.

DTU Wind Energy

Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Manufacturing of iron : From mine ore to metal

Blast furnace operating at 2000 °C

$$Fe_2O_3 + 3CO \rightarrow 2Fe(L) + 3CO_2$$

$$C + O_2 \qquad \rightarrow 2CO$$

$$2Fe_2O_3 + 3C \rightarrow 4Fe(L) + 3CO_2$$

Burn iron mineral with coal ➡ **Liquid iron + CO_2**

$E = 6.8$ MWh/ton$_{Fe}$

$m_{CO2} = 1.9$ ton CO_2 eq/ton$_{Fe}$

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0

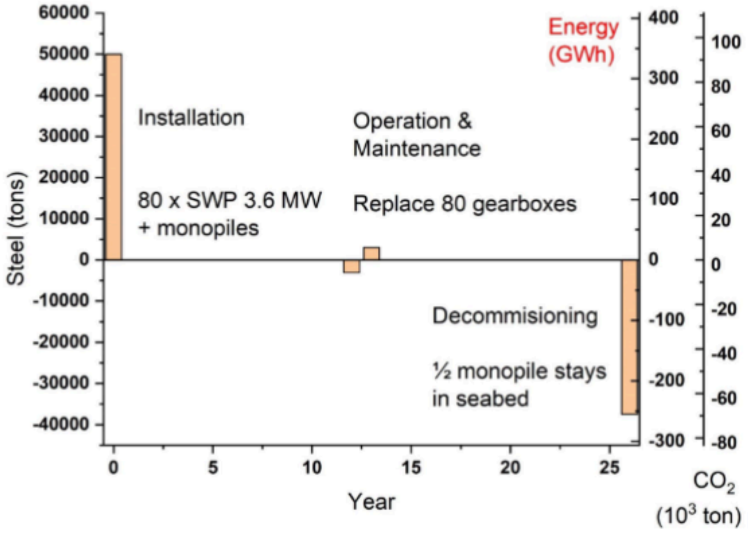
Turbine Annueal Energy Production					
Average wind speed installation site Uave	7,4	m/s			
Turbine rated power Prated [MW]	6,2	MW			
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year
Turbine design life time LT	20	years			
Hours per year	8760	Hours			
Capacity Factor CF	39,8	%			

Normalization of global warming potential by energy production		
Global warming potential per kWh	9,4	[gCO2eq/kWh]

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

DTU Wind Energy

Energy usage and CO_2 emissions due to steel balance



Emission

$m_{CO2} = 90 \cdot 10^3$ tons CO_2

Wind energy produced

E = 80 turbines x 3.6 MW/turbine x 365 days/year x 24 hours/day x 25 years x CF

= $25.2 \cdot 10^9$ kWh (25 TWh)

The capacity factor(CF) of the wind farms is assumed to be 0.4, which describes the average production due to the fluctuating wind.

Normalized emission

$$\frac{m_{CO2}}{E} = \frac{90 \cdot 10^9 \; g\,CO_2}{25 \cdot 10^9 \; kWh} \sim 4 \; \frac{g\,CO_2}{kWh}$$

DTU Wind Energy

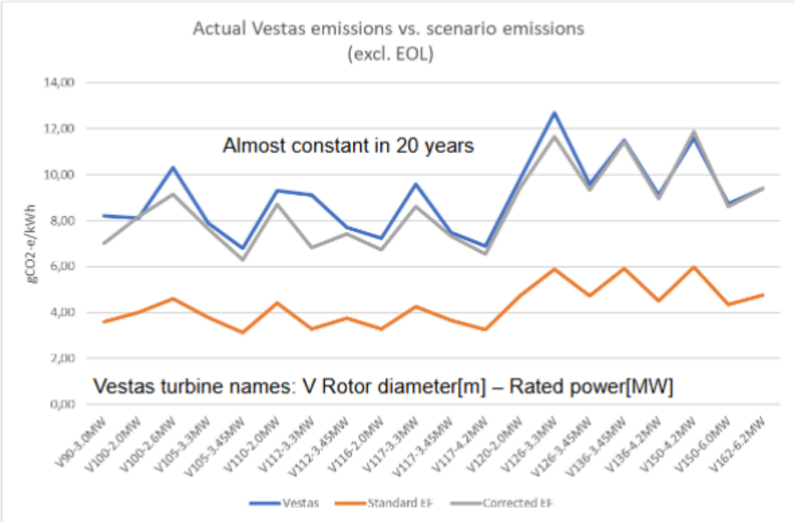
Simple model for estimating Global Warming Potential

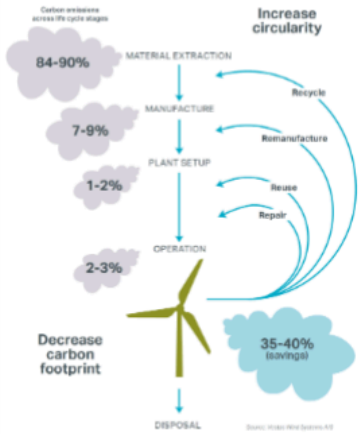
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

DTU Wind Energy

Onshore turbine emission from LCA studies of Vestas





MegaVind : https://megavind.greenpowerdenmark.dk/files/media/document/Sustainability-in-the-wind-industry-oct22.pdf

Kjeldsen & Mwiseneza, DTU Bachelor thesis summer 2023. Harden, Bachelor project 2021. Fauerskov & Laurberg, Bachelor project 2022.

Here they show that global warming potential was constant eventhough the size of the turbine has grown dramatically. The emission per kwH produced is also almost constant. We are producing more energy but we are also using more mateerials and we need more materials to produce them

84-90 % comes from extraction of materials, manufacturing takes 8%. So this is explaining that most of the emissions of offshore wind is coming from the manufacturing of the steel. If we can reuse the steel by circulating back we can save lots of CO2 emissions

DTU Wind Energy

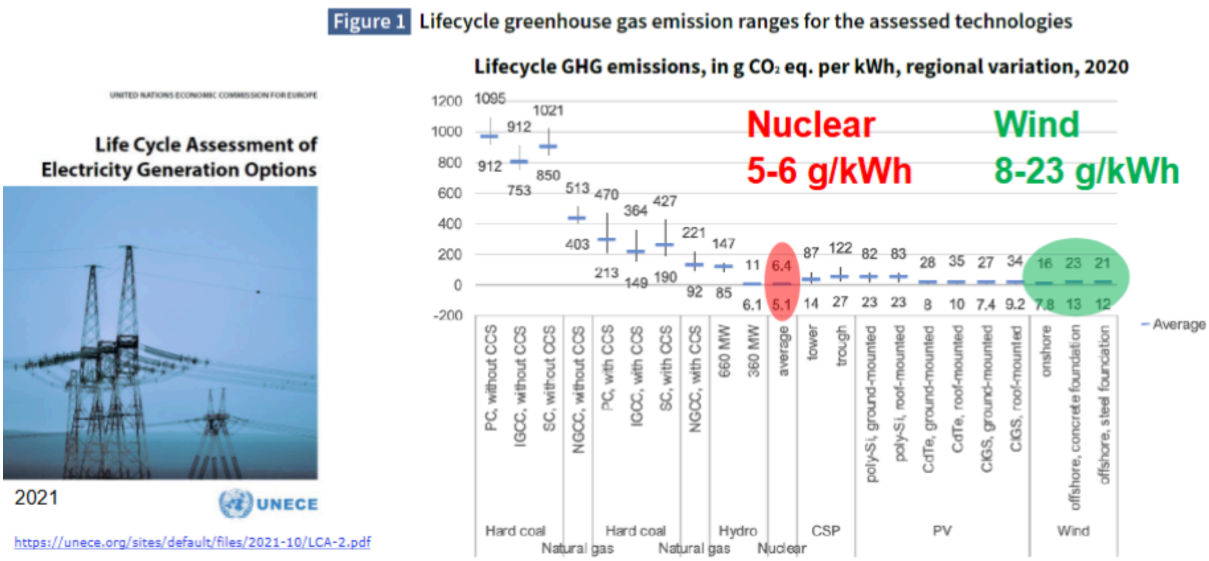
Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

UN ranking of electricity producing technologies

DTU Wind Energy



Other electricity producing technilofies area also here: fuel have high co2 emissions, while wind is part of the low emission technologies. Nuclear has even lower than wind. Is nuclear polluting less compared to wind? Waste should be taken into account.

Simple model for estimating Global Warming Potential

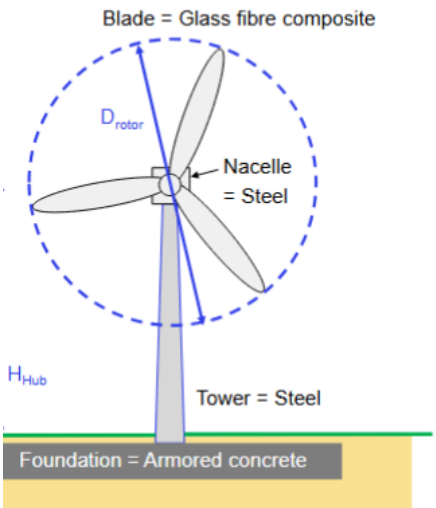
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

DTU Wind Energy

Simple model for estimating Global Warming Potential (g_{CO2eq}/kWh) of onshore wind turbine



Vestas V162 onshore wind turbine (example)

Rotor diameter	D_{rotor} = 162 m
Power rating	P_{Gen} = 6.2 MW
Hub height	H_{Hub} = 149 m
Design Lifetime	LT = 20 years
Annual Energy Production	AEP = 21.6 GWh/year (u_{ave} = 7.4 m/s)
Capacity factor	CP = AEP / (P_{gen} x 365 days x 24 hours) ~ 40 %

Simple Bill of Materials (BOM) per V162 turbine

Concrete	$m_{concrete}$	=	2453.6 tonnes	72 %
Steel	m_{steel}	=	819.2 tonnes	24 %
Glass fibre composite	m_{GFC}	=	59.0 tonnes	2 %
Other (Cu, Al, plastics,..)	m_{other}	=	85.8 tonnes	3 %
Total	m_{total}	=	3417.6 tonnes	100 %

Source : https://www.vestas.com/en/sustainability/environment/lifecycle-assessments

The design of the wind turbine has a dramatic impact on how much energy you are producing.

DTU Wind Energy

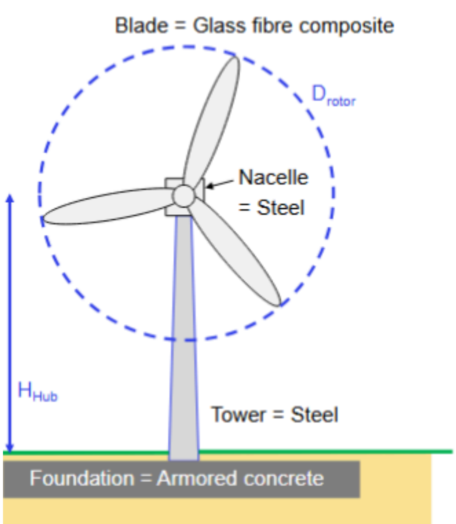
Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Simple model for estimating Global Warming Potential

DTU Wind Ene



Wind energy sector simple emission factor suggestion

Concrete	$EF_{concrete}$ =	0.17 g_{CO2eq} / $g_{concrete}$
Steel	EF_{steel} =	3.62 g_{CO2eq} / g_{steel}
Glass fibre composite	EF_{GFC} =	11.40 g_{CO2eq} / g_{GFC}

Simple total emission model

Emission factor material i, EF_i

Mass of material i, m_i

$$EM[g_{CO2\,eq}] = \sum_{i=1}^{N} EF_i \cdot m_i \; [g_{co2eq}]$$

The simple model includes the lifetime emissions of manufacturing, installing, and operating an onshore wind farm in Europe, but no recycling. These numbers are estimated from an analysis of the Life Cycle Assessment(LCA) reports of Vestas and represent approximate wind energy sector numbers for a typical European wind farm sourced from the European supply chain in 2023. This means that the energy mix of European countries have been used to determine the emissions resulting from the energy consumptions.

Source : https://orbit.dtu.dk/en/projects/simple-model-for-estimating-co2-emissions-of-wind-turbines

Simple model for estimating Global Warming Potential

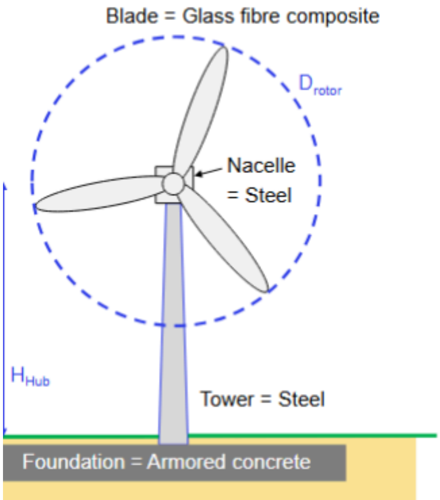
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Transport assumptions in simple GWP model

DTU Wind Energy



Transportation specifications

Component	Truck (km)	Ship (km)
Nacelle	600	9000
Hub	600	8600
Blades	1450	5100
Tower	425	0
Foundation	50	0
Other site parts	600	0

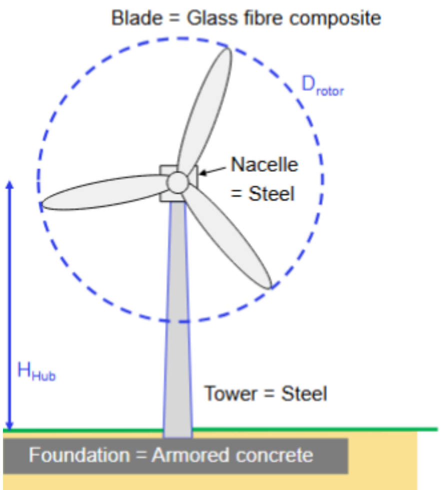
Installation site of the windfarm is Europe (Germany, see Table 15 in Vestas LCA report of V162)

Materials recycling is specified in table 3 on page 32 in report below.

Source : Sagar Mali & Peter Garrett, " Life Cycle Assessment of Electricity Production from an onshore EnVentus V162-6.2 MW Wind Plant ", Vestas, Version: 1.0 Date: 31.01.2023
https://www.vestas.com/content/dam/vestas-com/global/en/sustainability/reports-and-ratings/lcas/LCA%20of%20Electricity%20Production%20from%20an%20onshore%20EnVentus%20V162-6.2.pdf.coredownload.inline.pdf

Simple model for estimating Levelized cost of Energy of onshore wind turbine electricity production

DTU Wind Energy



Cost of onshore wind turbines

Capital cost	CAPEX	~ 1.4 M€/MW (inflation corrected)
Operational cost	$OPEX_{fixed}$	~ 12600 €/MW/year
	$OPEX_{variable}$	~ 1.35 €/MWh
Discount rate	w	~ 4-6 %/year

Levelized Cost of Energy (LCoE) = ?

Source : Danish Energy Agency, Technology data, page 225 and 2030 scenario
https://ens.dk/sites/ens.dk/files/Analyser/technology_data_catalogue_for_el_and_dh.pdf

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Levelized Cost of Energy estimate of onshore wind energy from Vestas V162-6.2 MW turbine

DTU Wind Ene

The levelized cost of energy can in a simple form be defined as

$$LCoE = \frac{\sum_{i=0}^{LT} \frac{C_i}{(1+w)^i}}{\sum_{j=0}^{LT} \frac{E_j}{(1+w)^j}} = \frac{C_{CAXEX,0}}{E_{AEP}} \cdot CRF + \frac{C_{OPEX,Annual}}{E_{AEP}} + LCoE_{OPEX,variable} = 32.2\,\frac{€}{MWh} + 3.6\,\frac{€}{MWh} + 1.4\,\frac{€}{MWh} = 37.2\,\frac{€}{MWh}$$

Where

- The capital expenditure(CAPEX) is
  - $C_{CAPEX,0}$ = 1.4 M€/MW x 6.2 MW = 8.6 M€ (see slide 14)
- The annual operational expenditure (OPEX) is
  - $C_{OPEX,Annual}$ = 12600 €/MW/year x 6.2 MW = 78120 €/year (see slide 14)
- The variable operational expenditure is $LCOE_{OPEX,variable}$ = 1.35 €/MWh (see slide 14)
- The Annual Energy Production E_{AEP} = 21.6 GWh/year (see slide 10)
- The Capital Return Factor(CRF) is given below using an interest rate w = 5 % and a design life time LT = 20 years (see slide 14)

$$CRF = \frac{1}{\sum_{t=1}^{LT} \frac{1}{(1+w)^t}} = \frac{w}{1-(1+w)^{-LT}} = \frac{0.05\,\frac{1}{year}}{1-(1+0.05)^{-20}} = 0.080\,\frac{1}{year}$$

LCoE levels of electricity sources of Europe

DTU Wind Energy

Figure 0-1 LCOE results for EU27 - main technologies' comparison - percentage change between 2008 and 2018

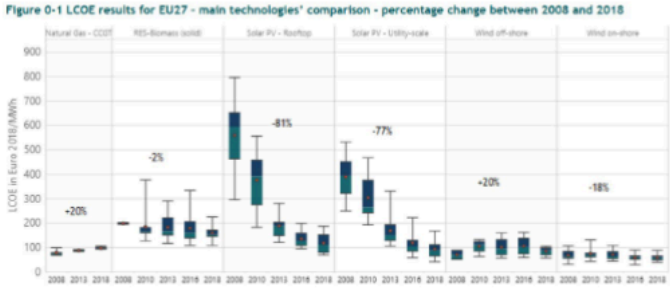
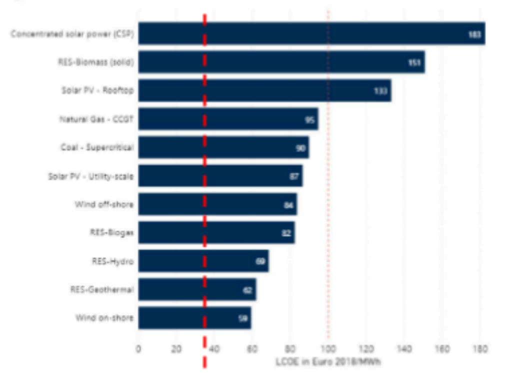


Figure 0-2 LCOE results for EU27 - in 2018



37 €/MWh

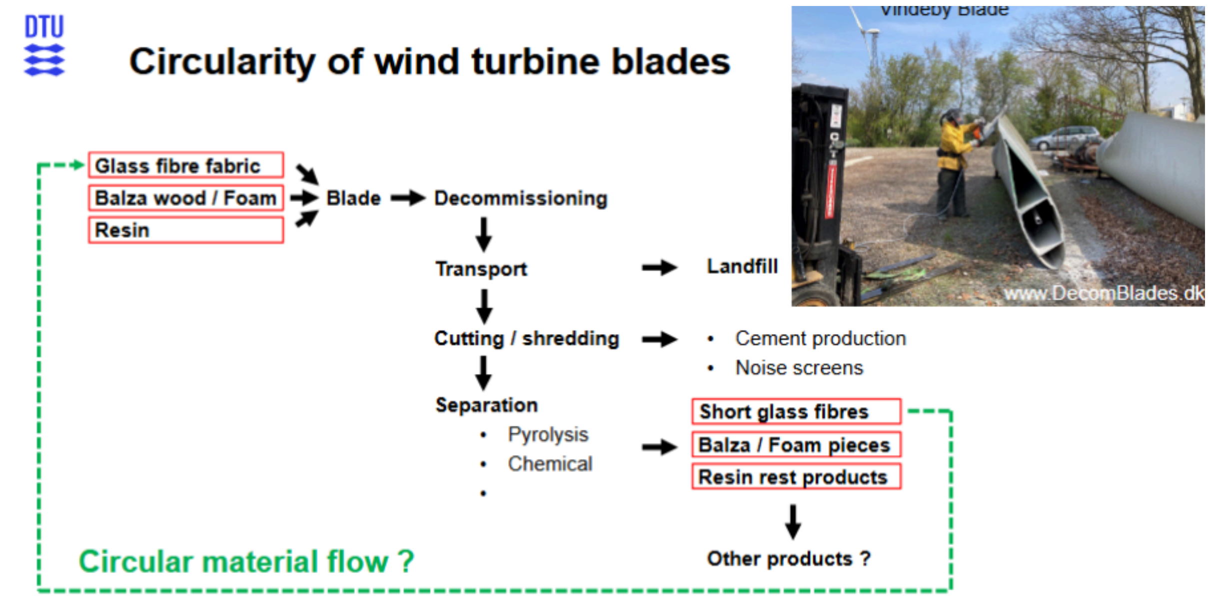
Thierry Badouard, Débora Moreira de Oliveira, Jessica Yearwood and Perla Torres, "Final Report Cost of Energy (LCOE). Energy costs, taxes and the impact of government interventions on investments", European Commission ENER/2018-A4/2018-471 (2020)

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



The steel of the tower is easily melted and can be recycled. So it can be recircualted. one component that is complicated: blades: are made from glass and a resin. They ar very strong, but to get them broken down is very hard. We need technologies for cutting and separate materials. But how do you get them back? Such recycling has been demonstrated:

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Great news on turbine blade recycling in 2023

DecomBlades and 3B-Fibreglass are ready to unlock circular recycling of glass fibre in wind turbine blades

Remelting recycled glass fibers

1) Cut turbine blades (5-10 tons)
2) Shredding
3) Grinding
4) Pyrolysis to remove epoxy
5) Milling recycled glass fiber

Mix 1-5 % recycled glass fibers into melt of production for new glass fibers by 3B (72 metric ton)

DTU Wind and Energy Systems showed mechanical properties of remelted glass fibers are as good a normal wind turbine grade fibers.
This can enable a fully blade to blade circularity of the glass fibers of the wind industry.

<u>Conclusion</u>

• CO 2 emission of the Danish Energy mix is expected to reach ~ 10-15 g CO 2eq/ kWh using only wind
turbines unless the production method of the materials used to build the turbines is changed.
• The main materials used in the wind turbines are: steel, concrete and glass fibre composite
• For offshore wind turbines the emissions will depend on the amount of recycled steel from monopiles
• Circularity in material recycling of wind turbines is improving by new blade recycling technologies
• New solutions
– Turbine designs with less material usage (especially concrete in the foundation of onshore)
– Usage of Green Steel and Green Cement?
– Low CO 2 footprint steel in tower and monopile by utilizing remelted steel

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

– Refining iron ore to iron using hydrogen route (water as chemical emission instead of CO 2)
– Turbines based on completely different materials (wood in towers?)
– Turbine design standards dictate current material usage (IEC 61400-1 and IEC 61400-3) since the
turbine manufacturers have to guarantee that the chance of major failures of the turbines is small
during the design lifetime

[Exercise planetary boundary of Global Warming Potential due to electricity mix]

Sustainable transition, trade-offs, identifying actions

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				**Simple global warming potential emission factors**		**CO2 emissions**	**CO2 emissions**	**CO2 emission fraction**
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Sustainability transitions

How can we interpret the results from the sustainability assessment and make them useful for taking the decision that moves us in the right direction of a sustainable future?

Process of decision making. Multicreiteria decision analysis is a structured and often mathematical way to support decision making. Some others approach aim to present these results in a more visual manner, leaving the trade off between the criteria to the decision makers. Trade offs will almost always be necessary.

Main takes away:

- Be critical to both your results. Evaluate your assumption thoroughly (how sensitive for example) you. Evaluate assumptions, uncertainty, and completeness
- Based on the types of data acquired and goal and scope of study, consider which types of decision support are adequate. Does the study support a quantitative assessment? Is the decision binary? Choosing one over the other?
- MCDA (multicriteria decision) methods have strengths in the guidance
- Visualizaitons have strengths in providing overview
- Trade-off are inherent

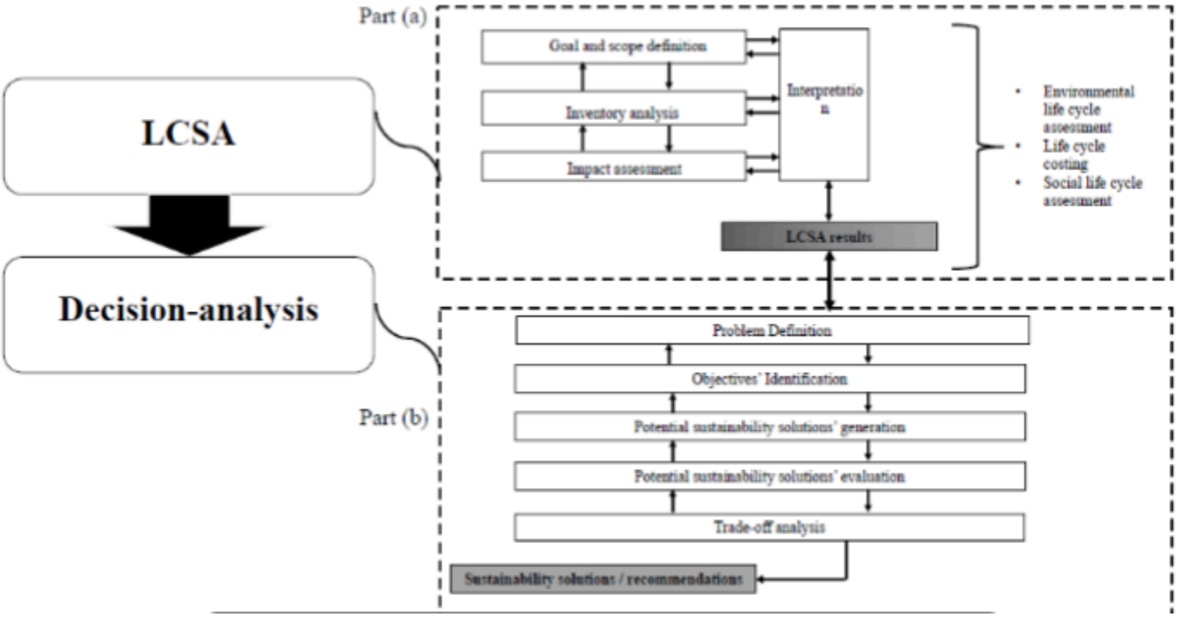
But how does the sustainability assessment fit into the decision making? Well, the decision making includes a number of steps from defining the problem, identify the objectives that should be considered in our decision (example:economy and contribution to climate change), then we generate potential solutions. In most cases, there will also be trade offs analysis between the different objectives that needs to be analyzed before we can give a full recommendation. What the last sustainability assessment does, is mainly to address the evaluation of thee alternatives. But the decision to be taken would, to a large extent depend on the goal of the assessment: what is the question we would like to answer. It also influence the scope of the assessment in terms of how to set the system boundaries.Example: what qualities should we persue, which indicators to include, among others.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



So the framework for sustainability assessment that we have seen is a rather simplified lifecycle sustainability assessment. It aims to evaluate the main sustainability impact areas

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

throughout the life cycle.

	Life Cycle Stage					
Sustainability Impact area	Extraction of raw materials	Manufacturing stage	Use stage	Disposal stage	Measured by:	Covered in module
Resources					Use of biotic and abiotic resources	4, DAVLU
					Circular economy indicators	8, TMcA
Environment					Climate change, Carbon footprint	3, OJOLL
					Absolute boundaries	7, MZHA
Economic					Life Cycle Costs	5, KAMORR
Social/Health					Socioeconomic impacts	6, KAMORR, OJOLL
					Health impacts	
Transition					Interpretation System dynamics	9, ASAB 10, DAVLU, SIOL

We have looked at resources, both from a scarcity perspective and from a circular economy perspective. The environmental aspects have been mainly looked at from a climate change perspective, but also put into planetary boundaries. The economic aspects are addressed through cost analysis.Socioeconomic impacts were introduced and a specific method of calculating the health impact was presented.

So now.. how we interpteate and use the report for supporting decision making.
The assessment can in principle generate several more indicators for each different lifecycle. And the challenge of course is hot to communicate this to decision makers andhow to prioritise between them.

Results must be interpreted and evaluated

How reliable and representative of our specific problem are they?
• Consider your assumptions and main uncertainties
– Which assumption are most sensitive and uncertain? Check assumptions and investigate which ones may have an impact on our results.

DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

– Which data do you consider being most uncertain? Can you improve? Example: how well the data represented geographically.
• Completeness
– Which parts of the life cycle did you not include? Potential influence?
– Do you consider all dimensions and aspects? Or can you reasonably argue for the omission

Another sign of big uncertainty is ithere is a big variance amount of data for a single indicator. Also you need to reflect on how well you cover the life cycle. Did you include all life cycle status for all indicators?

The interpretation is iterative, indicating that if data are influential and have a high uncertainty, then further collection of data might increase the accuracy and representativeness of the results. And you should increase the effort of collefcting the data further. If this is not possible, ask if data is sufficient to ask the questions or need to reformulate the goal?

Decision support: There is a need to this because everytime we buy staff for example, we need to decide how to buy the most sustainable product. The simple way is to chose to ecolabel products if they are available. This ecolabel product would be among the best 30% of that type of product.

A more precise information is to use an environmental product declaration, where you get a much better overview of the product impacts in different lifecycle stages. But not many consumers would be interested or even able to interpret an environmental product declaration.
This is mainly a business to business communication form . There is a lot of information and also if you are comparing 2 products, you have to compare several different criteria. And this is where multicriteria decision analysis can become useful. Several methods exist, The most frequently used is the analytical hierarchy process method which performs a pairwise comparison between each of the indicators of the system being compared and complies this into a preferable solution. One of the benefits of this method is that it does NOT need

DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

quantitative information necessarily. And it can even use decision and opinion of the decision makers from the beginning of the assessment.
Other methods are more mathematical and apply operations. Example: methods are compensatory: if takes into account that one of the sustainability dimensions is being depraved on behalf of the better performance of the others. In general, this type of analysis is useful to give guidance in choosing between one or more solutions, alternatives or products.

Visualizations of the results can be a good way to provide an overview . Most approaches compare 2alternatives. Often a reference solution (existing way of providing a service) vs the alternative. If you are just looking at one indicator, it is easy to show it in a graph, but if you have many, a radar plot would be nice: total area of each alternative could give a good indication of each alternative.
Another way to illustrate: 3D coordinate system that requires aggregation in each of the sustainability dimensions. So its possible to show its dimension with one single value.
Another principle: 3 sided triangle

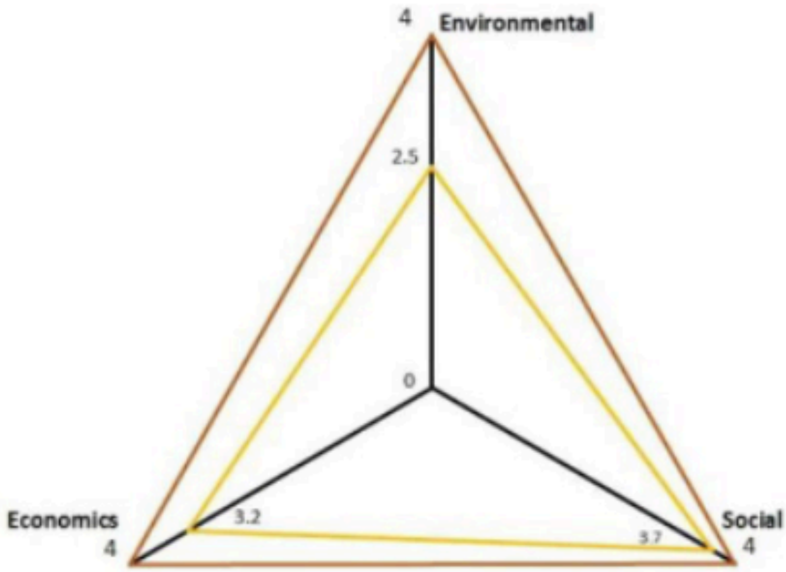
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Three sided triangle still requires aggregation within each dimension



Each sustainability dimension is on one side of the triangle. This provides a very quick overview of the trade offs. However we want to present as much information as possible without confusing the decision maker

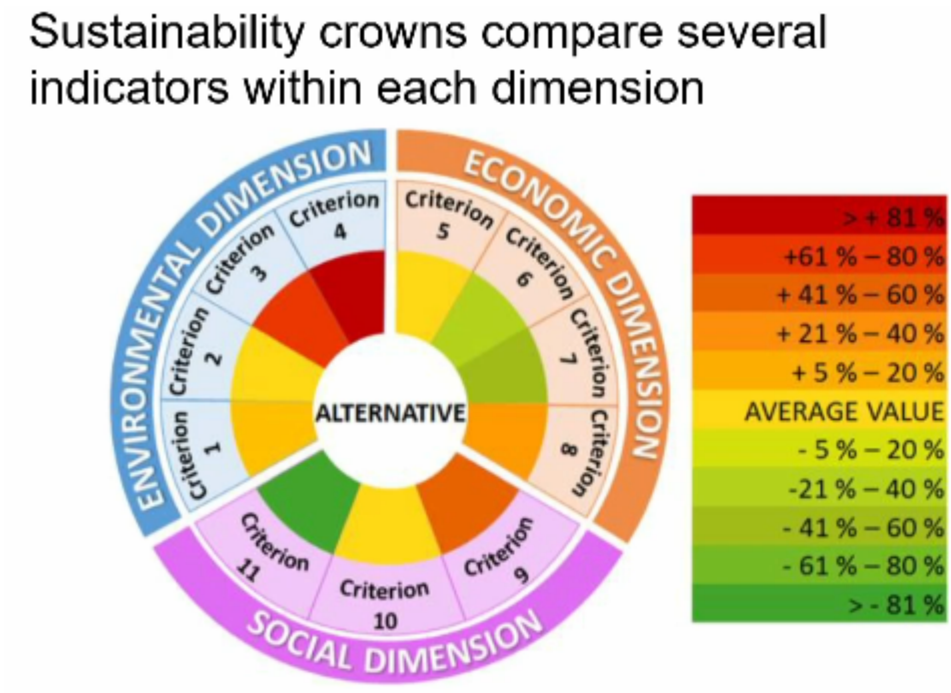
Sustainability crown: a way to illustrate the assessment results of 2 alternatives.

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



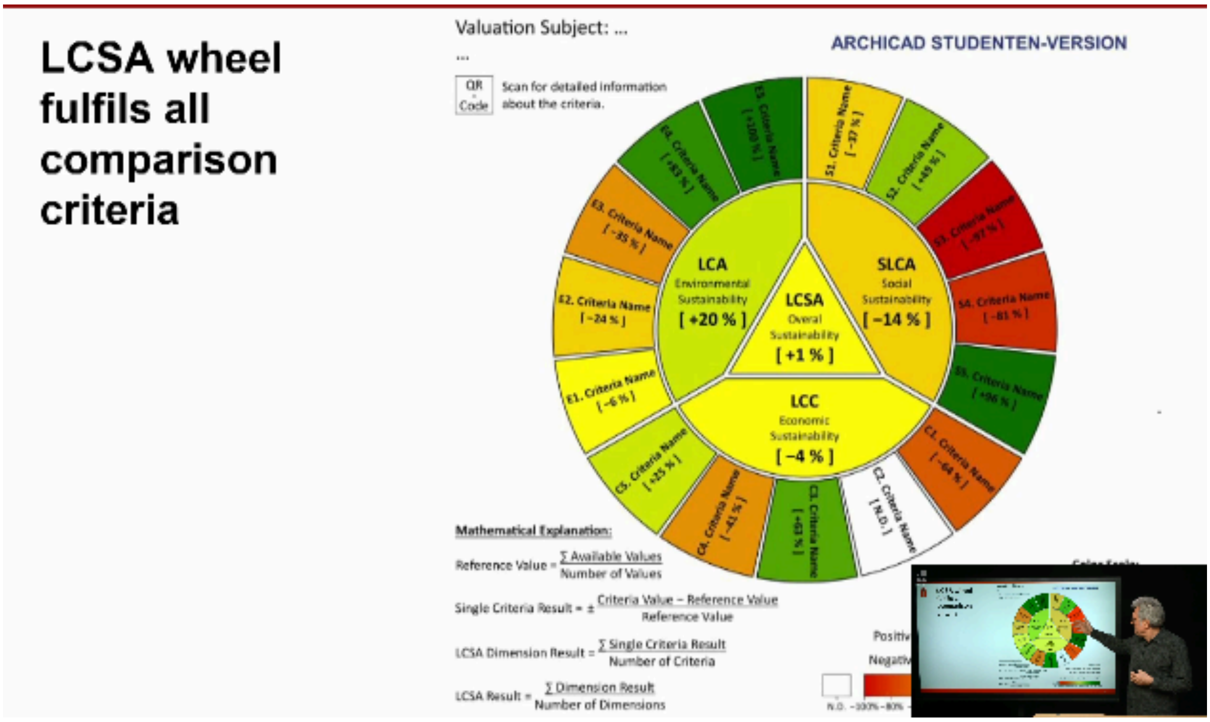
Here, each relevant indicator whithin each sustainability dimension is given the colour that corresponds to how it compares to the alternative. So if it performs worse: the color gets more red, and if it gets better than the alternative then is green
The downside: it does not provide an overall assessment.
To accommodate this gap:

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

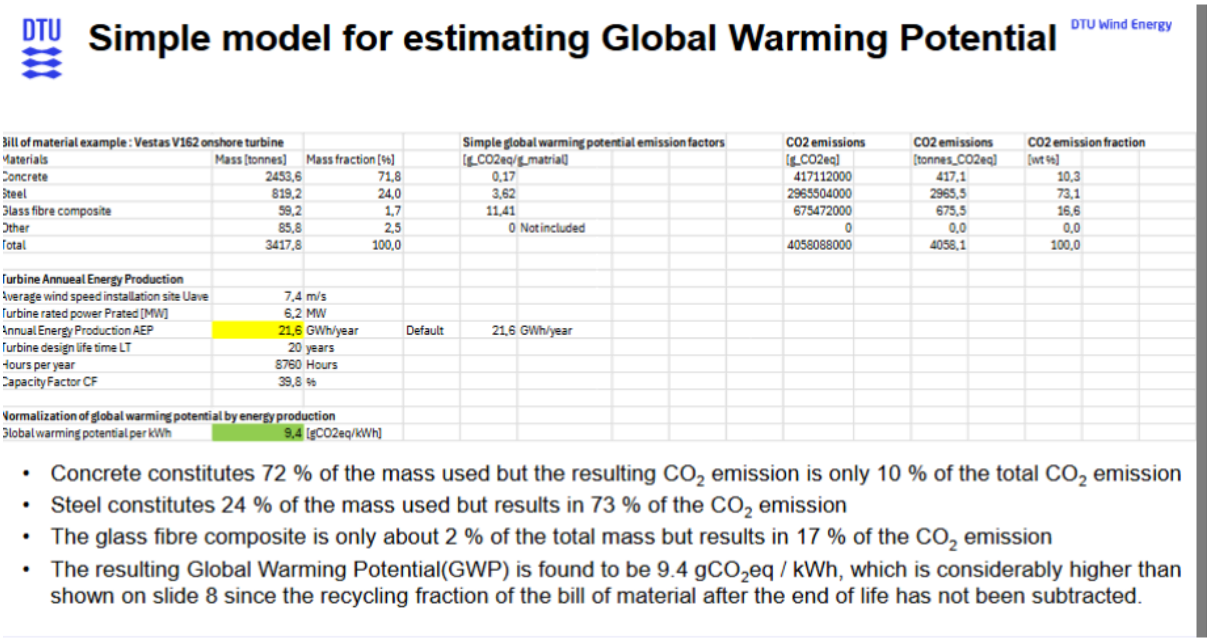
- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.



Does the same but in the center of the wheel, it aggregates the results of the assessment in the middel. The colors are the same.

Summary
• Visualizations have strenghts in providing overview of the impacts in different dimensions and also to make transparent trade offs between different alternatives.
• MCDA methods have strengths in the guidance since it chooses between different alternatives
• Evaluate assumptions, uncertainty and completeness
• Based on the types of data acquired and goal and scope of study, consider which types of decision support are adequate

Almost in all situations, trade-offs between different impacts would be necesasry



DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Pathways and interventions, Systemic sustainabilty transitions

Practical interventions that we can use:

Models: when we try to understand if something is sustainable: what we do, is develop a model of this process (LCA), mindmap, representation,etc. From this model we can then infer if something is sustainable or not. Models can take many forms and shapes. non of us nows what reality is really like, because we are integraitng our view to build a model of the world.
We have system representation of models
We can build algorithms, and also have formal relationships within things. For example with EDOs
There are many kind of models: all of them are useful and some of them can derive insights

We are gonna build models about systems

What does sustainability transition mean?

- Systemic interventions to
  - Sustain acceptable outcomes on the three dimensions of sustainability
  - Change the system currently in unacceptable state
- Applies to all scales:
  - Manufacturing system
  - Resource exploitation system
  - Socioecological system

Simple model for estimating Global Warming Potential

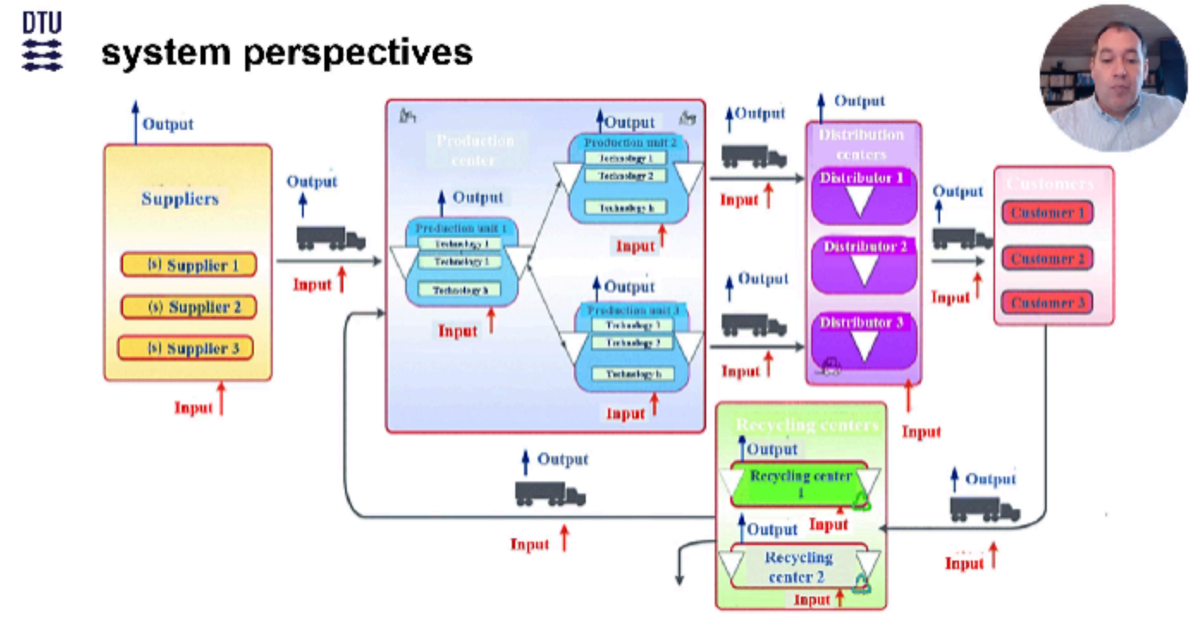
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Means that we try to understan what type of intervention takes place on a system so either sustain a sustainable outcome or to change the system that is currently unacceptable

That can apply to all scales.



This is a representation of the system, where we are manufacturing something

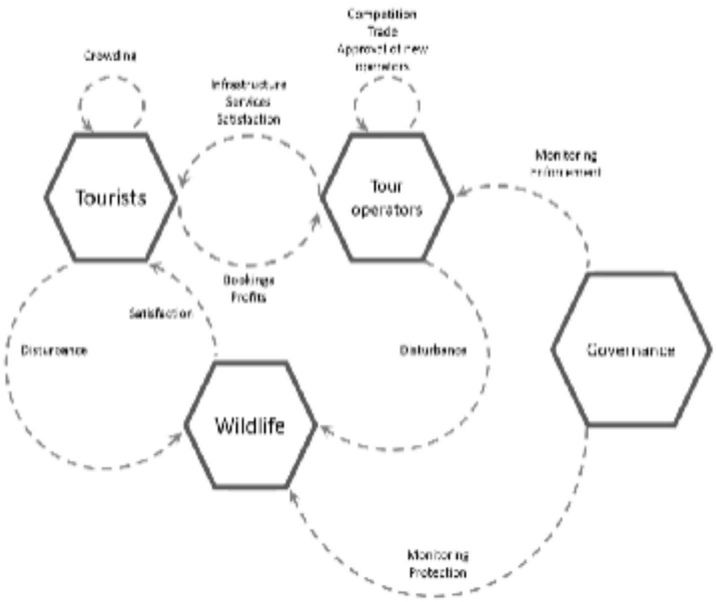
Simple model for estimating Global Warming Potential

DTU Wind Energy

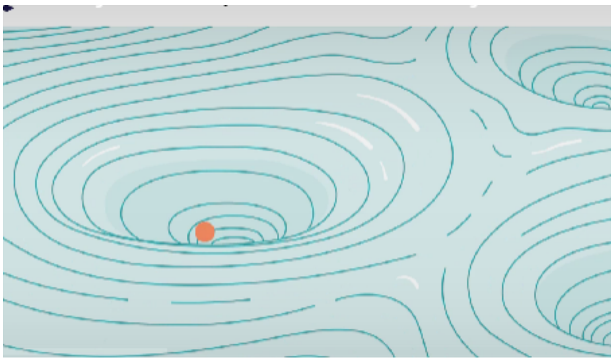
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Socioecological system perspectives



Another representation: we have a resource, exploited by operations that rely on peoplle coming.
With all these systems, as we increase the complexity, such systems can actually still as multiple states. The system can stay in the state and then, if the change is very big, it can go to another state



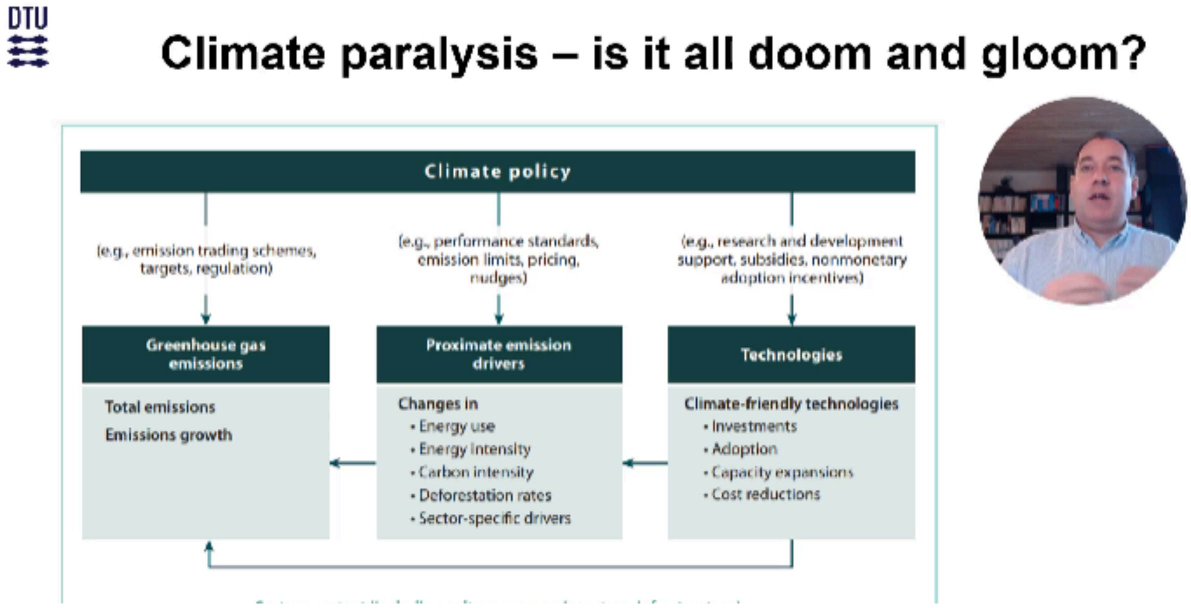
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

So from the sustainability perspective, if we are in a sustainable state, how we make sure that out ball states in that state. And if its not, how can we push it to s stat that is sustainable
System interventions: can be both public and private system driven to act on different components: individual, manufacturing etc
Example of public manipulation:



Trying to make changes across nations so that we reduce green house emissions either by reducing green hose or changing technologies.
And actually if we look at the actions that are emerging from global agreements from regulatory developments, we can see that the actions actually help reduce

Simple model for estimating Global Warming Potential

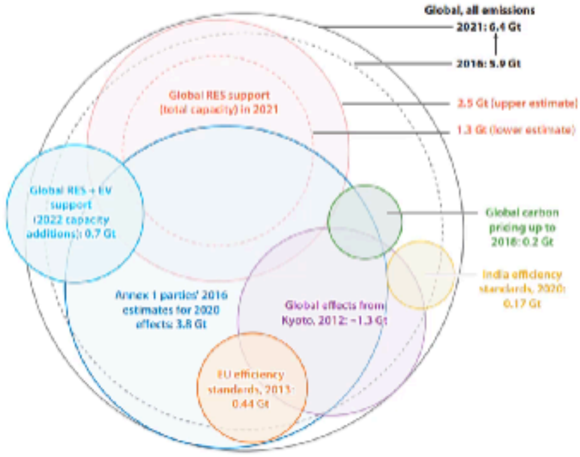
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Climate paralysis – is it all doom and gloom?

- Policy support for renewable development and uptake has been relatively most impactful to date



Amount of emission that have been saved thanks to systemic interventions of the governenments. Policies for renewable development have been the most helpful.

Simple model for estimating Global Warming Potential

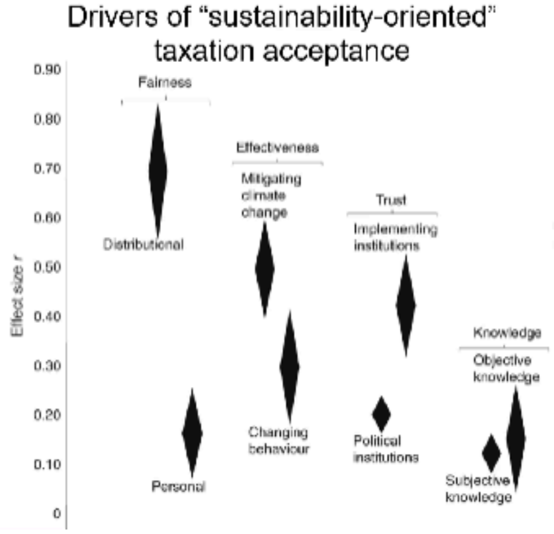
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

The carrot and the stick

- Economic interventions: pricing, taxation, subsidies
- Internalise in price of goods & services their socioecological costs



So how do we design policies, measures, interventions that cacn affect gas emissions knowing that we have to do that intervention in many component activities.
Economic interventions: taxation, pricing, subsidies: introducing carbon tax or cost for example. Offer subsidies for renewable resources for example.

Hardle: citizens need to accept in democratic systems. Approach for taxation: fairness - equitability . Perception of distribution of taxes. If you demonstrate that your actions will have a positive effect and fair for society, then most people will accept it

value creation: demand creates market opportunities across different markets

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

- There is public demand for ‘more sustainable’ goods & services
- A market creating opportunities (value creation)
- n.b. data showing the sustainable ‘value’ of goods & services is therefore valuable

Behavioural interventions

- All of this works if people are interested in the new goods and services or can change habits
- The concept of nudging, as a public policy tool, has been proposed as a way to change the average behaviour of population to increase sustainability.
  –(2017 Nobel Prize in Economic Sciences)

Try to find a way so that people change habits and their behaviour so that system has more sustainable outcomes. One way: nudging

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Nudging and plastic bags

- 5 pence levy fee introduced in Scotland in 2015
  - About 80% reduction in bags used (replicated in England, Wales and Northern Ireland)
- 2021: levy increased to 10p (partly to 're-shock' the system)
  - There is a dampening of the effect over time

Introducing small fee for plastic bags in shops for example.
Latency effect: after a while people think is not that much, and then they go back to some habits. So sometimes an adjustment needs to be done
Nudging: some papers say it nis not useful

How do we estimate this effects?

Methods - summary

- From a SES map to understanding its state, transient dynamics, and drivers of dynamics
- System dynamics (a branch of Ergodic theory)
  - Deterministic approach:
    - Coupled ODEs (and PDEs)
    - Qualitative approach: causal loop analysis / Bayesian Belief Network
  - Stochastic approach:
    - Simulations: agent-based models / multi-agent models

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

From a system where I can represent how different components are interacting, I understand many things: states, drivers, transient dynamics, etc.

Simulations: agent-based models because we put some rules and we analyze how it behaves under those rules

If I have a system of interest. There is a tractability challenge: to understand how changes on this different components is affecting viable outcome. The dynamics and emerging properties often are impossible to estimate

DTU

Agent-based models – what does this mean?

- Systems of interest are often composed of many interacting components and can exist in multiple states
  - Tractability challenge
- Their dynamics and emergent properties (sustainability is often an emergent property) are often near impossible to estimate deterministically or statistically
- Stochasticity plays a non-trivial role in system dynamics
- We can replicate a model of the interacting components to assess when to simulate their behaviour and estimate parameters of interest

Example: socioeconomic models.

Tourism and recreation has biodiversity footprint.

DTU

Simple model for estimating Global Warming Potential

DTU Wind Energy

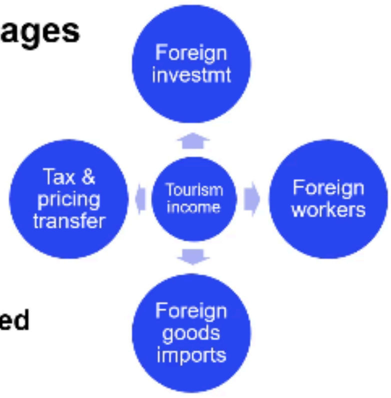
Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Threats	all	marine
Habitat modification	6,491	1,569
Disturbance	4,291	1,097
Both	**8,836**	1,757
Total species assessed	147,517	17,081
Proportion of assessed	6%	10%

We are introducing disturbance on behaviour and area of animals and plants. And this have conservation impacts. Close to 9k species has a conservation threat.
And then, tourism also have economic leakages: so money generated might not state in the community where it was generated.

Tourism & recreation economic leakages



1 € spent on tourism generate the following value added

country	Inbound tourism	Domestic tourism
Spain	**0.97**	**1.22**
Portugal	0.78	0.55
Italy	**1.20**	**1.14**
Germany	~0.63	~0.63
UK	0.67	0.51

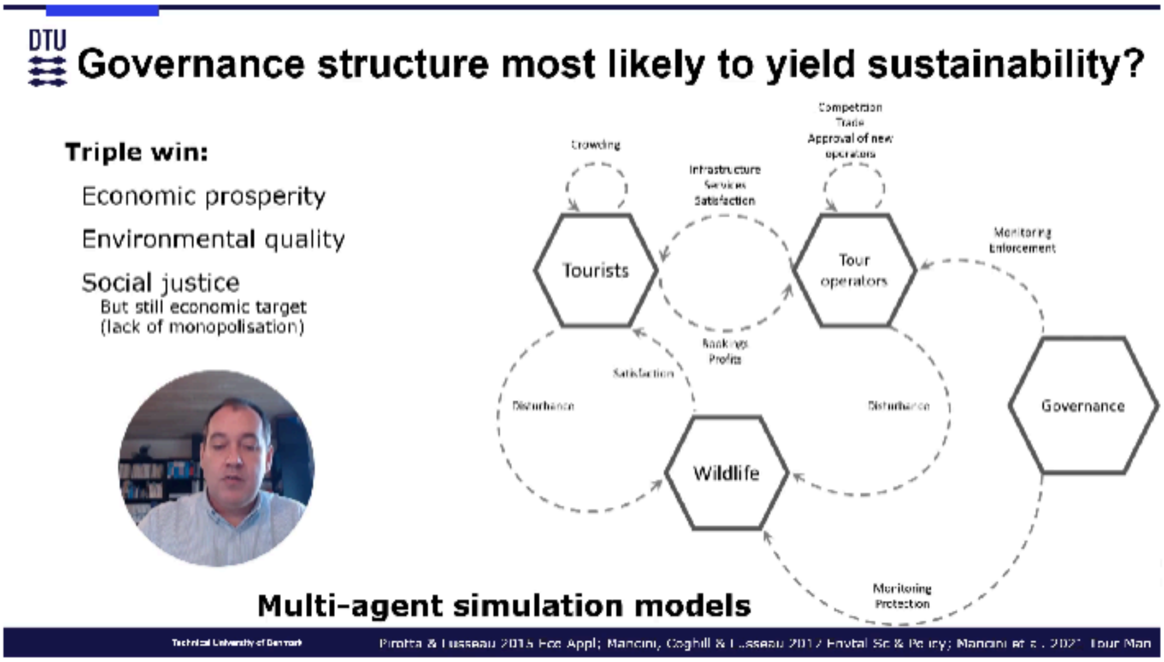
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

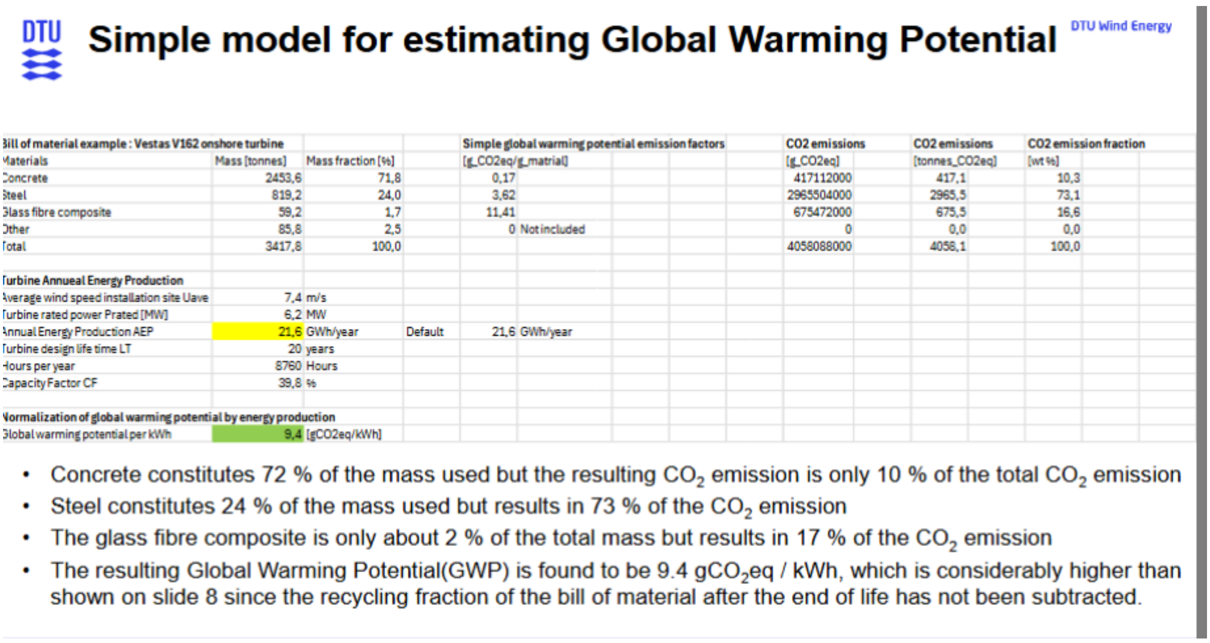
- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

How do we develop an integrative model of resource management actions in such a couple nature- human systems?



How do we design this? Social justice: there is no monopolizaiton. Many years of work. This is actually used.

With this model, we can then build a simulation



DTU Wind Energy

Simple model for estimating Global Warming Potential

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Governance models

- Structures
  - Free market
  - Regulations
  - Hybrids (eg Cap and Trade/co-management)
- Accounting for
  - Responsibility assignment
  - Uncertainties (mngnt & monitoring)
  - Operator & customer behaviour

Knowledge is not perfect so there are some uncertaintiyes, and then we can account for different behaviour

Simple model for estimating Global Warming Potential

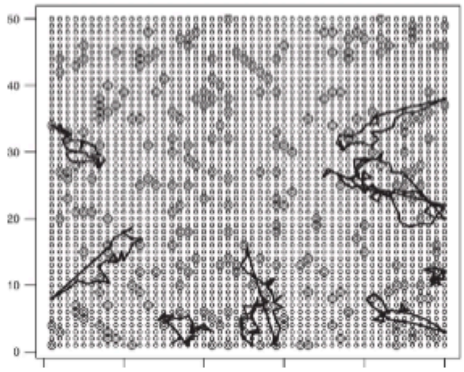
DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

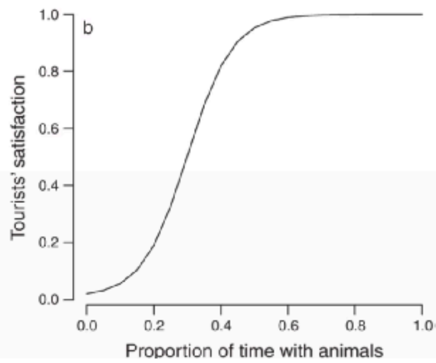
Tour operator component

- Realistic microeconomic decision in varying business models
- Tuned simulated tours and encounters
- Account for operator phenotypes indecision making:
  – optimist, pessimist, trustful or envious
- Rating dependent on tourist satisfaction



Tourists component

- Account for tourist phenotype and stochasticity in socioeconomic demography
  – specialists, generalists, mixed
  – income groups influencing willingness to pay
- Satisfaction dependent on time spent with animals
- Seasonal and annual trends in daily numbers



Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

Advantage: we can tune both models to particular situation and we can also explore the models. So we can find that out of all the governance approaches, that is most resilient and provide the most sustainable outcome, it is the Community eld public-private partnership.
It is important to adapt management, we need more specialists or not
Who you attract to destination is also affecting the sustainability

Outcomes: sustainable governance space

Community-led public-private partnerships

offer the wider sustainable space (over management error & defection rate)

Adaptive management

Changes with destination maturation phases

Tourist typology

Tourist behaviour & typology drives sustainability too

Summary:
how agent -based modelling can be used to make realistic information and advice on how to intervene in a system to get sustainability
We have a toolkit of systemic interventitions: governmental, economic, behavioural. This can change the functional relationships in way people use the planet
Mathematical tools: to understand how system can change state

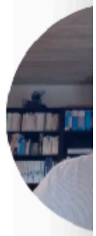
Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.

summary



- We have a toolkit of systemic interventions that can change functional relationships in the way people use the planet
- We have the mathematical tools to understand whether and how system can change state and identify factors that can drive this change
- Systemic changes to improve 'sustainability' are possible but contextual (the same change will not necessarily provide the same systemic outcomes across systems)

Simple model for estimating Global Warming Potential

DTU Wind Energy

Bill of material example : Vestas V162 onshore turbine				Simple global warming potential emission factors		CO2 emissions	CO2 emissions	CO2 emission fraction
Materials	Mass [tonnes]	Mass fraction [%]		[g_CO2eq/g_matrial]		[g_CO2eq]	[tonnes_CO2eq]	[wt %]
Concrete	2453,6	71,8		0,17		417112000	417,1	10,3
Steel	819,2	24,0		3,62		2965504000	2965,5	73,1
Glass fibre composite	59,2	1,7		11,41		675472000	675,5	16,6
Other	85,8	2,5		0	Not included	0	0,0	0,0
Total	3417,8	100,0				4058088000	4058,1	100,0
Turbine Annueal Energy Production								
Average wind speed installation site Uave	7,4	m/s						
Turbine rated power Prated [MW]	6,2	MW						
Annual Energy Production AEP	21,6	GWh/year	Default	21,6	GWh/year			
Turbine design life time LT	20	years						
Hours per year	8760	Hours						
Capacity Factor CF	39,8	%						
Normalization of global warming potential by energy production								
Global warming potential per kWh	9,4	[gCO2eq/kWh]						

- Concrete constitutes 72 % of the mass used but the resulting CO_2 emission is only 10 % of the total CO_2 emission
- Steel constitutes 24 % of the mass used but results in 73 % of the CO_2 emission
- The glass fibre composite is only about 2 % of the total mass but results in 17 % of the CO_2 emission
- The resulting Global Warming Potential(GWP) is found to be 9.4 gCO_2eq / kWh, which is considerably higher than shown on slide 8 since the recycling fraction of the bill of material after the end of life has not been subtracted.