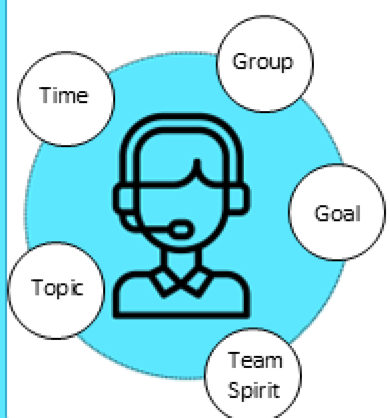
Carbon Cascadia
The Card Game

by Nils Matzner and Danny Otto

Your task

Climate change is already underway and CO_2 emissions are still rising. In addition to rapid emission reductions, international climate scientists see an urgent need for CO_2 removal (CDR) to avert the worst. Farmers, regulators, civil society actors, foresters, bioenergy producers, biochar start-ups, CO_2 storage operators and many others need to work together to establish the most effective, cost-efficient, enduring and sustainable processes possible to remove CO_2 from the the atmosphere. Only with joint efforts will they be able to achieve biomass-based CDR cascades, i.e. linking several biomass flows and CO_2 removal methods. The players cooperatively search for the best cascades.

Moderation



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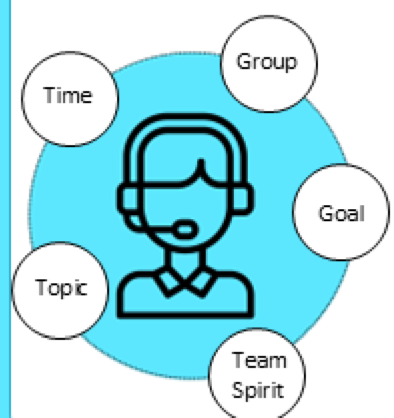

Time to take a tiny step back.

This card is a gentle signal that someone needs a bit more room in the conversation. It's friendly feedback, not criticism — thank you for pausing and taking it in.

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Forest Management

Forest Management

These are measures affecting the forest with an influence on its CO2 storage potential. They may involve the decommissioning of forest areas, the expansion of forest areas or afforestation measures.

Supplies biomass

Afforestation Beech

Stores CO_2

CO_2 removal potential (per ha and year)	≈ 3,8 t
CO_2 removal costs (per tonne of CO_2)	60-70 €
Storage permanence	<100 years

Special properties:
Full removal potential only from the age of 30

Forest Management

Afforestation with beech

The reforestation of beech-dominated, adaptable and resilient mixed forests as carbon sinks on areas previously not used for forestry (e.g. agricultural land) is carried out by planting seedlings. This allows carbon to be sequestered in the long term.

Supplies biomass

Afforestation Douglas fir

Stores CO_2

CO2 removal potential (per ha and year)	≈ 9,6 t
CO2 removal costs (per tonne of CO2)	8-9 €
Storage permanence	<100 Jahre

Special properties:
Full removal potential only from the age of 20

Forest Management

Afforestion with Douglas fir

The afforestation of Douglas fir-dominated, adaptable and resilient mixed forests as carbon sinks on areas previously not used for forestry (e.g. agricultural land) is carried out by planting seedlings. This allows carbon to be sequestered in the long term.

Stores CO_2

Decommissioning (beech)

CO2 removal potential (per ha and year)	≈ 14-16 t
CO2 removal costs (per tonne of CO2)	0 € (No investments)
Storage permanence	<100 years

Special properties:Full removal potential only from the age of 30

Forest Management

Permanent decommissioning (example beech)

The concept envisages the permanent abandonment of the management of old beech forests. Germany has an abundance of beech forests, about half of which are 100 years old and older. Due to their growth characteristics, they are able to accumulate high carbon stocks and store them beyond the usual rotation periods.

Supplies biomass

Afforestation Oak

Stores CO_2

CO2 removal potential (per ha and year)	≈ 1,1 t
CO2 removal costs (per tonne of CO2)	118-120 €
Storage permanence	<100 years

Special properties:
Full removal potential only from the age of 30

Forest Management

Afforestation with oak

The afforestation of oak-dominated, adaptable and resilient mixed forests as carbon sinks on areas previously not used for forestry (e.g. agricultural land) is carried out by planting seedlings. This allows carbon to be sequestered in the long term.

Supplies biomass

Afforestation Pine

Stores CO_2

CO2 removal potential (per ha and year)	≈ 4,8 t
CO2 removal costs (per tonne of CO2)	17-20 €
Storage permanence	<100 Jahre

Special properties:
Full removal potential only from the age of 20

Forest Management

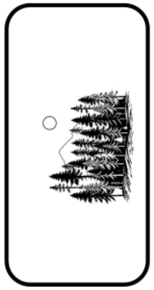
Afforestation with pine

The afforestation of pine-dominated, adaptable and resilient mixed forests as carbon sinks on areas previously not used for forestry (e.g. agricultural land) is carried out by planting seedlings. This allows carbon to be sequestered in the long term.

Forest Management

Expansion of forest area (succession)

The concept aims to allow a change in land use on previously unforested areas in Germany. Consciously allowing and controlling natural succession in the form of predominantly natural seeding enables long-term CO2 enrichment in trees and soils.



Supplies biomass

Forest area expansion

Stores CO_2

CO2 removal potential (per ha and year)	context-dependent
CO2 removal costs (per tonne of CO2)	context-dependent
Storage permanence	<100 years

CO_2 storage (geological)

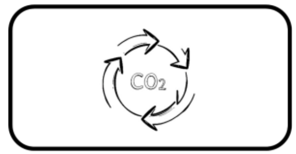
Stores CO_2

CO_2 storage capacity in Germany Europe	 ≈ 2,3-12,8 Gt ≈ 200 Gt
CCS costs (per tonne CO_2)	20-70 €
Storage permanence	>1000

Special features: Requires additional infrastructure for transport of CO_2

Storage of CO_2 in geological formations

Captured CO_2 can be permanently stored in various geological formations (e.g. saline aquifers, former natural gas fields) at depths of more than 800 metres. The CO_2 to be stored can come from various sources. The information on costs focuses on CO_2 from biomass-utilising energy production processes (including biogas production, biomethane production) and includes capture, transport and storage.



CO_2 utilisation

CO_2-Potential (per t and year)	Context-dependent
Costs (per tonne of CO_2)	Context-dependent
Storage permanence	Context-dependent

Special features: Requires additional infrastructure for transport of CO_2

CO_2 utilisation

The captured CO_2 can be used in various applications, such as the production of fuels, chemicals, building materials or even agriculture. CCU helps to reduce CO_2 emissions while optimising the use of resources by using carbon as a raw material instead of treating it as a waste product. Unlike geological storage, the permanence of storage can only be determined on a context-specific basis.

Agriculture and soils

Agriculture and soils

These are agricultural measures that have an impact on the CO2 storage potential of the soil. These include no-till farming, conversion to permanent grassland, year-round soil cover, the use of organic fertilisers and agroforestry systems.

Supplies biomass

Agroforestry

Stores CO_2

CO2 removal potential (per ha and year)	≈ 5-20,8 t
CO2 removal costs (per tonne of CO2)	125-1144 €
Storage permanence	<100 years

Special properties: Long-term carbon storage ensured by woody plants

Agriculture and soils

Agroforestry

Agroforestry systems are land utilisation systems in which woody plants (trees, hedges, shrubs) are combined with agricultural land. This combination ensures greater carbon accumulation in the soil. The area under the trees can either be used for horticulture and arable farming or as pasture.

Supplies biomass

Year-round ground cover

Stores CO_2

CO2 removal potential (per ha and year)	≈ 1,2 t
CO2 removal costs (per tonne of CO2)	30-66 €
Storage permanence	Uncertain

Agriculture and soils

Year-round ground cover

With the year-round ground cover method, the arable land is covered with plants all year round, which leads to an increase in carbon input and carbon storage in the soil and avoids fallow arable land.

Uses biomass

Organic fertiliser/compost

Stores CO_2

CO2 removal potential (per ha and year)	≈ 0,8 t
CO2 removal costs (per tonne of CO2)	20-44 €
Storage permanence	Uncertain

Agriculture and soils

Organic fertiliser/compost

By adding organic fertiliser and compost to the soil, the carbon content in the soil is increased by the applied material itself and the physical soil properties and nutrient availability are also improved. Soil improvement increases plant productivity, which in turn increases carbon accumulation in the soil by the plants.

Supplies biomass

No-till

Stores CO_2

CO2 removal potential (per ha and year)	≈ 2,1 t
CO2 removal costs (per tonne of CO2)	52-115 €
Storage permanence	Uncertain

Agriculture and soils

No-till

With direct sowing, the crops are sown and harvested at the same time using a direct sowing machine. This reduces tillage and limits soil erosion. Furthermore, the organic carbon stored in the soil is protected and additional carbon is introduced into the soil through the permanent soil cover by the crops and their roots.

Supplies biomass

Permanent grassland

Stores CO_2

CO2 removal potential (per ha and year)	≈ 3,1 t
CO2 removal costs (per tonne of CO2)	77-170 €
Storage permanence	Uncertain

Agriculture and soils

Conversion to permanent grassland

The conversion of arable land into permanent grassland increases the potential for carbon storage in the soil due to the year-round plant cover and the greatly reduced tillage. The resulting sequestration of carbon in the soil by permanent grassland thus has a CO_2-reducing effect.

Rewetting

Rewetting of peatlands

The rewetting of peatlands refers to the restoration of a stable groundwater table at the surface. Rewetting drained peatlands can immediately reduce or stop the net CO_2 loss and can also lead to a new CO_2 fixation in the litter layer and in the peat. As long as the peatland remains wet, carbon is permanently fixed.

Decommissioning of the peatland area

Stores CO_2

CO_2 removal potential (per ha and year)	≈ 1-8 t
CO_2 removal costs (per hectare and year)	1000-17000 € (Construction, investment costs)
Storage permanence	as long as moor remains wet

Special characteristics: High GHG avoidance potential (27-36 tonnes of CO_2 per ha and year)

Rewetting of peatlands

Decommissioning of rewetted peatlands

Rewetted moors are no longer utilised. The water level is kept stable so that the moor remains permanently wet in order to ensure permanent storage.

Cost reduction to 100-1600€ per ha and year for care, maintenance and upkeep.

Supplies biomass

Paludiculture

Stores CO_2

CO_2 removal potential (per ha and year)	≈ 4 t
CO_2 removal costs (per tonne of CO_2)	6000-34000 € (Construction, investment costs)
Storage permanence	as long as moor remains wet

Special characteristics: High GHG avoidance potential (27-36 tonnes of CO_2 per ha and year)

Rewetting of peatlands

Paludiculture

Paludiculture is a productive land use on wet and rewetted peatlands. Paludiculture includes any kind of biomass utilisation, from harvesting spontaneous vegetation on semi-natural sites to newly established crops on rewetted sites, under conditions that preserve the peat body or even favour new peat accumulation. Running costs: 1200-1700€ per hectare and year

Bioenergy

Bioenergy

Bioenergy is obtained from organic materials such as plants or waste. In biogas production, organic material is fermented to produce biogas for energy generation. Biomethane is processed biogas that serves as a substitute for natural gas. Biomass gasification converts biomass into a combustible gas. An important process for CO_2 capture is BECCS, in which biomass is used to generate energy and the CO_2 released is stored long-term.

Uses biomass

Biogas production

CO_2-Potential (per t and year)	≈ 3200 t (in model plant)
Costs (per tonne of CO_2)	139-313 €
Storage permanence	Dependent on CO_2 re-utilisation

Special features: Requires additional infrastructure for transport of CO_2

Bioenergy

Biogas production

Biomass is fermented in biogas plants, producing a gas mixture of CO_2 and methane, known as biogas.
Example calculation model plant:

- Mixed biomass substrate consisting of 50 % cattle slurry, 20 % solid cattle manure and 30 % wheat straw
- approx. 15,000 tonnes of substrate per year
- 500 kWel installed capacity
- 8000 full load hours per year
- 235 m3 raw biogas per hour with 47 % CO_2

Uses biomass

Biomass gasification

CO_2-Potential (per t and year)	≈ 60.000 t (in model plant)
Costs (per tonne of CO_2)	27-365 €
Storage permanence	Dependent on CO_2 re-utilisation

Special features: Requires additional infrastructure for transport of CO_2

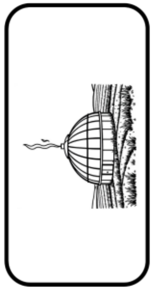
Bioenergy

Biomass gasification

In wood gasification, lignocellulosic biomass is converted into synthesis gas at high temperatures, which is then converted into biofuels via Fischer-Tropsch synthesis.

Example calculation model plant:

- 100 MWth installed capacity
- Approx. 160,000 tonnes of wood chips (beech wood) per year
- Approx. 3,000 full load hours per year
- Approx. 48,000 tonnes of biofuel per year



Uses biomass

Biomethane

CO_2-Potential (per t and year)	≈ 6500 t (in model plant)
Costs (per tonne of CO_2)	79-153 €
Storage permanence	Dependent on CO_2 re-utilisation

Special features: Requires additional infrastructure for transporting CO_2

Bioenergy

Biogas upgrading to biomethane

Biogas consists mainly of methane and CO_2. The two gases are separated in biogas upgrading plants. The biomethane obtained in this way can be fed into the natural gas grid.

Example calculation model plant:

- 2 500 kWel installed capacity
- approx. 8 400 full load hours per year
- approx. 1 000 m3 raw biogas per hour (40 % CO_2)

Uses biomass

Paludi biomass

CO_2-Potential (per t and year)	≈ 900-1400 t (in model plant)
Costs (per tonne of CO_2)	80-263 €
Storage permanence	Dependent on CO_2 re-utilisation

Special features: Requires additional infrastructure for transport of CO_2

Bioenergy

Combustion of biomass from paludiculture

The biomass from paludiculture, the cultivation of wet and rewetted moors, can be utilised for material and/or energy purposes. As the calorific value of paludi biomass is comparable to that of wood, the substrates are suitable for use in heating plants.

Example calculation model plant:

- 800 kWel installed capacity
- approx. 5 000 full load hours per year
- approx. 800 - 1,200 tonnes of substrate per year (sedges, rushes, reeds, etc.)

Uses biomass

Wood biomass

CO_2-Potential (per t and year)	≈ 2.99 t (in model plant)
Costs (per tonne of CO_2)	80-263 €
Storage permanence	Dependent on CO_2 re-utilisation

Special features: Requires additional infrastructure for transport of CO_2

Bioenergy

Combustion of woody biomass

Power plants for generating electricity and heat can be converted from fossil fuels to wood pellets. Wood waste, other lignocellulosic waste and primary wood can be used as starting materials for the pellets.

Example calculation model plant:

- 500 MWel installed capacity
- approx. 7 500 full load hours per year
- approx. 2.56 million tonnes of substrate per year

Biochar production Pyrolysis

Stores CO_2

Uses biomass

Pyrolysis Biochar production

Pyrolysis is a process where biomass is heated without oxygen. This turns the material into biochar, gases, and oils. Biochar is very stable and can store CO_2 for a long time.

Uses biomass

Biochar Agriculture

Stores CO_2

CO_2 removal potential (per ha and year)	≈ 0,87 t
CO_2 removal costs (per tonne of CO_2)	21-47€
Storage permanence	>100

Special properties: The degradation rate of coal in the ground is 0.3% per year

Biochar in agriculture

Biochar is a material obtained by pyrolysis of plant biomass that is applied to agricultural soils. The addition of biochar/vegetable charcoal to the soil as a so-called "pyrogenic carbon fertiliser" ensures long-term carbon storage by the charcoal itself and an improvement in soil conditions, which can lead to higher carbon accumulation in the soil through increased plant growth.

Uses biomass

Biochar Building materials

Stores CO_2

CO_2 removal potential (per ha and year)	91,6 t
CO_2 removal costs (per tonne of CO_2)	150 €
Storage permanence	>100

Biochar in building materials

Biochar is a material obtained by pyrolysis of plant biomass that can be used in building materials (e.g. biochar concrete, green roofs).

Long-lasting biomass materials

Long-lasting biomass materials

The use of durable biomass materials in the construction sector can store CO_2 in the long term. Possible areas of application include wood-based materials (timber frame constructions, solid wood constructions, timber frame constructions and hybrid wood constructions) and insulating materials made from renewable raw materials.

Uses biomass

RRM insulation materials

Stores CO_2

CO_2 removal potential (per residential complex, one-off)	≈ 6,5 t
CO_2 removal costs (per tonne of CO_2)	0-300 €
Storage permanence	>100

Long-lasting biomass materials

Renewable raw materials-insulation materials

Increasing energy-efficient refurbishment of existing buildings with carbon-storing insulation materials made from renewable raw materials. Increasing the proportion of CO_2 sinks in the thermal building envelope through refurbishment measures for insulating materials in wall and roof insulation in existing and future building stock. This includes all forms of insulation: board insulation/blown-in, loose-fill and tamped insulation, mat/bale insulation.

Uses biomass

Wood materials

Stores CO_2

CO_2 removal potential (per residential complex, one-off)	≈ 2120 t
CO_2 removal costs (per tonne of CO_2)	0-320 €
Storage permanence	>100

Long-lasting biomass materials

Wood-based materials

The concept considers a residential complex with multi-storey apartment blocks built in timber construction. The new construction of timber buildings is expected to result in an average carbon storage of 212 kg CO_2-equivalent/m2 gross floor area. The construction types of timber buildings include in particular timber frame constructions, solid timber constructions, timber frame constructions and hybrid timber constructions.

Residual materials

Supplies biomass

Residual materials

Residual materials from forestry, agriculture, construction, or paludiculture can be used as biomass in various processes that remove CO_2. Residual materials for CDR can come from many places: wood leftovers from forests and construction, plant cuttings from wetland crops, and crop residues like straw or prunings from farms. These materials can be turned into biomass for carbon-removal processes.

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Supplies biomass

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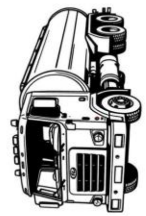
Transport



Tanker Truck

Transport of CO_2 by tanker truck

Captured CO_2 can be compressed into liquid form and moved by tanker trucks to storage or utilization sites. This allows transport even where pipelines are not available. The main environmental impacts come from diesel use, which causes CO_2 and air-pollutant emissions, and from the energy needed to keep the CO_2 at high pressure. Transport distances should be kept short to minimize these effects.

Transport

Truck

Transport of biomass by truck

Biomass can be collected and delivered to processing sites using standard trucks. This method is flexible and suitable for short to medium distances. However, truck transport creates emissions from fuel use, adds traffic, and can generate dust or noise. Using local biomass and optimizing routes can reduce environmental impacts.

Transport

Pipeline

Transport of CO_2 by pipeline

Pipelines can move large volumes of compressed CO_2 efficiently and with relatively low operational emissions. They are suitable for continuous, long-term transport to storage sites. Building pipelines, however, requires land use, construction energy, and careful safety management to avoid leaks. Once operating, pipelines generally have lower environmental impacts compared to truck transport.

Co-Benefit

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Uncertain knowledge


Uncertain knowledge


Uncertain knowledge


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Dissent


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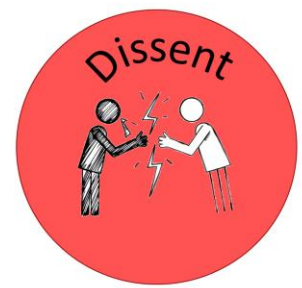
Dissent

Economics

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Environment

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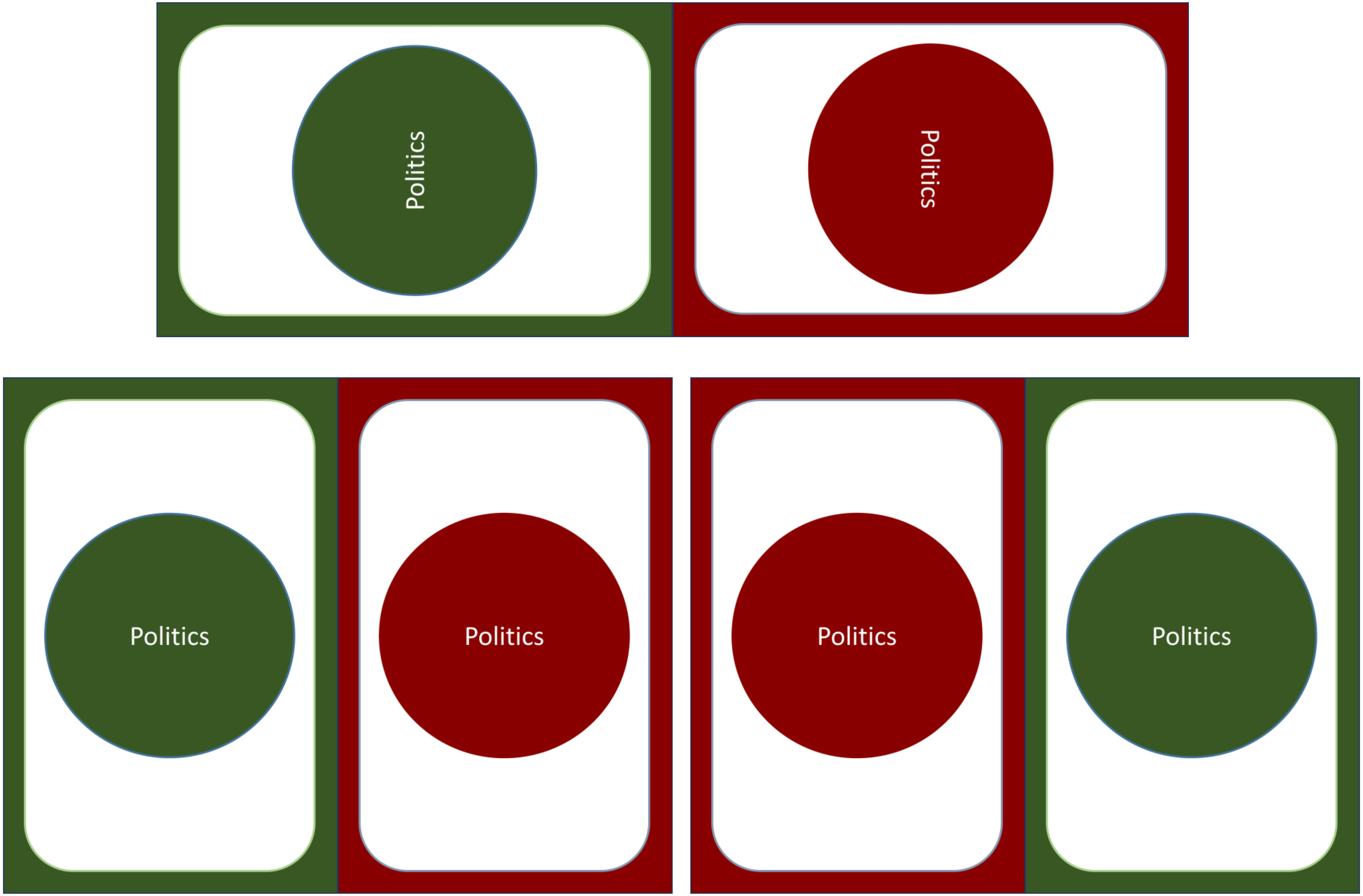
Politics
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Regulations

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Social

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Technology

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