Exercises to TSI ”Get On” climate reduction with climate assessment tool

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Content

1 Outset for the excercises

The European Green Transition requires establishment of a green energy production and infrastructure. One element is, of course, increased production of electricity from wind turbines and photovoltaics. In essence this production is one of two legs in the transition. The other is sourcing of green carbon as a means for energy storage in a circular system. Electricity cannot stand alone as the wind does not blow all the time and neither do we have sunshine. Our consumption varies over the day and year and taken together it is necessary to be able to even out the mismatch between momentaneous energy production and consumption needs. For this we need systems of energy storage, and conversion of electric energy into storable fluid energy via use of carbon is one main way to accomplish this.

Green carbon can be obtained only from the current living biosphere. That is, landuse for agriculture or forestry and marine production. To be able to plan the production potentials of as well electricity from green technologies as the carbon potential on a local level thus becomes an important element in creating efficient new energy systems.

This set of exercises takes the user through basic elements of planning the production potentials of a simplified CO2-based energy system with methane and methanol production. This is done from calculations of the pool of agricultural residues, use of current possible CO2 sources from e.g. incineration and possible future changes in the biogenic resource from agriculture, forestry and marine production.

By use of the municipal climate accounts made for Danish municipalities in accordance with IPCC nomenclature the data for calculations are made available. The needed data can be extracted from the accounts and used in the calculations. For the specific use of modelling an energy system, the accounts have been adapted to show 2018 data in duplicate. By inserting calculated results from the exercises in the accounts a “before” and “after” climate emission is shown, and in this way the accounts are converted into a scenario calculater.

An advanced user of the accounts with the needed technological knowledge at hand can further adapt the accounts for simulation of other systems and changes in all climate sectors. Thus, the accounts form a base-line for calculating effects of climate action and forms a tool for direct climate planning at the local level.

Given that a sufficient data-set is available the accounts themselves can be adapted to use in other regions than Denmark. They one-to-one mirror the Danish Inventory Report with emission factors for all kinds of emissions. These factors can be replaced with factors from any other country. By doing so the accounts can be changed to a tool for local use in other countries and regions. Adequate data sources thus become the limiting factor of use as a baseline for climate action.

2 Aims of the exercises

Three aims of this set of exercises have been identified:

1. To increase users' understanding of sector coupling between the energy sector and the biosectors.

2. To train users' understanding of the tool

3. To train users in creating af climate impact reduction scenario.

Aim 1 is to make users of the climate accounts work actively with attaining a basic insight in the connections between the energy sector and biosectors and the planning challenges of creating af whole new energy and biomass infrastructure. An infrastructure, where the utility of the food and energy potentials is maximized while also taking into regard that future climate change, that is challenges with increased droughts, flooding and change of land use can change the basis for creating new integrated industries.

Aim 2 is to train users in understanding and using the accounts as a planning tool. The exercises are construted to ask the user to find specific data in the accounts, use them in calculation and calculate an outcome. In this way, users get a much better insight in the construction of the accounts and how they in general can be used for strategical planning of reduced climate impact.

The 3rd and final aim is, as stated, to train users in creating a climate reduction scenario. A full scenario will contain other elements than the ones used in the exercises, but the exercises gives the user an understanding of how to implement similar elements.

Knowledge:
Users get a basic knowledge of some core technologies behind climate neutral food and energy production and of the construction of the climate account tool.
Skills:
Users are through exercises trained in spatial planning of industrial symbiotic networks across sectors and in using climate accounts as basis for this planning.
Competences:
Users can take part in dialogue with industrial players, citizens and other stakeholders about placing and dimensioning, benefits and bads from new energy production systems. Users can include the acquired knowledge and skills in municipal planning.

How to work with the exercises

The idea of the exercises is to solve them in groups of at least 2 persons in order to inspire to discussion about physical, regulatory and infrastructural obstacles to implementing new green energy systems and adapt agricultural and other biobased production to changing growing conditions and output demand. Originally, the exercises have been used in a series of workshops for employees in Danish municipalities where group members came from different municipalities in order to inspire to cross-border cooperation and networking.

Beside this exercise description, an excel sheet with the accounts adapted for groupwork and an excel sheet for calculations behind the energy- and production system were supplied to the participants. The accounts used comprised the aggregated data behind 4 to 5 municipalities.

3 Background of the exercises

The global climate crises can hardly be solved without large scale solutions for production and storage of green energy and CO_2. These solutions should convert parts of the green power production to other energy-dense, compact and easy-to-store and transport fuels, because electricity is problematic to store and because some consumers – primarily large industrial consumers – cannot use power alone in their commodity production. And even though it is possible to produce sufficient amounts of green power at competitive prices, it is far from always possible to cover demand on a minute-to-minute or hour-to-hour basis as current technologies are very dependent on weather, that is, wind blowing or sun shining.

But not only energy production from renewable sources are needed. The main emitters of climate gasses must in general either reduce or compensate their emissions. The currently largest emitter of climate gasses in Denmark is agriculture on a whole. Options of reduction from agriculture are part of the exercise set, and this part is intertwined with the energy exercises, as the basis for energy production in the future ironically is exactly agriculture and it potential of producing carbon for CO_2.

Because of Denmark geographical conditions with a very long coastline and relatively shallow waters also far from the coast it has been strategically decided to build a massive wind turbine capacity supplemented with photovoltaics and to convert parts of the power production to hydrogen and fluid fuels with so-called power-to X technologies. The common denominator for these technologies is conversion of power into something else in a chemical process. Therefore the "X", which symbolizes that output from the processes depensds on the technology and that it encompasses a range of different kinds of fuels.

Power-to-X (PtX) involves in a first phase production of hydrogen. By use of electric power water with the chemical formula H_2O is separated into oxygen (O_2) and hydrogen (H_2). The energy in the electric power is partially converted to heat and partially stored in the hydrogen which is a burnable and highly explosive gas. Hydrogen can be fluidized but at quite high costs as it must be pressurized and cooled to very low temperatures to switch from gas phase to fluid phase. At direct contact with oxygen the gas will explode and altogether it can be desirable to convert the gas to a less problematic product.

Several options of conversion are possible. Either it can combine with CO2 to form methane or methanol, or it can be combine with nitrogen to form ammonia. Methane and ammonia are also gases at atmospheric pressure and normal temperatures, but to pressurize these gasses is much easier than pressurizing hydrogen. Unfortunately ammonia is quite toxic which also makes it a bit problematic to store and use as fuel. Methanol on the other hand is a fluid at atmospheric pressure and normal temperatures. It is not very toxic or immediately explosive and can be mixed with gasoline for use in cars. It is thus quite attractive to produce.

Other technologies for production of concentrated and/or easily transported fuels are based on conversion of biomass. They are not really included in the term PtX as it is biomass which carries the energy – not electrical power, but they have the same properties of conversion and the same function.
Let us call them bio-to-X (BtX) as a common concept. Biogas is a well know technology in this respect, but other technologies are available as e.g. gasification of wood and other feedstocks bye superheating without oxygen present. This makes the carbon structures break and convert them into so-called syngas (synthesis gasses), tars and oils. Gassification technologies (pyrolysis) are in themselves of varied character and very much dependent on the temperature regime used.

High temperatures (above 900ºC) convert almost all carbon structures to gasses whereas relatively low temperatures (350 – 450ºC) leaves somewhere close to 50% of carbon as coal or char. By deliberately lowering temperature for maximizing the biochar fraction, this char can be used as a CO_2 sink as biochars only break down over hundreds or thousands of years in nature. Biochars are non-toxic and functions as soil improvers when added to soil. Thus, production of biochar and energy from waste biomass poses an interesting option of simultaneous energy production, co2-storage and adding to soil health and thus sustained food production.

One single technology cannot solve the whole problem regarding green energy supply and sustainable production. A technology mix is needed where several technologies at the best are intertwined because all of them have different side streams of valuable wastes. In many cases a leftover or waste from one technology is a needed input in another technology and in some cases an industry needs to be run continuously while in other cases it is possible to switch production on and off. The latter thus can make value of peak production of green electricity power.

One very important input to some PtX technologies is CO_2. The very substance which is the main problem in climate change is also a core building brick in a green energy system e.g. for production of methane or methanol. Pure CO_2 can be extracted from combustion gasses (smoke) from burnt biomass or fossils including waste incineration and from raw biogas. Approximately 40% of raw biogas is CO_2 as is 10-11% of combustion gasses and there are mature technologies on the market to make the extraction. Production and conversion of biomass to energy with ensuing concentrated CO2-emission thus is almost as important an activity as is the energy production itself for the conversion of energy to green fuels. And for that reason the energy-sphere and the biosphere intertwine and must be integrated in the industrial networks behind energy and food/feed production.

Biomass can be converted directly to fluid fuels. Ethanol produced with sugar cane or maize as feedstock is already mixed in gasoline for cars. And fats are converted to biodiesel. There are though, ongoing discussions of how reasonable it is to convert possible sources of food to energy for transportation. But in ethanol production the raw materials actually are up-graded from a nutrition perspective, as constituents of proteins and minerals are concentrated and made more digestible. Only the energy in starch and other carbon structures is converted to alcohol (ethanol). This fraction in the ethanol process is often named distillers grain (when cereals is raw material) and can be used in bread and other foods. Ethanol factories thus can either be viewed as biorefineries (like breweries) or energy production plants.

So-called 2. generation ethanol is made from straw or wood. In this process inedible wood or straw is actually converted to an edible molasses. But the process is more complicated and is somewhat more expensive than production from grains or sugarcane or roots.

One important worry about ethanol production is if it in dry climates is a sustainable practice to irrigate a crop for feed and energy production when water is a scarce resource. But if it possible to grow crops which are resistant towards drought and where the distillation improves the feed value ethanol production should not be overlooked. In Denmark a relatively drought resistant crop would be sugar beets which have a deep root and for that reason can thrive also in dry summers. This also gives the crop the advantage of being an environmentally interesting low-leaching crop as it grows very fast during autumn and is very efficient in collecting all available nitrogen from the soil and thus reduces nitrogen leaching during fall and winter.

Besides direct production of ethanol and food/feed in the distillation process also CO_2 is produced. In this way there is a loop back to PtX. But the destillation process needs input of heat. Thus, placing e.g. methanol production with its residue stream of heat next to an ethanol production increases the value in both productions as just about all residues are reused in the neighboring technology.

As biomass production is dispersed all over the countryside as are wind turbines and photovoltaics and as PtX/BtX preferably should be concentrated in larger units there is a schism between transportation of biomass with its often high water content (dead weight), area use and agricultural crop composition and proper placing of e.g. BtX and PtX production plants. In addition, proper dimensioning of the full system demands a good overview of the total production potentials for all input factors in all parts of the system. And finally, good planning also takes into consideration the effects on landscape values, suburban and rural communities, other crucial infrastructure and long forgotten security issues in the light of new geopolitical realities.

For all these reasons there is a need for authorities to make top-level planning from a societal perspective and for well-balanced demands to developers and investors behind the new energy production plants. In this respect municvipalities have an important role to play.

The municipal climate accounts gives the authorities a good means to make preliminary calculations of capacities in as well agricultural or forest production as in green energy production. They can simultaneously be used to derive the changes such production gives rise to in a climate impact sense.

For such calculations it is needed to have access to certain technical background information about inputs and outputs from the technologies used in the set-up. In a similar way it is necessary to make qualified assumptions regarding as well outlooks for energy consumption, general consumption patterns and production potentials in the biosectors under varying climatic conditions. If many different technologies are assumed implemented it will be a complicated but not impossible exercise.

For the "TSI- Get on" project a set of exercises have been made where the CO_2 potential in a geographical limited area consisting of 4-5 Danish municipalities can be calculated and used as background of an exemplification of dimensioning a production grid consisting of biogas, hydrogen production, methanization and methanol production where the size of the latter two production capacities depend on the CO2 potential from other activities in the geography. These 2 productions on their part lay the grounds for dimensioning a minimum hydrogen production and accordingly the size of wind turbine and photovoltaic capacity

Ethanol and biochar production has been excluded in the set of exercises as it complicates calculations for every additional technology. In the exercises specific input-output information for three kinds of hydrogen, methanization and methanol technologies are used, information which has been publicized by the Danish Energy Agency in the Technology data - renewable fuels (https://ens.dk/sites/ens.dk/files/Analyser/technology_data_for_renewable_fuels.pdf). The choice of specific technologies do not reflect any kind of preference, but is solely based on a possible interdependence when optimizing the exploitation of the green energy source. Thus, no evaluation of feasibility, economic properties and the like lies behind the choice of technology background for the exercises, and the exercises are only illustrative for how the climate accounts can be used to model production potentials and production synergies. The exercises thus should not be tried used for concrete planning.

4 Exercises

For the exercises you need:

- A Laptop/PC
- A map of the area/municipality and stickers/markers for marking existing infrastructure and energy production facilities
- Description of the exercises for guidance. Optimally in print for ease of use.
- Excel file with exercises including formulas for calculations of intermediate results.
- Excel file with account prepared with 2 copies of the base year.
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Files are found on SharePoint and can be accessed via Moodle.

4.1 Place existing and planned infrastructure on map

Time frame: 30 minutes.

In this starting exercise the group must mark the biogas facilities, large area PVs, heat boiler facilities and PtX facilities which already exist in the area or are planned or under construction. Facilities must be marked with a sticker if they are in use or under construction. If they are still in the planning phase they should be marked with a coloured plastic brick.

Important main energy infrastructure like main gas pipelines and main parts of the electricity grid may be marked with a marking pen.

Do not try to make research for high precision – it is more important to discuss how things are connected by use of existing knowledge.

	Do this	Outcome
	Materials: • Printed map • Stickers • Plastic bricks • Marker pens	
1	Agree on which colours represents which kind of energy production plant. Yellow may for example represent PVs and green biogas etc.	
2	Place stickers where existing plants/facilities are placed, and also facilities which are under construction (cannot be stopped), and mark projects under discussion or decision with plastic bricks. You may let the size of the sticker or bricks symbolize its size. You can draw other important infrastructure with marking pens and also maybe items that can be a hindrance for establishment of new energy plants.	
3	Mention all types of facilities on the list of symbols under the map.	Now you have hopefully achieved an overview of the existing energy infrastructure.
4	Discuss along the way the connections and dependencies (and lack of such) between the different facilities in the area/municipalities.	You have now visualized a beginning bid on the energy landscape and maybe discussions have touched upon what might be coming.

4.2 Forest

Timeframe 15 min

Now you will calculate the climate effect of planting forest. 2018 was in that respect a bad base year in Denmark because of an unusually dry summer and wet fall and winter. Combined with high wood harvest these conditions had as consequence, that mature woodland was net emitter of CO2 rather than a CO2 sink. If you check up in the account for

Area use there is a net emission or low uptake from the municipal forestland depending on which municipality you work with as the combination of mature and young forest differs between municipalities. Because of the weather conditions, the effects calculated in the account from possible new forest wil have a minimal climate effect which is neither correct on average or pedagogically acceptable.

Therefore, we will make some adaptions in the annexes to the account to reflect a more realistic effect of new forest in the longer run. We do this only because the objective is to show reduction effects of deliberate changes in favor of climate impact reduction. Thus, it is not valid method to change an account.

	Do this	**Outcome**
1	We assume, that all new forest is established on agricultural mineral soils. You may wish to allocate some new forest area to soils with grassland. You may do so – but you have to keep track on how on your own. Why do we take new forest land from mineral agricultural soils? Because organic soils should rather be rewetted for a larger CO2-effect, grasslands are in most cases nature anyway and to some extent protected and it would not be realistic to diminish the area with settlements.	
2	Find annex WK6 2018.	
3	Increase the area in cells B12 and D12 by the increased forest area you expect.	
4	Check in the account ”Area use W2018” that the area in cell D18 has been increased by tha new area with forest. You can compare to the same cell in Area use 2018:D18.	
5	Check also that the numbers in T11 in annex WK6 2018 is in accordance with O18 in “Area Use W2018”.	
6	Find annex WK7_2018.	
7	Reduce the areas in cells C10 and B10 by the new forest area.	
8	Check that numbers in cells D11, O11, P11, Q11, D18 O18, P18 and Q18 in ”Area Use W2018”, have been corrected to include effects of changing agricultural area to forest. Compare with “Area Use 2018”. Why is it not Forest in row 10 and agricultural area in row 11 that has changed? Because row 10 counts existing forest which is more than 30 years old.	You have now changed the account for Area Use by the changes to area with forest you expect by use of original emission factors for 2018.
9	2020 was a more ”normal forest year” than 2018. Thus, we allow ourselves to use the 2020 emission factors in the Annexes K6 2018 and WK6 2018 to give a more realistic picture of the uptake of CO2 in new forest areas. Below this table you can find a copy of an annex for 2020. Now, copy the number in cells F10:L14 into annexes K6 2018 and WK6 2018.	Now you change the emission factors for forest to reflect the ”normal” forest year 2020. These factors are closer to a long run average of actual emissions than are the factor for 2018.

	We ought to reduce the use of fertilizers and change the cultivated area in annex K4 2018 too for areas converted to forest. But we skip it for now because the effects are marginal and it will take a lot of time, but if you insist you are welcome to do so, if you can find your way around.	

A	E	F	G	H	I	J	K	L
PlanEnergi								
Til index								
Forkortelser (fra CRF):	ted). Se baggrundsnotatets begrebsliste for en uddybning af de enkelte begreber.							
		Ændring i levende biomasse pr. ha					Ændring i jord pr. ha	
Skov	**Heraf: Ikke kat. jordtype [ha]**	**Opbygning kulstoflager [ton C/ha]**	**Tab kulstoflager [ton C/ha]**	**Ændring kulstoflager [ton C/ha]**	**Ændring kulstoflager i dødt træ [ton C/ha]**	**Ændring kulstoflager i skovbund [ton C/ha]**	**Netto ændring af kulstoflager i mineralsk jord [ton C/ha]**	**Netto ændring af kulstoflager i organisk jord [ton C/ha]**
Total skovjord (2020)	7,94							
Blivende skov (1990-2020)	7,13	0,2	IE	0,2	0,1	0,4	NA	-1,3
Skovrejsning (1990-2020)	0,81							
Landbrugsjord ændret til skov	0,69	2,8	0	2,6	0	0	0	-1
Permanent græs ændret til skov	0,13	3	0	3	0	0	NA	-1
Vådområde ændret til skov	0,00	3	IE	3	0	0	NA	-1
Bebygget område ændret til skov	0,00	NA	NA	NA	NA	NA	NA	NA
Øvrig land ændret til skov	0,00	NA	NA	NA	NA	NA	NA	NA
Søer, åer mv.	0,00	NA	NO	NO	NO	NO	NO	NC
Uklassificeret areal ændret til skov	0,00	NA	NO	NO	NO	NO	NO	NC

4.3 CO_2-potential

Time frame: 15 min

CO_2 is a neccesary ingredient in production of methanol or in methanation of hydrogen. The options of extracting CO2 from potential high-concentration sources thus is a limiting factor in the overall potential for production of green methanol or methane. CO_2 is present in an adequate concentration from as well fossil as biogenic sources when burning or bacterial digestion happens in large energy-producing plants.

Thus, we need to estimate the size of the potential sources of usable CO_2 from existing and future plants. In practice sources will be power plants for electricity and heat production when either fossils, woodchips/pellets or straw is feedstock, or it will be incineration of plastic waste or biogas. New ethanol production facilities can also be a source of CO_2.

In the energy accounts the energy from burning carbonic materials are presented. This energy can be converted to the amount of dry matter which is further converted to CO_2 emitted. In the excel-file with exercises, 4 tables for calculating CO_2 potential from 4 different sources are presented. All you need to do to make the calculation is to find the energy use in the source and insert in the tables – then CO_2-emissions are calculated automatically.

	Do this	Outcome
1	Find annex WK2a.	
2	Find also the excel file with exercises and go to the sheet ”CO2-potetial”.	
3	Copy the numbers for animal slurry from the annex into the green cells in the exercise table for CO_2-potential from slurry. Do not copy empty cells.	
4	Evaluate and note how large a fraction of the slurry you think realistically can be used for biogas. Write the fraction in the green cell at the bottom of the table. Have a short discussion in your group about what a realistic fraction may be.	Now you have an estimate of the CO_2 potential in tons from slurry. The dry matter percentage in the table is higher tha actual contents in slurry as it is assumed, that there is added materials like straw or deep bedding as feedstock besides slurry.
5	Go to the energy account E2018. Copy the number for Terajoule (TJ) from waste incineration – non biogenic in cell Z82. Insert it in the green cell in the exercise table “Waste”. Consider whether it is realistic that the amount of waste incinerated will remain unchanged in the future, or if it should be corrected	Now you have an estimate of the CO_2-potential from waste incineration.

	up or down. You may make a correction by noting a fraction over or below 100% in the green cell at the bottom of the table.	
7	Go to the exercise table "Biomass incineration". In the green cells there are references to cells in the sheet E2018 in the climate account. Copy the number of TJ from biomass incineration "Straw, wood and wood chips" and "Wood pellets and wooden waste" to the relevant cells in the exercise table to calculate the CO_2 – potential from burning biomass. An increased area with forest for wood production will contribute to maintaining the amount of wood burnt in the future, but on the other hand the option of making pyrolysis for biochar production will reduce it. So will possible future policies of stopping imports of biomass. Make an evaluation of the future potential relative to the current and make possibly a correction as a reduced or increased percentage in the green cell at the bottom of the exercise table.	You now have an estimate of the CO_2-potential from biomass incineration.
8		You have also made an estimate of the future CO_2-potential from biogenic sources in the little table at the top of the the exercise sheet "CO2- potential which will be used later for calculating the potential for methanization and methanol production.

Co2-potential from slurry							
Gylletype	**Ton slurry**	**Dry matter (DM)**	**Ton DM**	**DM fraction**	**DM digested**	**CO2 fraction**	**CO2 (ton)**
Cattle slurry							
Pigs slurry							
Mixed slurry							
Poultry slurry							
Slurry total	-	0,14	0	0,5	0	0,73	0
				Fraction of slurry used			0,00%
				Estimated CO2-potential			0

CO2-potential from waste incineration (non-organic)		
TJ from waste incineration	ton CO2/TJ from waste	CO2 (ton)
	74	0
		100%
		0

Biomass incineration							
Straw	Wood and wood chips	Wood pellets and wood waste	TJ from biomass burning in total	TJ/ton DM	Ton biomass (DM)	CO_2 weight fraction (molar basis)	CO2 (ton)
+T82	+U82	+V82					
-T18	-U17	-V16					
-T27							
-T28							
0	0	0	0	0,175	0	0,71	0
							100%
							0

Total estimated CO_2-potential	-

4.4 PtX

Timeframe: 20 min

Many different types of Power-to-X exist as the name suggests: Power-to-something. To avoid an very high level of complexity in the exercises they only include Methanation of hydrogen with CO_2 and methanol production. It has also been chosen in advance, that the hydrogen plant behind is of the type SOEC as it makes a high utilization of heat-residue possible in a combined grid of symbiotic technologies. This has also been chosen as the combination will be able to take up variations in power production from wind turbines and PVs over time. Methanol plants should preferably be run continuously at the same intensity whereas a methanation plant can run at a more varied intensity. At the same time, the methane can be saved in the already existing gas net. The choice of technologies does not in any way reflect an evaluation of which kinds of technologies will be implemented in practice – the only reason for the choice is that it is possible to model a balanced combination relatively easily. Other relevant technologies could be of a different type or it could be completely different productions like pyrolysis for biochar and energy, biooil, ethanol etc.

but these have been left out for simplification. In the exercises it is assumed, that all hydrogen is converted tio methane or methanol, which would not necessarily be the case in practice, as e.g. industrial consumers may use hydrogen directly.

In this exercise, we must begin from the rear and work us forward to the needed power production. Thus, based on the calculated CO_2-potential the maximum combined capacity of methanation and methanol production can be calculated. When this has been done the capacity of hydrogen production is found, and after this the capacity of power production form wind turbines and PVs. If it is not possible to achieve a high enough power production capacity, the calculations must be reversed, with the power production as limiting factor.

Methanation		
	Do this	**Outcome**
1	Find the exercise table "PtX - Methanization" in the excel file with exercises. Insert how large a fraction of you calculated CO_2-potential you think will be used for methanization in the green cell. The sum of CO_2 used for conversion to methane and to methanol cannot exceed 100%. Discuss in your group what to expect and which hindrances may exist for a high exploitation.	
2	Transfer the calculated output of methane (pink cell) to the sheet WE2018 cell I59 in the accounts – as a negative number (blue cell).	
3	Transfer the calculated output of surplus heat (pink cell) to the sheet WE2018 cell AI60 in the accounts – as a negative number (blue cell).	
4	Transfer the calculated number for "Process power" (pink cell) to cell AG59 i WE2018 (blue cell).	Now you have made correction in the account for an estimated CO_2-emission reduction effect of producing methane by use of green CO_2. The produced methane is assumed used in the gas net where it displaces natural gas.

PtX - Methanization		Base data for scaling		Calculated capacity
CO_2 potential	ton/year			0
Exploited CO_2 potential	%			
Exploited CO_2 potential	ton/year	89.700		0
Hydrogen consumption	ton/year	16.560		0
Hydrogen - energy	TJ/year	2.418		0
Process power	TJ/year	4		**0,0**
Elektrolysis-capacity (SOEC)	MW	100		0
Output - PtX - Methanization				
Methane	TJ/year	1.840		**0,0**
Surplus heat	TJ/year	546		**0,0**

Methanol		
	Do this	**Outcome**
1.	Insert your expectancy of exploited fraction of CO_2-potential in the green cell. The sum of CO_2 used for conversion to methane and to methanol cannot exceed 100%. Discuss in your group what to expect and which hindrances may exist for a high exploitation.	
2.	Transfer the calculated output of methanol (pink cell) to the sheet WE2018 cell K58 in the accounts – as a negative number (blue cell).	
3.	Add the calculated output of surplus heat (pink cell) to the sheet WE2018 cell AI60 in the accounts to the number you already put there from methanization – also as a negative number (blue cell).	
4.	Transfer the consumption of power ”Power use – fraction for synthesis” to cell AG58 in WE2018.	Now you have calculated the effect from production of methanol as a displacement effect in transportation and in district heating. As the exercise is constructed the whole production is subtracted from consumption in the municipal account though in reality the majority must be expected to be delivered to the common grid of fuel supply as there is no agreed method to use.

PtX - Methanol		Base data for scaling		Calculated capacity
CO_2 potential	ton/year			0
Exploited CO_2 potential	%			
Exploited CO_2 potential	ton/year	121.762		0
Hydrogen consumption	ton/year	16.560		0
Hydrogen - energy	MW	100		0
Process power				
Power use for synthesis includin	TJ/year	3.110		**0,0**
- fraction for synthesis		1.125		**0,0**
Methanol	TJ/year	1.827		**0,0**
Surplus heat from methanol prod	TJ/year	1.008		**0,0**
Surplus heat after regeneration t	TJ/year	527		**0,0**

Hydrogen Plant		
	Do this	**Outcome**
1	When you calculated the methane and methanol production you also automatically calculated the hydrogen production. Now transfer the use of "Heat consumption for electrolysis" to cell AI57 in WE2018 (blue cell) as negative number!	
2	Transfer the power consumption " Power use for SOEC electrolysis" to cell AG57 i WE2018 (blue cell).	As you supposedly have used all hydrogen for methanization and methanol production there will not be a surplus for direct consumption in the industrial sector. The effect on CO_2-emission have been included under the other two technologies.

PtX - Hydrogen		Base data for scaling		Calculated capacity
Elektrolysis-capacity	MW	100		0
Full load hours	FLH	6.850		6.850
Yearly production, hydrogen	TJ	2.466		0
Yearly production, hydrogen	ton	16.577		0
Power use for SOEC elektrolysis	TJ/year	1.985		**0**
Heat consumption for elektrolysis	TJ/year	481		**0**
Regenerable heat	TJ/year	363		**0**
Heat lost	TJ/year	118		**0**

When the CO2 potential from slurry is realized for methanation and/or methanol production it is implied that the slurry is used for biogas production. Therefore, we must calculate a new biogas capacity too in addition to what is already there in the account.

Biogas		
	Do this	**Outcome**
1	Find once again annex WK2a 2018.	
2	Calculate for every type of slurry the amount that can be used for biogas production in addition to what is already used for this. Do it by subtracting the numbers in column D from the ones in column C.	
3	Transfer what you calculated to the exercise table "Biogas" in the sheet PtX.	
4	Reuse the exploitation fraction from the exercise about calculating the CO_2-potential. Insert it in the green cell next to the pink cell.	Now you have calculated how much more biogas will be produced in the municipality.
5	Transfer and add the number in the pink cell to the number which is already there in WE2018 cell I27. Remember to note it as a negative number as natural gas is displaced in the gas net.	

Increased biogas production					
	Ton slurry	**Methane potential Nm^3/ton)**	**m^3 CH_4 total**	**energy content per m^3 CH_4 (Joules)**	**Energy-potential (TJ)**
Cattle slurry		14	0	39,8	0
Pig slurry		12	0	39,8	0
Mixed slurry		12	0	39,8	
Poultry slurry		12	0	39,8	
Slurry, total					0
				Fraction used	
Energy in increased biogas production				0%	0

4.5 Wind and photovoltaics

Timeframe: 15 min

Power from renewable energy sources is the basis for green fuels. As the sun shines more during summer while the windspeed typically falls and vice versa during winter, er reasonable mix of the two energy sources is needed for reduced fluctuations in total production. And even though PtX technologies has as one objective to exploit peaks in production when direct power consumption is low, a better return on investment will be obtained with as close to constant production as possible.

In this exercise we will only make a simple distribution of capacity on the two technology types, while actual calculations of optimality over the year is left out since that is a much more complex exercise which requires special calculation tools.

What you are estimating here is the capacity of land-based production. It is assumed, that ½ of total power is covered by state driven ocean-based projects while the other ½ is the responsibility of municipalities and is land-based. But in this exercise we are only calculating the need for PtX industries – we do not include consumption for private households, the service sectors and industries. Thus, for simplification we assume that the state responsibilities cover all other consumption than PtX, while the municipality must cover the whole need for PtX.

For information it is said as a rule of thumb, that no more than 20% of renewable energy capacity should come from photovoltaics.

Distribution of increased power capacity on wind turbines and photovoltaics	
1	If you disagree in the assumption that power from ocean-based production should not take its part of PtX, but covers other consumption, then you may note a fraction in the green cells in the table “Distribution of power production on wind turbines and PVs”. Otherwise, you only fill in the distribution between the two technologies in the next 2 tables.

Division of capacity between wind turbines ans photovoltaics						
	TJ	**Hereof ocean wind (%)**	**Hereof landbased wind (TJ)**	**Wind (TJ)**	**PVs (TJ)**	**Control must be < 0**
Power for hydrogen production	0	0%	0			
Power for methanol og met,hane prod	0,0	0%	0			
Sum	0		0	0	0	0

Production from photovoltaics		
	Do this	**Outcome**
1	Fill in the table with the number and areas of different kinds of PV-projects, that is roof-based or landbased, which may or must be realized to supply new PtX technologies.	
2	Add the sum of TJ to the number which is already there in the energy accounts (WE2018) cell O23.	You have now corrected the account for an increase in production from PVs.
3	Per default we expect landbased projects to be placed on mineral agricultural soils. If you wish to place some of them on organic soils, of which you later will calculate climate effect of rewetting, there will be no further climate effect from mounting PVs. In that case you must subtract the area with PVs mounted on organic soils in the total landbased area with new PVs before you proceed with the exercise below.	
4	Now, find annex WK4_2018	
5	Add the numbers in cells B9 and B10 in the annex and divide this sum by the number in cell B91. In this way you find the amount of nitrogen allotted to an average hectare crop area. Now, multiply with the area with PVs:	
6	The number you just calculated must now be subtracted from the number in cell B112 i annex WK4 2018 (beware: there is a formula in the cell, so go via the editor into the formula and subtract from the formula there).	Now you have calculated the climate effect of ceased use of fertilizer on the area with PVs.
7	Go to the table ”Kg N from crop residues”! In annex WK4 2018.	
8	For simplicity we assume, that the only crop grown on areas converted to PV so far is winter wheat. Reality is somewhat more complex, but for now we stick to a simple solution. Now subtract the area with new landbased PVs from the area with winter wheat in cell F31 and add the same number to the area in cell F46 (permanent grass).	
9	Find annex WK5 2018.	
10	Subtract the area with new PVs from the areas in the cells G8, G16 and G24 (Beware of formulas in the cells!).	You have now finished calculating reductions in climate impact from cultivating the soil which will from now on be used for PVs.

Photovoltaics increased capacity	Production pr. unit (TJ)		Number of units or area	TJ
Rooftop units, family houses (4,5 kWp-anlæg)	0,014	/unit.	0	0
Rooftop units, high rise buildings (25 kWp-anlæg)	0,1	/unit.	0	0
Industrial building projects	4,0	/ha	0	0
Landbased projects	4,0	/ha	0	0
New PVs production				**0**

New wind turbines		
	Do this	**Outcome**
1	Fill in the table ”Landbased wind, increase” with a sufficient amount of wind turbines to cover the need for PtX production. Remember, that parts of the production should be covered from PVs.	
2	Add the sum of TJ in the pink cell to the number which is already there in cell M24 in the energy account (WE2018).	You have now corrected the production of power from wind turbines with the expected new capacity for PtX production. Note, that the power import in cell A12 changes downward when you add the production from as well wind turbines as PVs.

Land based wind, increase	**TJ pr. turbine**		units
125 m turbine (2,3 MW, 2.800 FLH)	24,8	units	
138 m turbine (3,5 MW, 3.000 FLH)	37,8	units	
150 m turbine (3,5 MW, 3.400 FLH)	42,8	units	
150 m turbine (4,2 MW, 3.000 FLH)	45,4	units	
180 m turbine (4,2 MW, 3.700 FLH)	55,9	units	
Total, new landbased turbines		units	0
New turbines, production		**TJ**	**0**

4.6 Surplus heat

Timeframe:15 min

The Ptx technologies yield a significant amount of surplus heat which should not be wasted. In the chosen technology combination surplus heat amounts to around 2/5 of the energy in the system, and maximation of its utility is of course important. The possible exploitation highly depends on how far PtX production is placed from a possible consumer of the heat – e.g. another industry or a district heating system. This since the transportation distance to the consumer highly affect heat losses in distribution pipes. The possible degree of exploitation also depends on whether it is possible (and economical) to store summer production until winter.

Part of good planning therefore is to place the facilities well in relation to use of the heat, but also to means of input and output to the process. Power, CO_2, gas and fuels are relative easy to transport in cables and pipes without significant losses, but heat is not. Another angle on use of heat is to move large consumers close to the source of heat – e.g. food production industries, large scale greenhouses or laundry companies. Here obviously, ethanol production could come in play. And finally, working with storage systems for the heat kan be of value.

In this exercise we assume, that heat from 5 months summer production can be stored in a large borehole facility. And based on the calculations you made previously the size of the facility is calculated automatically.

Discuss in your group:

1.	- How surplus heat can best be utilized in the area you work with,
2.	- whether it is realistic to use the heat in local district heating in the proposed area, or if you should consider finding a better location for the PtX production,
3.	- if you have geological knowledge about the area in case, whether you think geology allows for a borehole system, or if another kind of heat storage system would be more relevant,
4.	- Which percentage of exploitation of the calculated heat output you find reasonable based on your discussion. Make corrections to the exploitation percentage in the exercise table based on your conclusion.
5.	If you lowered the exploitation percentage below 100% you must correct the number you previously noted in cell AI60 in WE2018 for the reduction in heat use. Delete the number in the cell and fill in the sum of the 2 pink cells from the exercise table “Heat surplus” instead.

,

Borehole heat storage		
	TJ	
Surplus heat from PtX facility	0	
Heat consumption in SOEC-facility	0	
Net yield of heat	0	
Fraction stored for 5 months+ (may-to september)	0	
Loss at storage	27%	**% actual use of**
Net effect of stored heat in district heating*	0	**net yield**
Net yield total in district heating	0	100%

*based on experience from a system i Crailsheim, Germany

	Scale*	Dimensioning
kWh/m^3 volume	33	33
Volume, m^3	19.000	0
Heat storage capacity, Mwh	627	0
Converted to TJ	2,3	0
Area, hectares at 35 meters depth of borehole	0,0625	0,0

*Effecter based on experience from heat storage in Brædstrup, Denmark

4.7 Protein crops

Timeframe: 15 min

Change of agricultural production from husbandry to growing crops for human consumption or change of the composition of the mix of husbandry production towards animals with a smaller climate impact (poultry rather than cattle and pigs) lowers the total agricultural impact on climate change. In Denmark, especially in the western parts of the country, there is a large production of milk from dairy cows with high resulting emissions of methane.

By reducing the number of animals and by reducing nitrogen input to crops due to use of crops with capability of producing their own nitrogen from the air, or by changing to crops with a better ability to take up the allotted nitrogen fertilizer. By doing so leaching of nitrogen and conversion of nitrogen to N2O is limited, thus reducing emissions. Even by growing more protein crops for feed for animals like pigs or poultry, and in order to avoid imports of protein feed, emissions are reduced since it will not be possible to maintain the number of animals (in Denmark there are only few options of increasing yields to compensate for reduced imports) as the total available area for agricultural production is fixed or even falling.

A growing market for plant-based foods rather than meat and a market for locally produced protein feeds is emerging, and both points to a change in average crop rotations in favor of the described climate effects.

Some "new" crops like grass for biorefining protein or sugar beets, where the leaves are used for biorefining protein and the root for ethanol production also leaves residues which are suitable for biogas in case the total production is larger than what can be used for feed. Thus, there is a potential that this kind of crops can both yield more food and displace animal manure in biogas production. Typically, it will be cereal crops which are displaced by these other kinds of crops.

	Do this	Outcome
1	Find annex WK4 2018.	
2	Find also the sheet in the excel exercises with the name “Protein crops”.	
2	Copy the numbers for ”Cultivated area in the municipality” for all crops and fill them into the blue cells in the exercise table as numbers.	
4	Fill in the column ”change in crop combination” in the exercise table with you expectations of changes in the areas of different crops. Remember, that reducing an area is done with negative numbers. The sum at the bottom of the column must be 0.	
4.1	-Increase the areas with ” Legumes for maturity” by the total area wiht crops like horse beans, quinoa etc. which you think could be expected or a goal to reach.	
4.2	- Increase the area with sugar beets accordingly if you think af combined protein production from the leaves and ethanol production from the root is an option. Even though we have not worked with the technology including the capacity in a normal factory it should not hinder that we look at the climate effect in agriculture from changing the crops.	
4.3	-Increase the area with ”lucerne (alfalfa)” and ”grass and clover in rotation” with the area you think would be relevant for biorefining.	
5	When one area is increased another must be reduced equivalently as the total area cultivated cannot change (upwards) We do not know in practice which crops will be reduced at the benefit of another. In this exercise you can either reduce all of it in winter wheat or you can disperse it on all cereal types and maize. That is your choice.	
6	Copy the new areas of all crops into annex WK4_2018 in the column “cultivated area in the municipality”. Delete the numbers that are there already.	Now you calculated the effect of changes to crop residues on climate gas emissions.
7	In the exercise table estimated changes to the use of nitrogen fertilizer is calculated automatically.	
8	Subtract the estimated reduction in the use of nitrogen fertilizer from the number in cell B9 in annex WK4 2018. Beware: there is a formula in the cell!).	You have now corrected the account for changes in climate gas emissions from soil cultivation and crop growth. You may compare

		the new emissions with the original K 2018 account.

Crop type	Cultivated area in the municipality (ha)	Change in crop combination [ha]	New area with crop	Nitrogen norm / ha	Estimated reduction in use of nitrogen fertilizer (ton)
Winter wheat			0	200	0
Spring wheat			0	170	0
Rye			0	158	0
Winter barley			0	177	0
Spring barley			0	150	0
Oats			0	125	0
Triticale and other grains to maturity			0	185	0
Maize for maturity			0	185	0
Maize for feeding			0	180	0
Potatoes			0	190	0
Lucerne (alfalfa)			0	0	0
Legumes for maturity			0	0	0
Sugar beets for factory and feed beets			0	135	0
Cereals and pulses for silage (whole grains)			0	70	0
th			0	300	0
Grassland outside the rotation			0	0	0
Total rapeseed + flax + other industrial seeds			0	170	0
Control: The sum in column E must be 0.	0	0	0		**0**

4.8 Husbandry production

Timeframe 15 min

When areas are taken out of cultivation and used for PVs, rewetting or forest, and when existing crops for feed ar converted to crops for food or for replacing imported protein feed the size of the husbandry production will inevitably be reduced. How the reduction will be destributed on types of animals and regions is difficult to anticipate. But it will have an impact on the amount of manure available for biogas and thus potentially the available amount of CO_2 for PtX, and it will have a reducing effect on the climate gasses emitted.

In this exercise it is assumed that a reduction in husbandry production as a consequence of reduced areas for cultivation will be distributed proportionately on animal types and have full effect in the municipality in case. As a result, the potential for biogas production will be diminished unless more crops with a dual purpose of making protein foods or feeds and energy will offset the fall in available manure. Such crops could be protein grass, sugar beets or hemp. Alternatively, production of CO_2 can come from ethanol production rather than biogas with use of the same crops.

	Do tjhis	**Outcome**
1	Below you will find a copy of the table ”sum of number of animals” from annex WK2 2018. It has been named table 1 and is empty.	

2	Go to annex WK2_2018 and kopi the number of animals in the table. Insert as numbers in the exercise table in the sheet "Husbandry".	
3	Go to the account LULUCF 2018 and copy cell D11. Insert as a number in exercise table 2 where the reference to the cell is given.	
4	Go to the account LULUCF 2018 and copy cell E12. Insert as a number in exercise table 2 where the reference to the cell is given.	Now you calculated the number of animal units (a measure for the excretion of nitrogen from the animals) per hectare in the municipality.
5	Insert the relevant areas from the previous exercises in the green cells in the table.	Now you calculated the reduction in husbandry as an effect of the changes in area use from previous exercises.
6	Now you can use the reduction fraction of the number of animals to change climate gas emissions in the annexes WK2 2018 and WK3 2018 and to reduce the amount of manure in WK2a 2018. The emission of CH_4 from stables in annex WK2_2018 cellsR24 to R31, emissions of N_2O from stables in annex WK3_2018 cells R23 to R30 and the amount of manure in cells C8 to C11 in annex WK2a_2018 should be reduced by the calculated percentage. In annex WK2 2018 and WK3 2018 every kind of animals and the emission from each kind of animals also should be reduced with the same percentage, but we do not need the information just now, so only do that if your sense of order requires it.	
7	Copy the numbers of animals after reduction (the last row in the exercise table 2) to the respective animal types in annex WK1 2018 cells C7 to C23.	You have now calculated the climate effect of reducing husbandry production proportionately with the reduction in available cultivated area. You have also calculated a reduced potential for biogas production from manure, which also changes the CO2 potential for PtX.
8	In principle you should change the available CO2 for PtX in the PtX calculation, but if it is assumed that the reduction is offset (and maybe even more than offset) by residuals from crops for human consumption or protein feed, a correction is not needed.	

Table 1

Number of animals by area [yearly animals or produced number by year]																	
Sum of animals	Column markers																
Row markers	**Beef cattle, cows**	**Breeding**	**Poultry**	**WTS-pigs**	**Goats/she**	**Heifers**	**Deer**	**Horses**	**Fur animals**	**Sl. Pigs**	**Slaughter ca**	**Slaughter**	**Piglets**	**Heifer calve**	**Dairy cows**	**Sows, year**	**Main total**
Stanchion-tied																	-
Deep litter																	-
Free range																	-
Loose housing / box																	-
Loose housing / box/ cage																	-
Loose housing / slatted																	-
Loose housing - cubicles																	-
Main total	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Tabel 2

AUs/Animals*, **	0,64	0,24	0,01	0,03	0,17	0,44	0,17	0,504	0,0025	0,03	0,126	0,24	0,0047	0,267	1,61	0,24	
AUs/geographical area	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Agricultural area																	LULUCF 2018' cel
Permanent grass																	LULUCF 2018' cel
Total agricultural area																	-
AUs/ha																	-
Reduction in hectares:																	
Rewetted area																	
New forest																	
PVs																	
Protein crops for food/feed																	
Total reduction in hectares agricultural areas and permanent grass:																	
Reduktion in animal units, total																	-
Reduction in %																	-
Reduction per animal type	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AUs after reduction	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Number of animals per animal type afe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

*Nutrient norms for animal manures

**1 animal unit corresponds to 100 kg nitrogen excreted ab animal

4.9 Organic soils

Timeframe: 35 min

This exercise about rewetting organic soils is the calculation-wise most complex of the exercises. This is because emissions from organic soils occurs in many different ways and therefore are included in several annexes and as well the LULUCF as the Plant Production accounts. Furthermore, emissions change from year to year due to changing weather conditions. This is also the reason why it is not possible to make just one emission factor for taking out organic soils from cultivation and other agricultural use.

The most complicated part of a precise calculation would be to predict which crops will no longer be cultivated on the areas taken out of production. As crop- rotations constantly change, this will always have the character of an estimate. In the exercise, it hsas been chosen not to include this part a a calculation, as the intention with the exercise is to encourage to increased understanding of the construction of the accounts rather than reach a precise result.

	Do this	**Outcome**
1	Find annex WK8 2018.	
2	Find the number in Cell C28. Insert it in the exercise table for organic soil where the cell name is given. Find the number in cell C29 and insert it in the exercise table where the cell name is given.	
3	Decide how large areas you wish to take out of production to nature and rewetting. If you think in percent, then calculate the number of hectares first. Insert the share of the areas you take out on "taking out for rewetting" and for nature in the green cells.	
4	Find the numbers in cell C48 and C49 in annex WK8 2018. Insert them in the exercise table where its cell name is given.	
5	Decide how much of the area you wish to take out for rewetting. If you think in percent, then calculate the number of hectares first. Insert the share of the areas you take out on taking out for rewetting and for nature in the green cells. The table calculates how large an area that is taken out all together.	Now you have a table, which shows how much agricultural soil should be taken out of agricultural use.
6	Reduce the numbers in cell C10 and B10 in the annex WK7 2018 by the total area which is taken out for rewetting and nature (orange and pink cell) (Make sure you keep the number you previously inserted for new forest).	
7	Increase the numbers in cells C29 and B29 i WK7 2018 by the sum of agricultural soil taken out for nature purpose (orange cell).	

8	Increase the numbers in cells C55 and B55 in annex WK7 2018 by the sum of areas taken out for rewetting (pink cell).	
9	Reduce the area in cell C26 in annex WK7 2018 by the sum of rewetted permanent grass (pink cell).	
10	Increase the numbers in cells C56 and B56 in annex WK7 2018 by the sum of permanent grass taken out (pink cell) for rewetting. (periodic wetland).	
11	Check that the change in cell B10 has had effect in the now corrected LULUCF account "LULUCF W2018" cell D11 by comparing to the same cell in "LULUCF 2018".	
12	Check in the same way, that the number in cell R10 in the annex has had effect in "LULUCF W2018" cell O11.	
14	In a similar way you can check up on other changes.	
15	Find annex WK8 2018 and the table "Emission from drained and rewetted agricultural area".	
16	Reduce the number in cell C27 by the area in the exercise table taken out for rewetting - 6-12% organic matter and increase the number in cell C67 by the same number.	
17	Reduce also the number in cell C28 by the area from the exercise table which is taken out for rewetting > 12% organic matter and increase the number in cell 67 further by the same number.	
18	Repeat the procedure for areas with permanent grass in the table" Emission from drained and rewetted permanent grass" in annex WK8 2018	
19	Check that the changed numbers in column C in the annex have changed the results in the account "LULUCF W2018). You can trace where numbers in the account comes from by looking into formulas.	You have now corrected the LULUCF account for the effect of taking out agricultural area to either nature or rewetting. The change is due to reduced turnover of carbon from the carbon rich soils.
19	Find annex WK4 2018.	
20	Reduce the areas in cells B99 to B102 by the respective areas from your exercise table. It is assumed, that all areas taken out are deeply drained – but we do not know. If you choose another combination of deep and shallow drained it is fine.	
21	Check how the number in cell D18 in the annex has changed and that it has been changed in the account for Plant Production W2018 cell AA13.	You have now corrected the account for Plant Production for the most important changes due to taking our organic soils of agricultural production.

Below you find a copy of the exercise table.

	Organic agricultural soil							Organic permanent grass						
	6-12% carbon (area from annex K8 2018)	6-12% carbon (area taken out - max 100%)	%-age taken out	>12% carbon (area from annex K8 2018)	>12% carbon (area taken out - max 100%)	%-age taken out	Sum of areas taken out	6-12% carbon (area from annex K8 2018)	6-12% carbon (area taken out - max 100%)	%-age taken out	>12% carbon (area from annex K8 2018)	>12% carbon (area taken out - max 100%)	%-age taken out	Sum of areas taken out
Taking out to nature use (conversion t	C28			C29			0							
Taking out for rewetting - periodic wet	C28			C29			0	C48			C49			0

4.10 Marine instruments

Timeframe 20 min

Cultivating seaweeds (macro algae) and mussels for food, feed and energy is a just about completely forgotten option of simultaneous environmental solution for avoiding eutrophication in inner seas and at the same time increase the production of biomass. Yields per hectare of macro algae is considerably higher than any land cultivation, and the nutrient content of algae is about the same as in comparable landbased crops. Furthermore, the whole algae is edible as opposed to e.g. wheat, where only the inner part of the seeds are edible. But neither humans or animals can live from a pure algae diet and therefore algae must be viewd as a crop which must be refined for protein and other valuable substances while the residues can be used for energy and displace fossils.

By introducing commercial algae production, the total biomass potential can be increased considerably and at the very least compensate for ceased imports of foods and feeds and biomass for energy. Mussels functions in a similar way as water cleaners and is at the same time a high quality food or feed. Moreover, there is a hitherto non-exploited potential of up-cycling the shells for eg. Binder in cements, cosmetics or nutritional supplements. The proetin quality is very high, and the systems for production with lines is fully developed. In table 1 below calculations have been made for the displacement potential from marine instruments when used in the energy system as input for biogas or biochar production.

Eelgrass is the only species of gras which belongs to the sea. Eelgrass cannot be eaten but functions as an important habitat for the sea fauna and accumulates nutrients and carbon in leaves and roots. Over time it builds up banks of carbon on the bottom of the sea. Denmark was in previous years just about locked in behind eelgrass at all shores, but because of an overload of nutrients the eelgrass meadows have shrunk to only very small areas. Reestablishment of eelgrass meadows thus can contribute as carbon sinks at at the same time increase the quality of the marine environment. In the table below, eelgrass has been included as a climate impact reduction instrument.

	Do this	Outcome
1.	Go to the exercise table in the sheet “Marine Instruments”.	
2.	Insert for every instrument the areas of the sea which you think could be used for growing seaweeds, mussels or eelgrass. The table only includes on makroalgae - ”seasalad” – but if you should have knowledge of other species production data you can add more.	
2.	The climate account have not been prepared to include marine instruments as the coastal areas are not included in IPCCs climate accounting format. But that should not hold us back from calculating the benefits from production. In ”Plant Production W2018” a column and a row has been added to the original layout. Here the effect of including marine instruments can be inserted. It is the sum of hectares from the exercise table and the sum of CO_2 and N_2O effects, that should be used.	
3.	Go to the account for "Plant Production W2018"	
4.	Insert the sum for "Area in the municipality” from the exercise table into cell X12 in the account.	
5.	Insert the sum of ”Displacement potential CO_2, ton" from the exercise table into cell AD12 in Plant Production W2018. Remember it is a negative number.	
6.	Inserty the sum of "N_2O effect (ton N_2O)" from the exercise table into cell AF12 i Plant Production W2018. It is a negative number.	You have now corrected the account for the estiamted effect in CO_2-e of using marine instruments for climate impact reduction when it is expected they are used for producing green energy. Hopefully they will also partly be used for food and feed and other high value uses. I that case the displacement will not occur in Denmark but in third countries as scope 3. And that is all in all probably better for the climate.

Table 1 - Marine biomass

CO_2-effect from marine instruments

Production	Harvest/ growth (ton per ha)	Dry matter share	Dry matter harvested per ha (ton)	Area in municipality	Dry matter potential (ton)	C-content, share of dry matter	N-content (share of dry matter)	Total ton C	Total ton N	Dispalcement potential CO_2, ton	Ton C/ha	Ton N/ha	N_2O effect (ton N_2O)	N_2O effect (ton CO_2-e)	Total emission-reduction
Mussels, n	53	0,09	5		0	0,43	0,09	0	0,00	0	0,00	0,00	0,0	0	0
Mussels, s	105	0,173	18		0	0,2	0	0	0,00	0	0,00	0,00	0,0	0	0
Seastars			0		0	0	0	0	0,00	0	0,00	0,00	0,0	0	0
"Konksnails"					0	0	0	0	0,00	0	0,00	0,00	0,0	0	0
Oysters			0		0	0	0	0	0,00	0	0,00	0,00	0,0	0	0
Seasalad	53	0,3	16		0	0,25	0,023	0	0,00	0	0,00	0,00	0,0	0	0
Sugarweed	12		0		0	0	0	0	0,00	0	0,00	0,00	0,0	0	0
Other weeds			0		0	0	0	0	0,00	0	0,00	0,00	0,0	0	0
Other weeds			0		0	0	0	0	0,00	0	0,00	0,00	0,0	0	0
Eelgrass	NA	NA	NA		NA	NA	NA	0	0,00	0	0,00	0,00	0,0	0	0
Total CO2-effect								0	0	0			0,0	0	0
Sources:	*Seasalad: Notat fra DCE – Nationalt Center for Miljø og Energi , 2020.Høst af eutrofieringsbetingede masseforekomster af søsalat - status på viden om miljøeffekter og økonomi. Mussels:*	*Seasalad: Notat fra DCE – Nationalt Center for Miljø og Energi , 2020.Høst af eutrofieringsbetingede masseforekomster af søsalat - status på viden om miljøeffekter og økonomi.*	*Seasalad: Notat fra DCE – Nationalt Center for Miljø og Energi , 2020.Høst af eutrofieringsbetingede masseforekomster af søsalat - status på viden om miljøeffekter og økonomi. Mussels:*			*Seasalad approximated from Double Crop results*	*Seassaladt: Nationalt Center for Miljø og energi, 2020*	*Eelgrass: Lange et. al., 2020. Storskala-transplantation af ålegræs - Metoder og perspektiver*	*Eelgrass: Lange et. al., 2020. Storskala-transplantation af ålegræs - Metoder og perspektiver*						