What is a sustainable development?

a materials perspective

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Learning objectives for this lecture unit

Ansys software mentioned	• Ansys Granta EduPack™, a teaching software for materials education

Intended Learning Outcomes	
Knowledge and Understanding	Understanding the role of materials in sustainable development
Skills and Abilities	Ability to analyze a proposed development
Values and Attitudes	Realization of the complexity of sustainable development

Resources

- **Text:** "Materials and Sustainable Development", by Mike Ashby, Didac Ferrer Balas and Jordi Segalas Coral, Butterworth Heinemann, Oxford, 2015
- Ansys Granta EduPack software Sustainability Database

Outline of the lecture unit

- *The idea of sustainable development*
- *Triple bottom line and the three capitals*
- *Stakeholders*
- *Fact finding*
- *Integration and reflection on outcomes*
- *The Ansys Granta EduPack Sustainable Design database*
- *Case study: Wind Turbines*

The evolution of materials science

Yesterday

Today

Tomorrow (2)

Polymer science
- **Metallurgy**

Ceramic science

Mechanics,

Structures
- **Materials science**

Design

Economics

Sustainability

Environmental
- **Materials systems and design**

Economic, Legal

Social impacts

Sustainability

Fuel efficient, but sustainable?

Safe, but sustainable?

The starting point

Mission statement

Provide a framework within which a student can form critical, independent assessments of "Sustainable Developments"

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

Report of the Brundtland commission of the UN, 1987

- ***But how?***
- ***And where do materials fit in?***

Headlines

"Chinese company produces world's largest 16 MW wind turbine " (Global times, 23 November 2022).

"The SDG Summit in September (2023) must be a moment of unity to provide a renewed impetus and accelerated actions for reaching the SDGs"

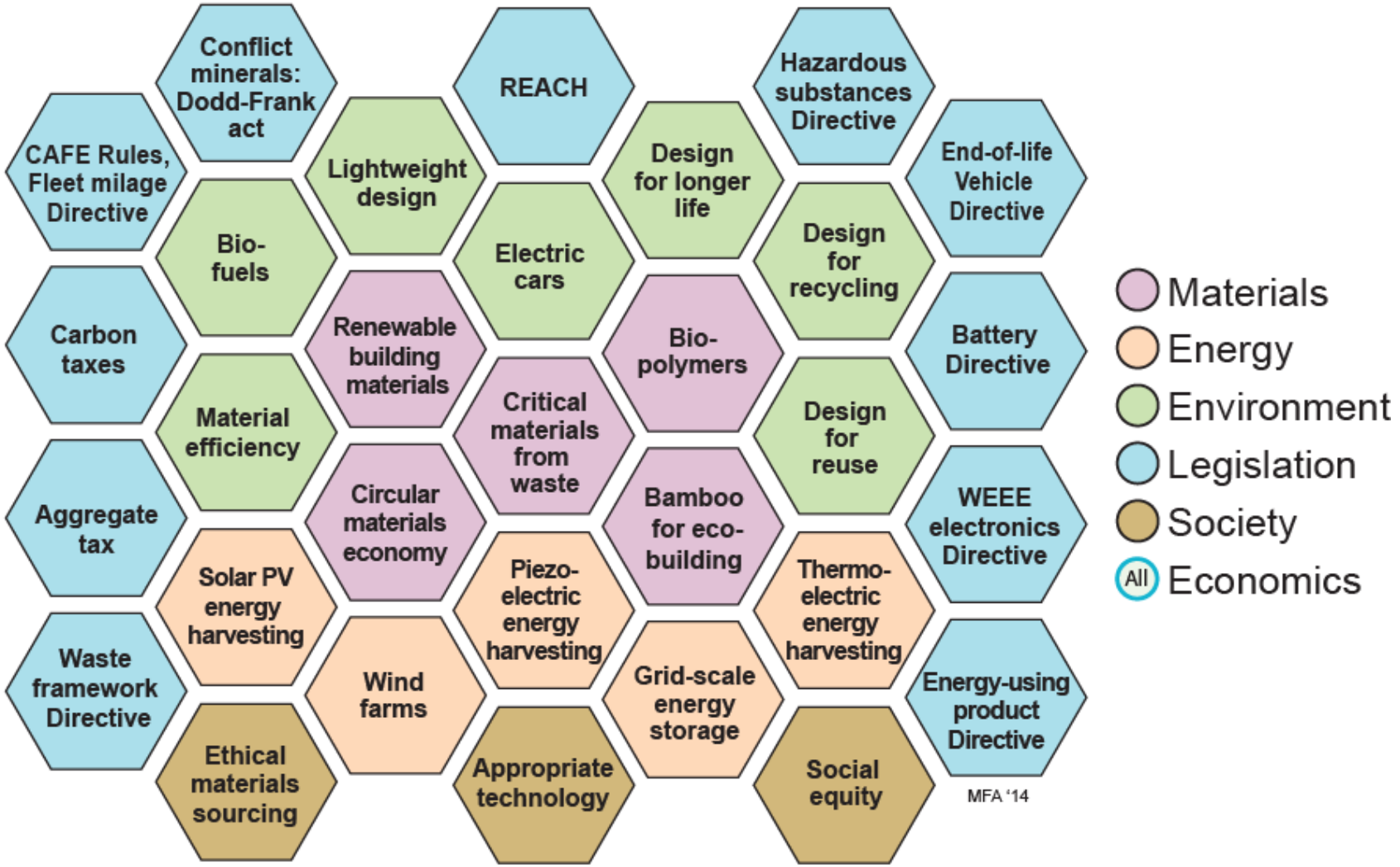
– Antonio Guterres, United Nations Secretary-General, 2023

"Half of all new cars must be electric by 2030 to meet emission targets"
– The Times, 26 November (2015)

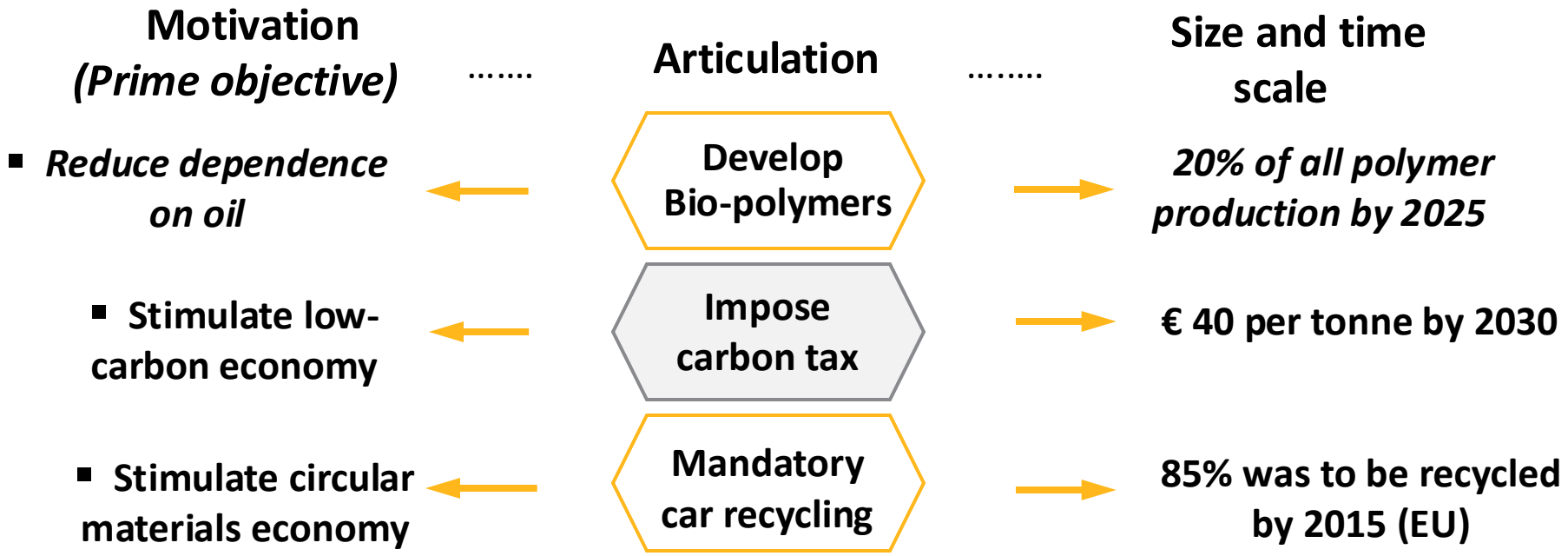
"Recycling turbine blades: the Achilles heel of wind power" (euronews.com 27 June 2021)

"Articulations" of sustainable development

“Articulations” of sustainable development



Objective, size and time-scale



Each articulation has a

- ***Objective***
- ***Size scale***
- ***Time scale***

Needs FACTS

Layer 1
Define objective, size and timing

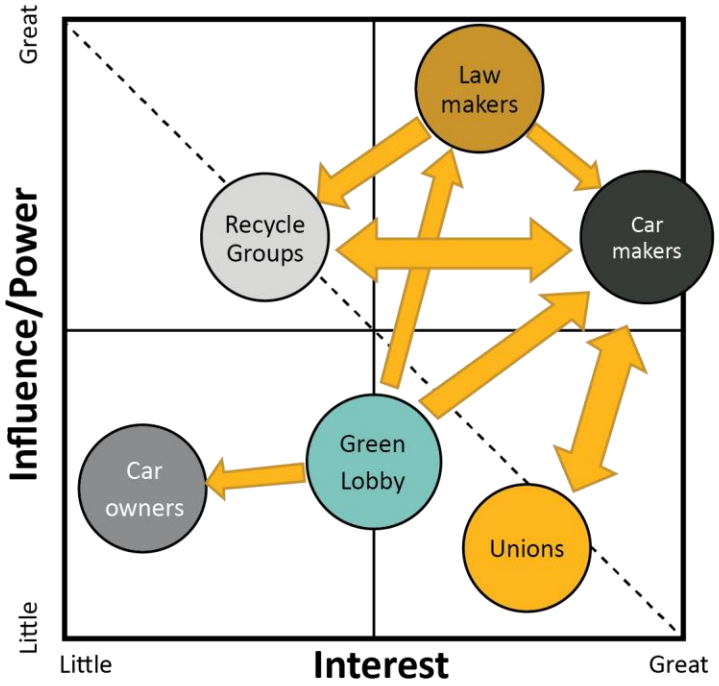
The context: stakeholders

Stakeholders

- ***Who are they?***
- ***What are their concerns?***
- ***What power do they have?***

- ***Government***
- ***The public***
- ***Local communities***
- ***Owners***
- ***Manufacturers***
- ***Suppliers***
- ***Trade Unions***
- ***Customers***
- ***Lobbyists***
- ***Investors***
- ***National press***
- ***Managers, colleagues, team***

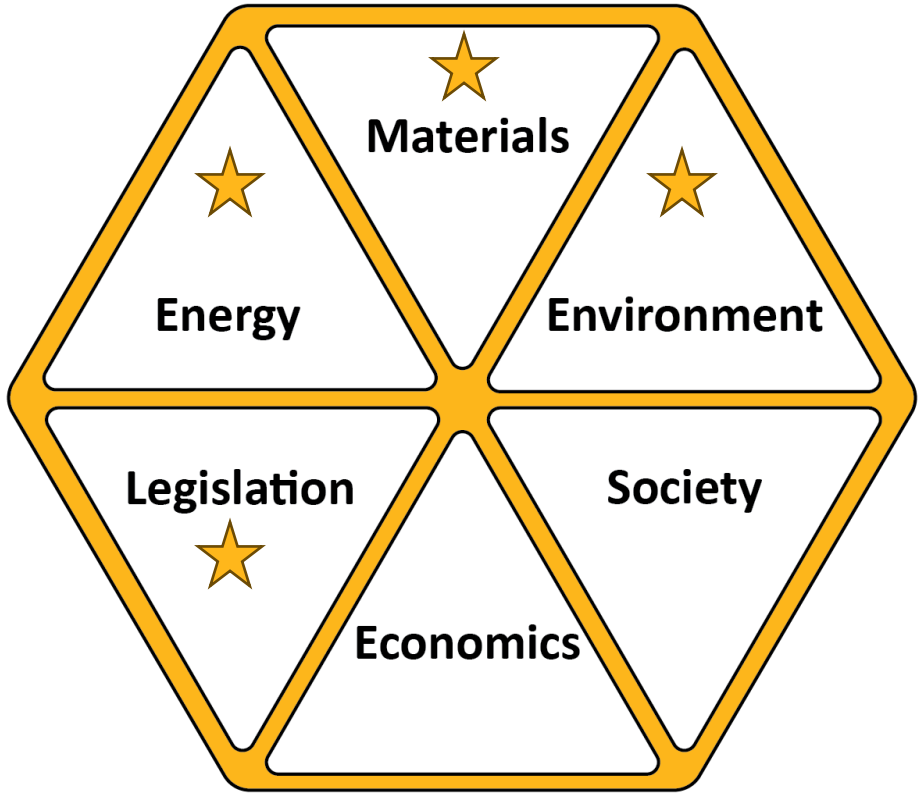
Mandatory recycling of cars



Layer 2
Stakeholders and their concerns

Needs FACTS

What FACTS do we need?



Layer 3

Fact-finding

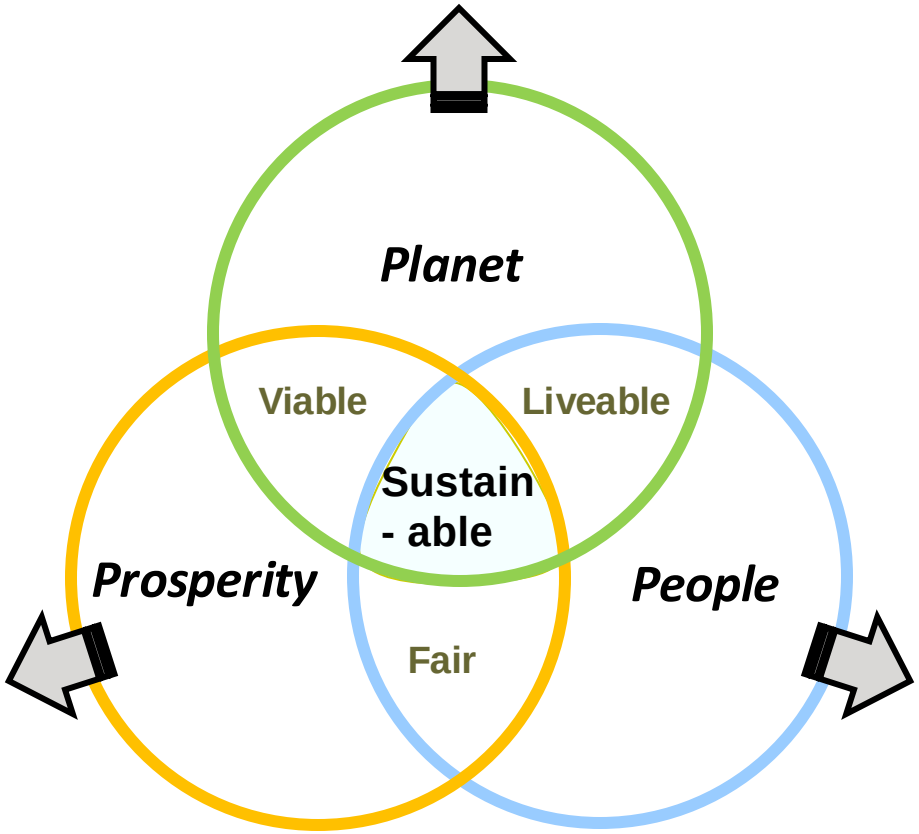
Material-efficient design

Resource-efficient design

Eco-design

Sustainable design

The business view: triple bottom line accounting



Corporate sustainability report (SR):

- *Financial bottom line*
- *Social / ethical performance*
- *Environmental performance*

Analyzing an “articulation”

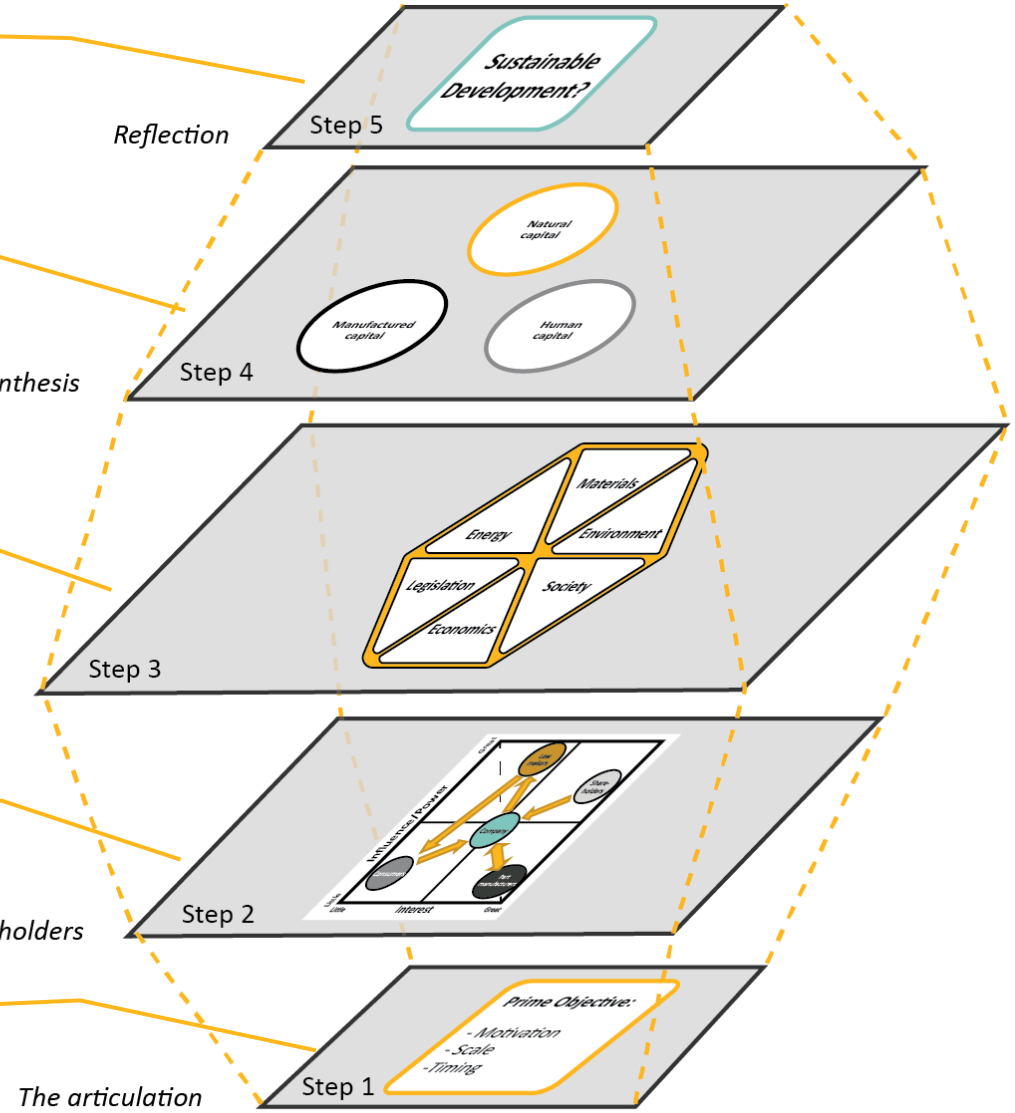
Reflection

Synthesis ***(Subjective)***

Fact-finding ***(Objective)***

Stakeholder *analysis*

Define ***objective***



1 Objective

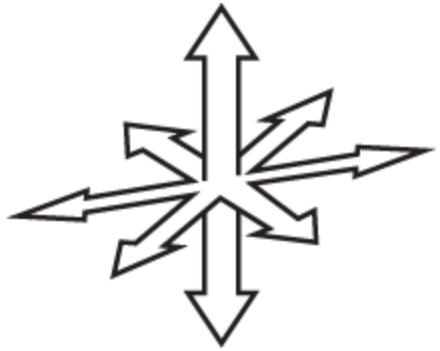
2 Stakeholders

3 Fact-finding

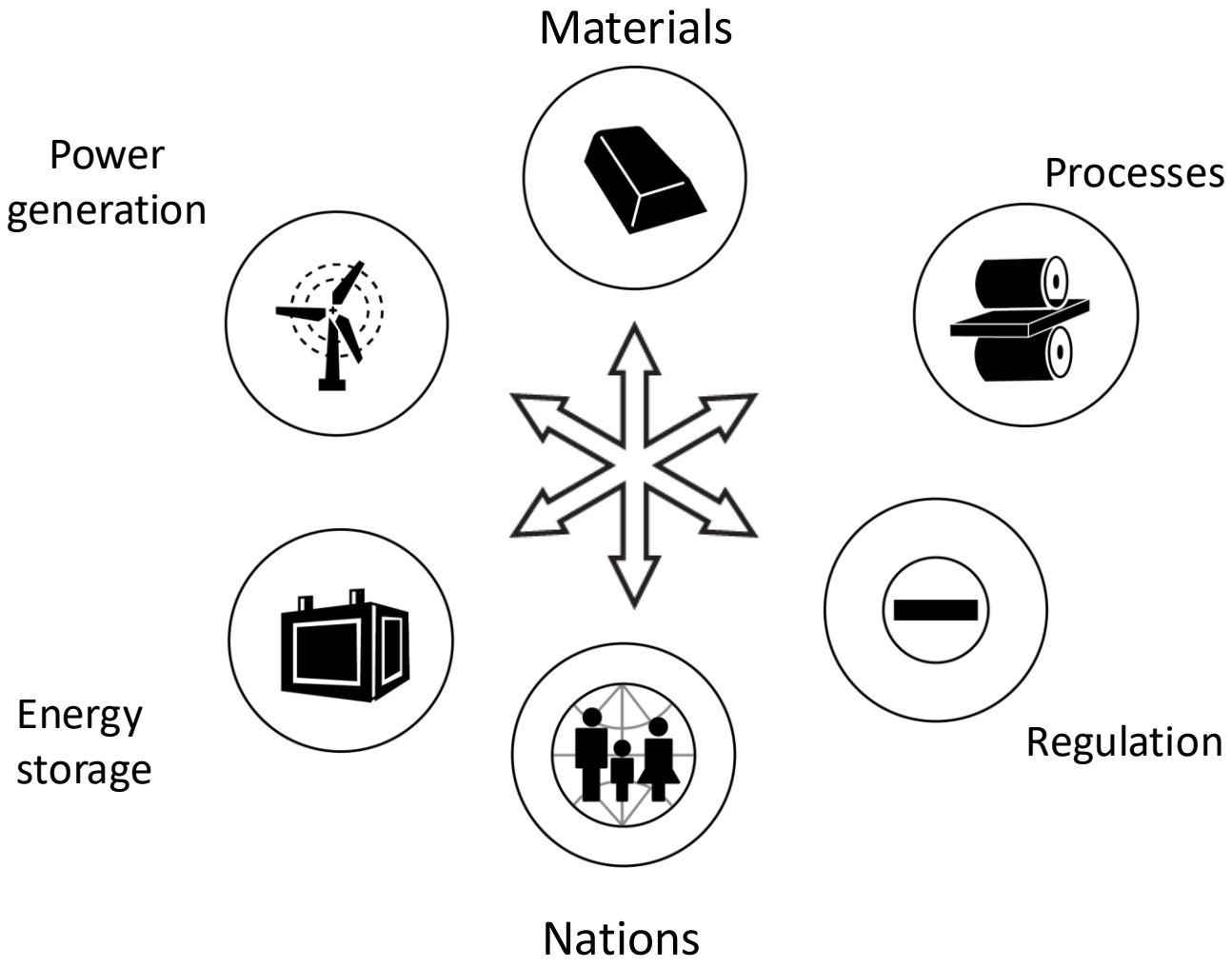
4 Synthesis

5 Reflection

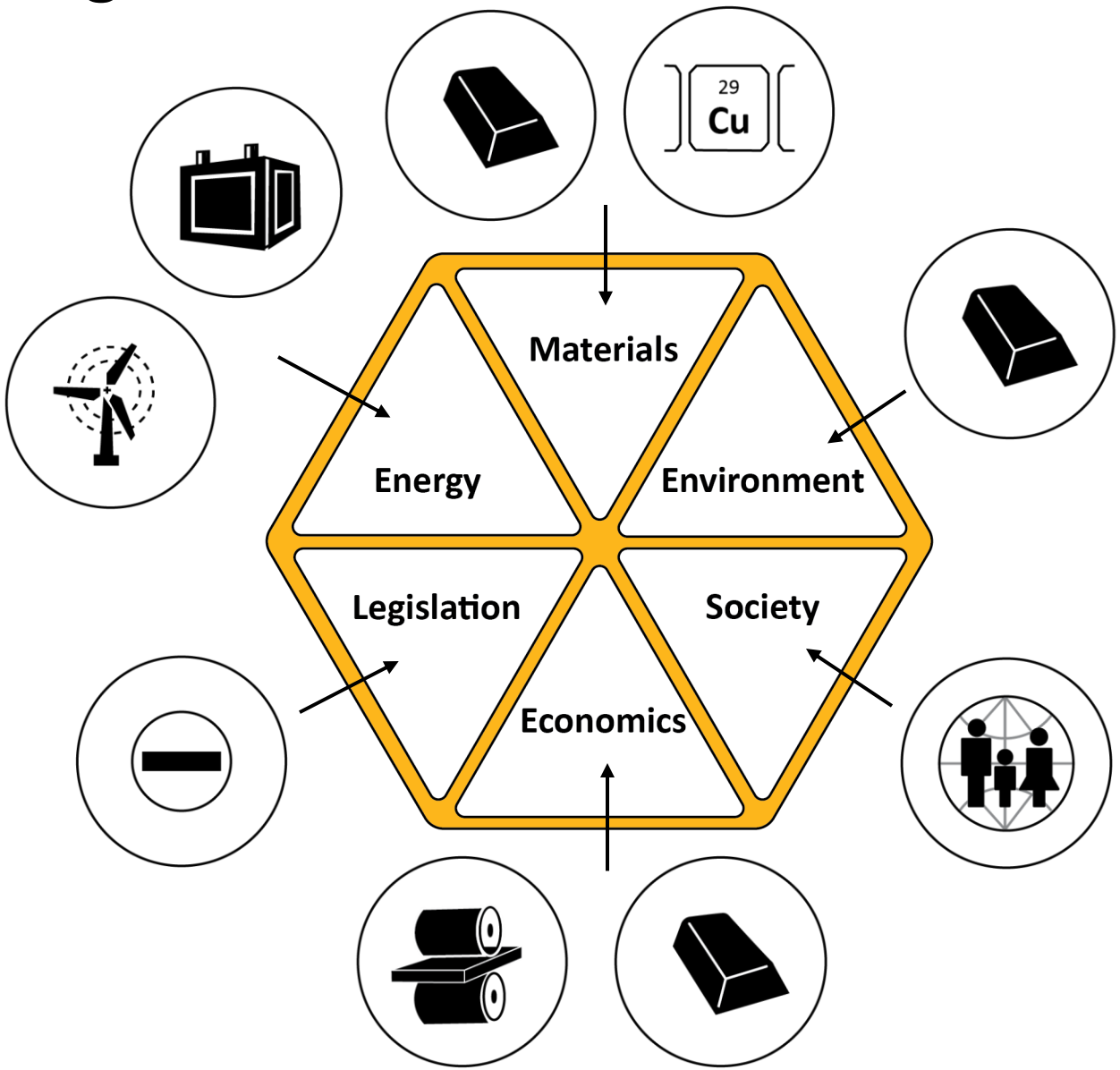
Interaction between layers



Ansys Granta EduPack Sustainability Database for fact-finding



Fact finding alignment



Case studies

Biopolymers

Plastic Books

Electric Appliances

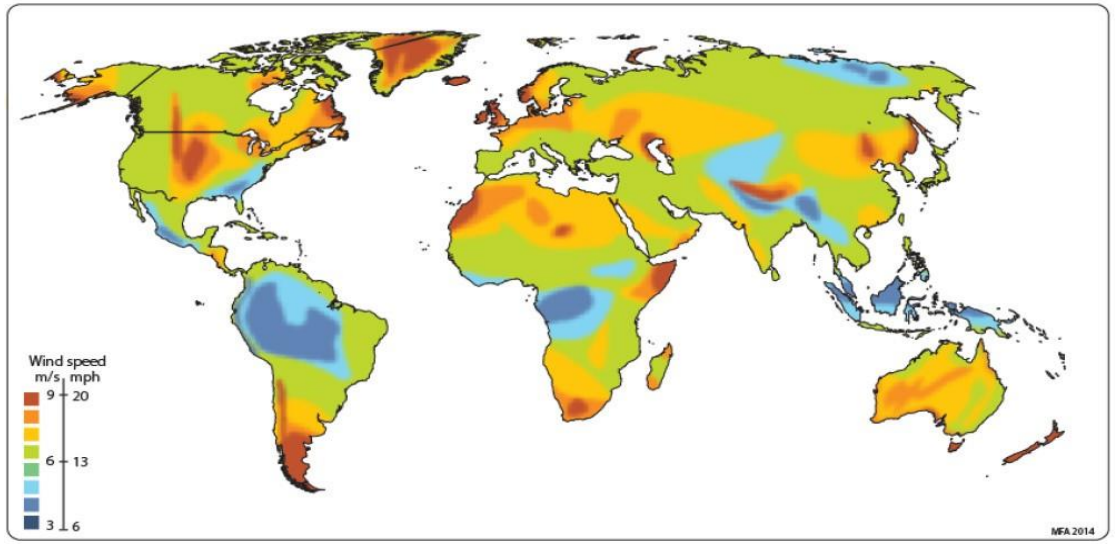
Built Environment

Wind farms

Step 1: the articulation, objective, size, and time scale

- **Objective:** to reduce global carbon emissions and increase energy self-sufficiency
- **Size scale:** Growing currently installed capacity of wind turbines to 3,200GW which averages 300GW of newly installed every year
- **Time scale:** by 2030

Layer 1

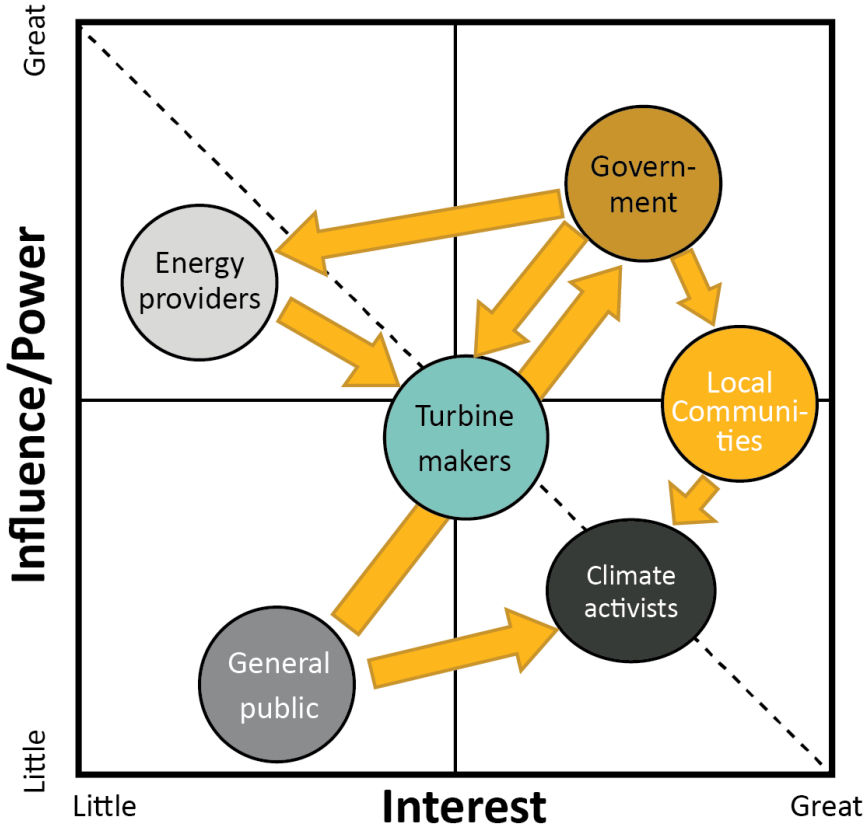


A global map of average wind speed

Step 2: stakeholders and concerns

Summary of the significant concerns

- The security of supply of the critical materials on which wind turbines depend.
- Wind farms don’t reduce carbon emissions
- Wind farms are uneconomic without subsidies
- Wind farms are visually unacceptable.
- Wind farms are a danger to wild life
- Turbine blades raise landfill concerns as not recyclable



Layer 2

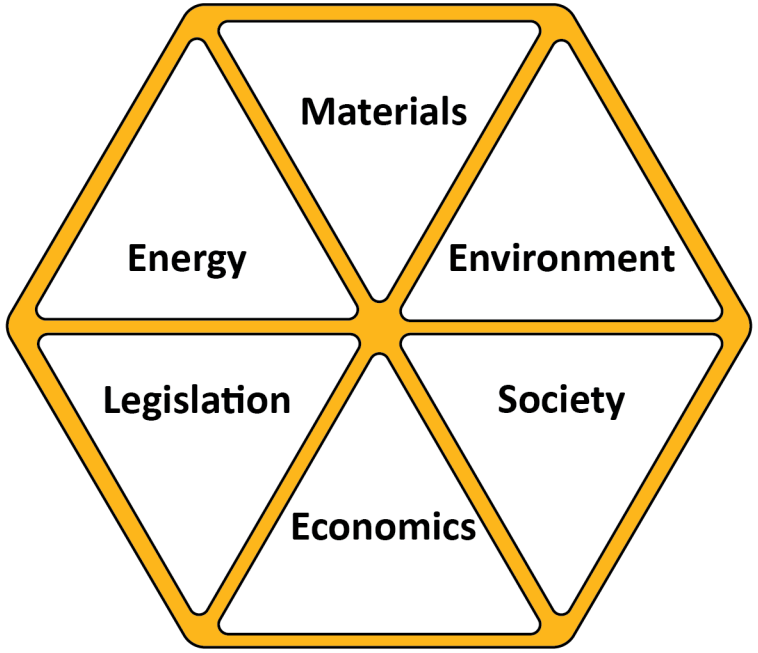
Step 2: stakeholder details

- *National and Local Government.* National Administrations have made commitments to reduce carbon emissions over a defined time period. They see wind farms as able to contribute, but also as a source of local wealth and employment. To encourage their construction they subsidize renewable energy production and impose taxes on carbon emission
- *Energy providers.* Carbon taxes or carbon trading schemes and carbon penalties create financial incentives for energy providers to reduce the use of fossil fuels.
- *Wind turbine makers.* Turbine makers want assurance that government policy on renewable energy is consistent and transparent, that incentives will not suddenly be withdrawn and that the supply chain for essential materials is secure.
- *Local communities and the wider public.* The acoustic and visual intrusion of wind turbines and their power- distribution system is seen as unacceptable by some, as is the danger they pose for birds or other ocean wildlife.
- *Recycling companies*. While 90% of a wind turbine can be recycled, there are no options available at the end of life for blades, outside of landfill or incineration.

Step 3: fact-finding

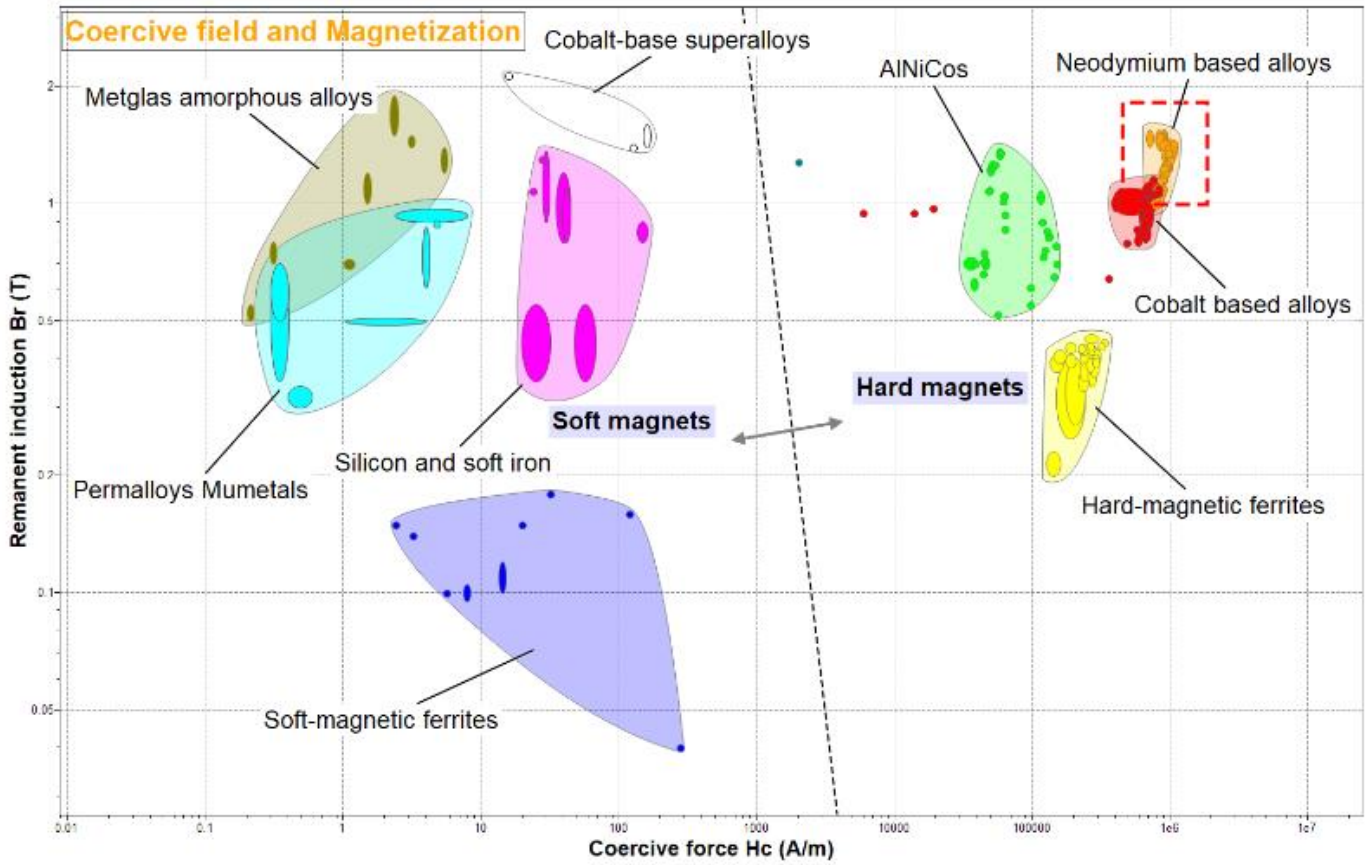
- **Summary of significant facts**

- Wind power can produce electrical power with significantly lower carbon emissions than gas or coal-fired power stations
- The construction energy of a wind farm is returned as electrical energy in 4-6 months
- Compact, efficient turbines require neodymium, categorized as critical, with significant supply-chain risk
- End of life scenario for the composite blades are not satisfactory
- The cost of energy from a wind farm has significantly dropped, reaching levels or below levels that of gas or coal-fired stations. This asset is mitigated as grid-scale energy storage is needed to smooth the intermittent generation.
- Wind farms are intrusive to the communities in which they are sited. If wind farms are to contribute a significant fraction (say 15%) of energy needs this intrusion becomes widespread.



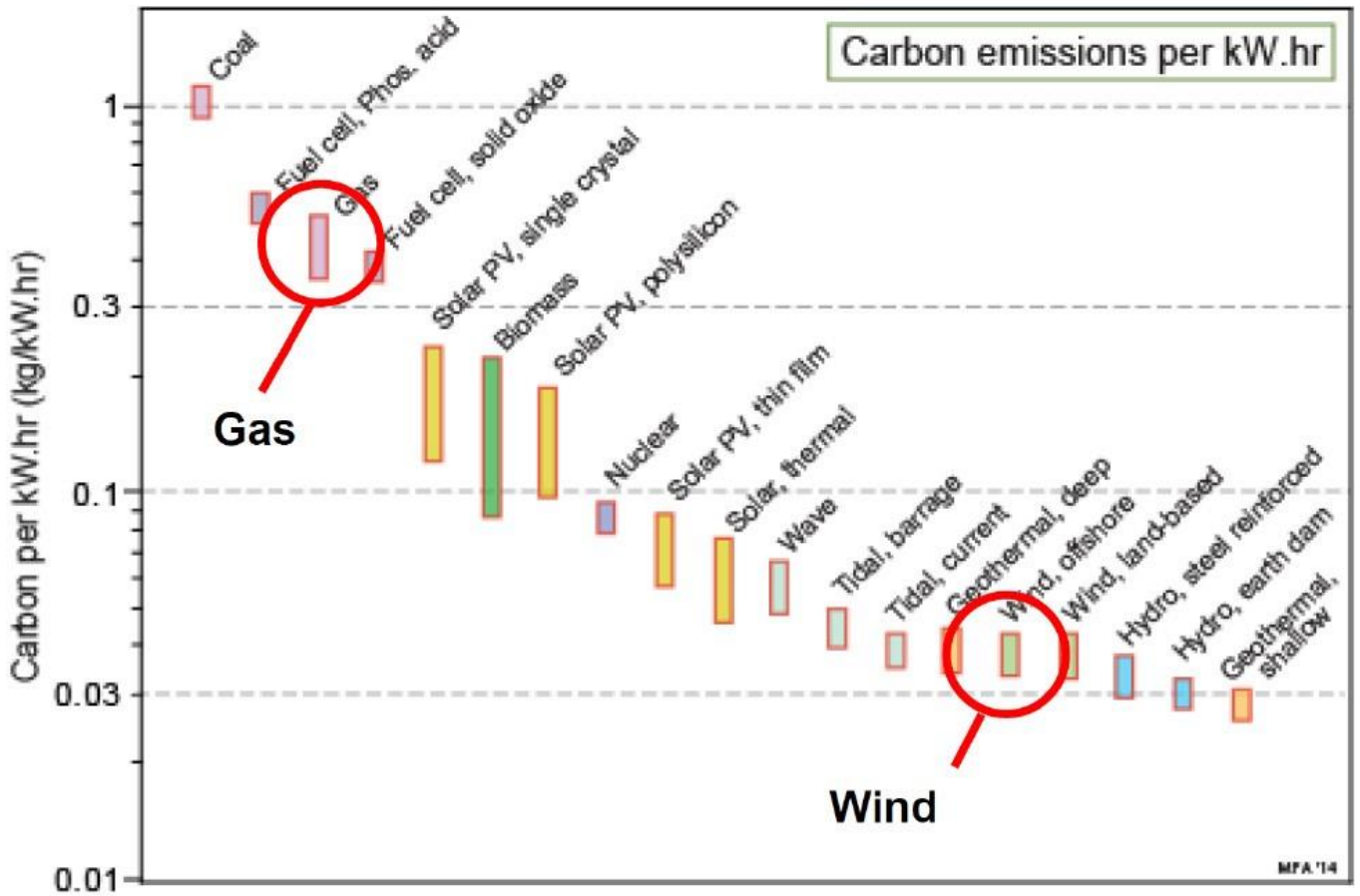
Layer 3

Fact-finding 3a



The remanent magnetization and coercive force of magnets, plotted from Ansys Granta EduPack software 2023 R2 sustainability lvl 3 database. Nd-B magnets rectangled in red.

Fact-finding 3b



The carbon emission per kW.hr of delivered power for alternative systems. They are approximate, but sufficiently precise to establish that wind power has the ability to generate electrical power with significantly lower carbon emissions than gas or coal fired power stations when averaged over life.

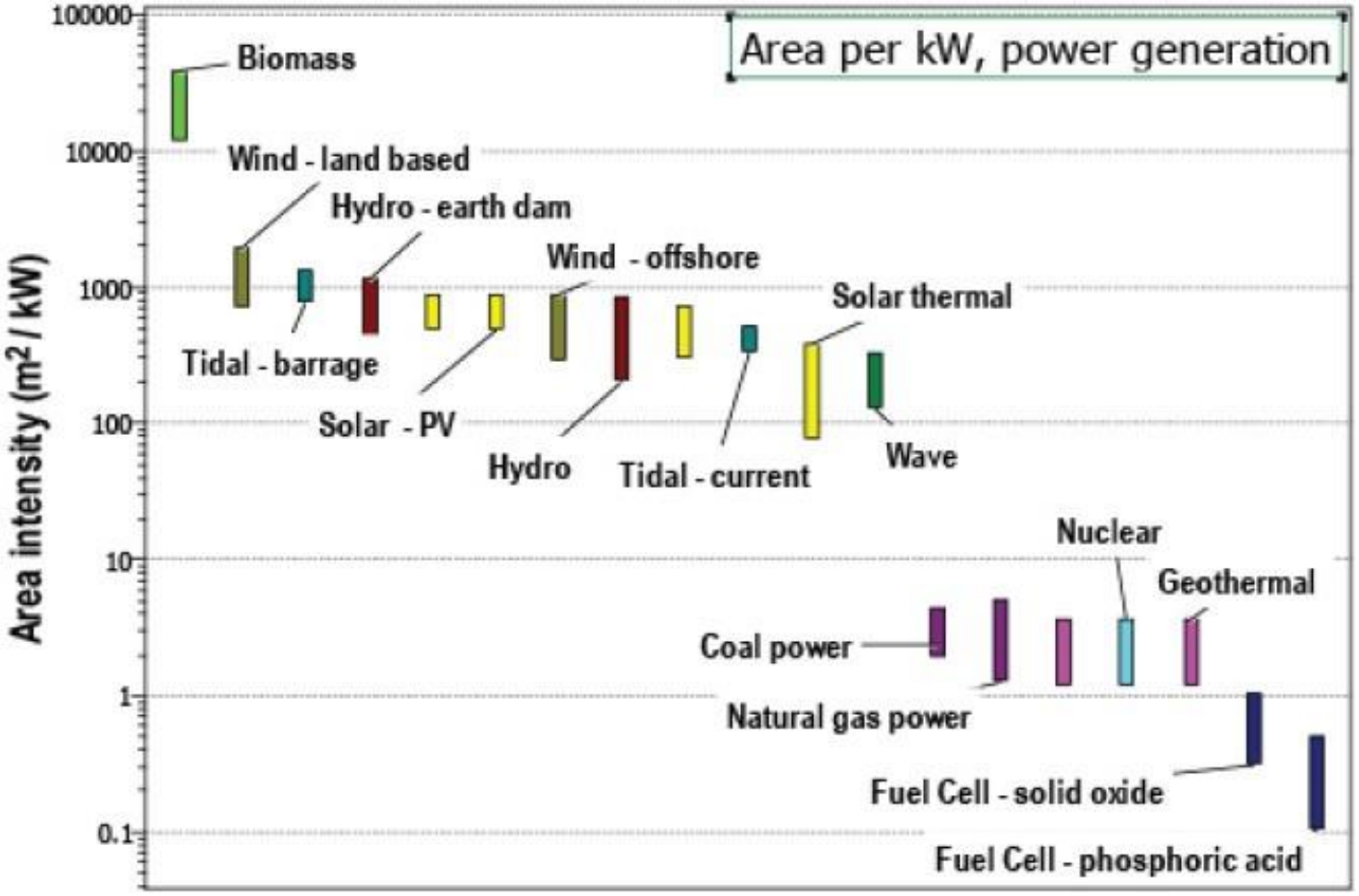
Fact-finding 3c

Neodymium is co-produced with other rare-earth metals, of which it forms 15% on average. The table lists the nations that produce rare earths and the quantities they produce.

Rare earth producting Nation	Tonnes/year (2022)
China	210,000
United States	43,000
Australia	18,000
Burma	12,000
Thailand	7,100
Vietnam	4,300
Other	5,600
World	**300,000**

https://pubs.usgs.gov/periodicals/mcs2023/mcs2023.pdf

Fact-finding 3d



Wind farms require a land-area per unit of generating power that is almost 1000 times greater than that of a gas-fired power station and while this land can still be used for agriculture the scale of the intrusion is considerable.

Step 4: Stacking the first three layers

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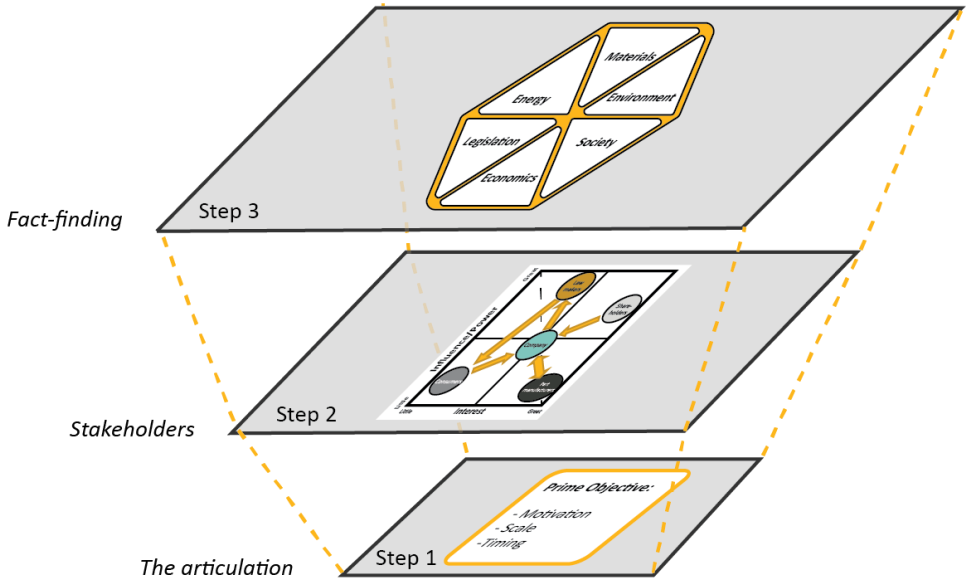


Step 4: forming a judgement

	Human capital - Health? Wellbeing? Convenience? Culture? Tradition? Perceptions? Equality? Morality?	Natural capital - Can prime objective be met? Material and energy demands? Impact on natural environment? Circularity?	Manufactured capital - Cost – Benefit? Conformity with law? Meets codes and standards? Legitimacy?
Materials			
Energy			
Environment			
Legislation			
Economics			
Society			
Synthesis			

Assess impact
Good? +
Bad? -

Debate acceptability

4a. Human and social Capital

On the positive side, large-scale deployment of wind farms creates employment. If these jobs and the wealth they generate are distributed in a fair and equitable way, a contribution is made to Human Capital. The reduction in emissions is a contribution to a healthier population. The mix of energy sources increases independence and a distributed rather than a centralized power system is more robust, harder to disrupt and less vulnerable to a single catastrophic event.

On the negative side, the visual and acoustic intrusion, already mentioned, represents to many people a significant loss of quality of life. Schemes to re-invest a proportion of the revenues generated by the wind farm in the local community in ways that help everyone, coupled with research to reduce the acoustic problem, offer a way forward.

4b. Natural Capital

The Prime Objective in building wind farms was to reduce green-house gas emissions. The studies cited above suggested that they can. The dependence on critical elements, particularly neodymium, for the turbines, is a concern for manufacturers in non-mining countries. The placement of wind turbines being fixed and known, and large groups of them are managed by a single operator, this can be addressed by making sure their recovery, reconditioning or recycling at end of life are scheduled. Encouraging a full life cycle management of wind farm is also a way forward in dealing with end-of-life scenario of fiber composite turbine blades, which management is not satisfactory.

Injury to bird life might be dismissed as trivial when domestic cats kill far more, but this is not a productive way to respond to stakeholder concerns – a more considered response and exploration of mitigating measures (ultrasound, perhaps) is a better way forward.

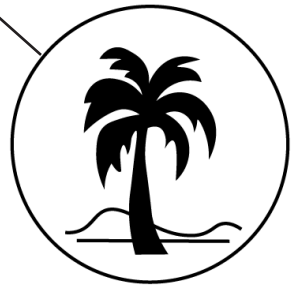
4c. Manufactured and financial Capital

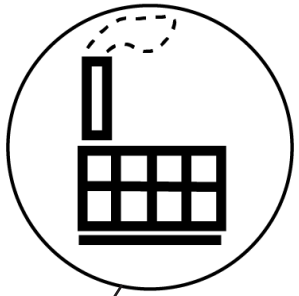
The typical design-life of a wind turbine is 25 years. Building the equivalent of 300GW of turbines per year is a significant investment in energy infrastructure. Is it a good investment? Recent farm deployments have competitive or even cheaper prices than fossil plants equivalents which can be a sign to encourage future investments by banks and hedge funds. However much questions remains on grid investments needed to cope with intermittency and decentralized characteristics of wind energy. Levels of financial gains will depend on storage technology evolution (like batteries) over the next 25 years and the cost of carbon-induced climate change.

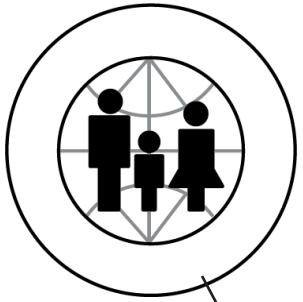
Step 4: Summary

Natural Capital

- x Visually and (sometimes) acoustically intrusive
- ✓ Provides electrical power with lower emissions than gas or coal
- x materials of some components have scarcity or recycling issues







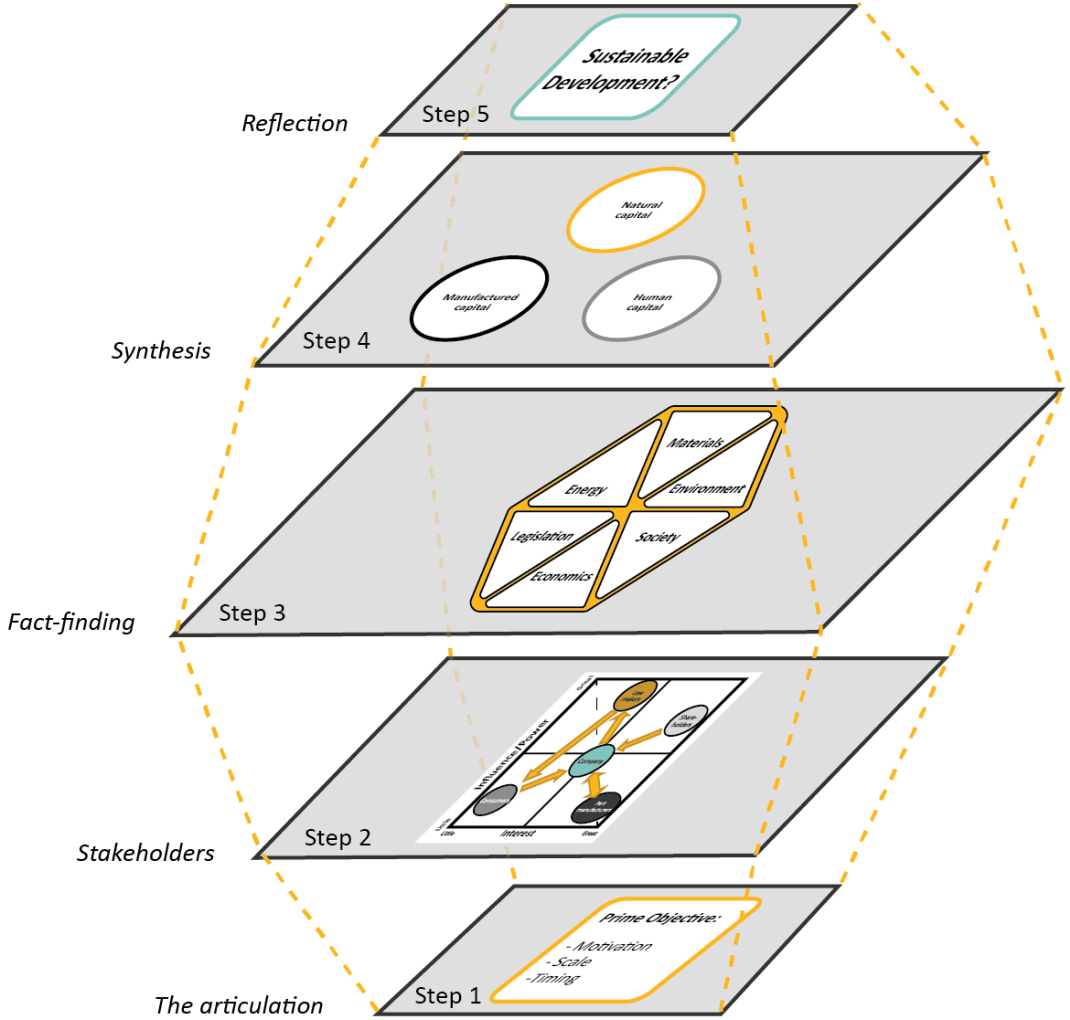
Manufacture Capital

- ✓ LCOE is competitive with other energy systems, construction costs per kW.hr are projected to continue dropping by 2030
- X Energy storage needed to smooth intermittent generation
- X Manufacturing capacities necessary to match ambitious goals do not exist

Human and Social Capital

- x Visual intrusion impacts quality of life
- ✓ Provides clean energy and a degree of energy independence

Step 5: Stacking the top layers



Step 5 – reflection, short and long-term

Short term

The Prime Objective of wind farms – to generate electrical power with a low carbon footprint – appears to be met, making a contribution to Natural Capital. By mixing onshore and off shore farm types and stressing out local employment and benefit distribution sites can be found for them without major disruption, and the reduction in emissions is a positive contribution to Human Capital. While wind energy has become economic, current manufacturing capacity cannot meet the deployment pace required by nations' pledges.

Long term

Energy is one of mankind's most basic needs and electrical energy is the most versatile and valuable form it takes. We are in transition from a carbon-powered economy to one powered in other ways but the detailed shape of the future is not yet clear. In recent reports wind is forecasted to cover up to 15% of electricity demand worldwide. Some countries like Denmark have wind providing already 50 % of Power generation of the country. Enabling such large-scale shift while solving the natural, manufacturing and human challenges raised here would not be an easy task.

Was the objective right?

Alternative strategies?

Summary

Energy is one of mankind's most basic needs and electrical energy is the most versatile and valuable form it takes. We are in transition from a carbon-powered economy to one powered in other ways but the detailed shape of the future is not yet clear.

A distributed energy-mix in the economy is desirable. Recent improvements in wind technology has made its economic case stronger and no longer subsidy dependent. However the impact of the cost of energy storage needed to smooth the intermittent power from wind is still under debate.

- **No completely "right" answer to questions of sustainable development**
- **Instead, a thoughtful, well-researched response recognising the conflicting facts and interests, seeking best compromise**
- **Layer-based approach database provides a practical framework**
- **Meets many ABET, CDIO and EUR-ACE Accreditation criteria**

Well suited for capstone projects and Problem-Based Learning (PBL)

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