Estimering af CO2-emission fra landjorden ved hjælp af satellitbilleder

Projekt initieret af Landsforeningen for Bæredygtigt Landbrug, som har bistået med referenceberegninger af biomasseproduktion til validering af resultaterne, samt skrevet den indledende tekst.

Billedbehandling og beregninger blev udført af firmaet CarbonSpace, som har udviklet en teknik, der gør dem i stand til på basis af satellitbilleder at estimere den nettoflux af carbondioxid, der er ved jordoverfladen.

Som primært projektområde blev valgt Holmegaard gods, der velvilligt har stillet deres mark og udbyttekort til rådighed for projektet.

Projektet er finansieret af "Fonden for større landejendomsbesiddere og arbejdsgivere i det tidligere Præstø amt"

Baggrund

Kulstofkredsløbet i landbrugets planteavl

Kulstof findes i alle organiske forbindelser og herunder i de fossile brændstoffer som olie, kul og naturgas, der især gennem det seneste århundrede er udnyttet af menneskeheden og har medført den truende klimakrise. Men kulstof findes også i jordbunden og i planterne, for hvilke kuldioxid (CO_2) er det betydeligste næringsstof, der bidrager med op til 80 % af tørstofindholdet.

Kuldioxid (CO_2) er et næringsstof på gasform: Begge bestanddele af CO_2, nemlig kulstof og ilt, er vigtige byggesten for planterne. Gennem de seneste 60 år er luftens indhold af CO_2 steget på grund af udledning fra forskellige kilder som især afbrænding af kul, olie og naturgas, vulkanudbrud og udånding fra højere organismer som dyr og mennesker. Ligeledes frigøres CO_2 fra jorden under nedbrydning af organisk materiale ved hjælp af jordens indhold af mikroorganismer, orme m.v. Alt i alt er atmosfærens indhold af CO2 steget fra ca. 315 til 410 ppm siden 1958, hvor de første målinger på den amerikanske østat Hawaii fandt sted.

Man bør her skelne mellem det gamle kulstof fra de fossile kilder, som kul, olie og naturgas, og det kulstof, der cirkulerer i alt det levende – og har gjort det gennem århundreder i menneskehedens historie, uden at det har påvirket indholdet af CO_2 i jordens atmosfære i stort omfang.

Det vurderes, at landjordens vegetation årligt forbruger 5-10 % af atmosfærens indhold af CO_2. En sukkerroeafgrøde på 75 ton modsvarer ca. 15 ton tørstof, der indeholder 7,1 ton kulstof svarende til 25 ton CO_2. Det er en mængde CO_2, der svarer til indholdet i 34 mio. m^3 luft, som afgrøden ”låner” fra luften, frem til den atter frigøres, når sukkeret fortæres, og planterester nedbrydes. Det kaldes den korte livscyklus. Tilsvarende eksempler kan laves for alle etårige afgrøder.

I Bæredygtigt Landbrugs projekt med satellitmåling af Danmarks CO_2-udledning kan man se, hvordan afgrøder og skove i vækstsæsonen optager store mængder CO_2, og hvorledes større byer udleder store mængder af primært fossilt kuldioxid. Billedet fra marker og skove ændrer sig over efteråret, hvor der er en nedbrydning af planterester, ligesom jordens åndingstab overstiger planternes optag, da væksten går i stå.

Når man ikke regner optaget af CO2 på markerne med, får man ikke det fulde billede. Det er klart, at anvender man den dyrkede biomasse til fødevarer eller foder, så er CO2 hurtigt på vej ud i kredsløbet igen, men anvender man det som brændsel, så fortrænger det fossile brændstoffer. Bruger man det til byggematerialer eller nedmulder det i jorden, så reducerer man den mængde CO2, der er i kredsløb. Jo mere biomasse man dyrker, jo mere CO2 trækker man ud af luften. Den langsigtede effekt af at optage CO2 i biomasse via fotosyntesen afhænger af, hvad man anvender den producerede biomasse til.

Formålet med dette projekt, som ”Fonden for større landbesiddere og arbejdsgivere i det tidligere Præstø Amt” har valgt at støtte, er med Holmegaard gods som eksempel at vise, at der er et overordentligt stort optag af CO2 i de almindelige markafgrøder.

FAGLIGE KOMMENTARER.

Metoden til estimering af CO_2-flux er ny og ikke særligt veldokumenteret. Den viser dog god korrelation med de beregninger af biomasseproduktion og fjernelse, som vi lavede på baggrund af udbytteregistreringer fra Holmegaard. Derfor er der heller ikke grund til at tro, at de målinger, der er lavet på Holmegaards arealer, ikke skulle være retvisende, om end der altid er stor usikkerhed forbundet med måling af CO_2 på større arealer.

I forbindelse med resultaterne for Holmegaard er der opgivet, at skoven har et optag på 70 tons pr. hektar. Der er ingen tvivl om, at skov i vækst har et stort optag, men da der kun er målt på to hektar, og tallet er markant højere, end man ville forvente, vælger vi at se bort fra det resultat, til vi kan få det verificeret med mere omfattende målinger.

Projektet søges fortsat i en fase 2, da yderligere validering af metoden synes nødvendig, hvis den skal have større udbredelse.

FREMTIDEN

Nærværende undersøgelser bygger på de data og algoritmer, der er tilgængelige med eksisterende satellitter i 2021 og sandsynligvis frem til ESA sætter nye satellitter i kredsløb i 2025, der kan måle udledning af metan og CO_2 mere detaljeret. Men frem til da vil vi søge at validere og forfine de nuværende satellitbaserede estimater, så vi undgår store samfundsmæssige fejlinvesteringer.

HVAD VISER DET OS

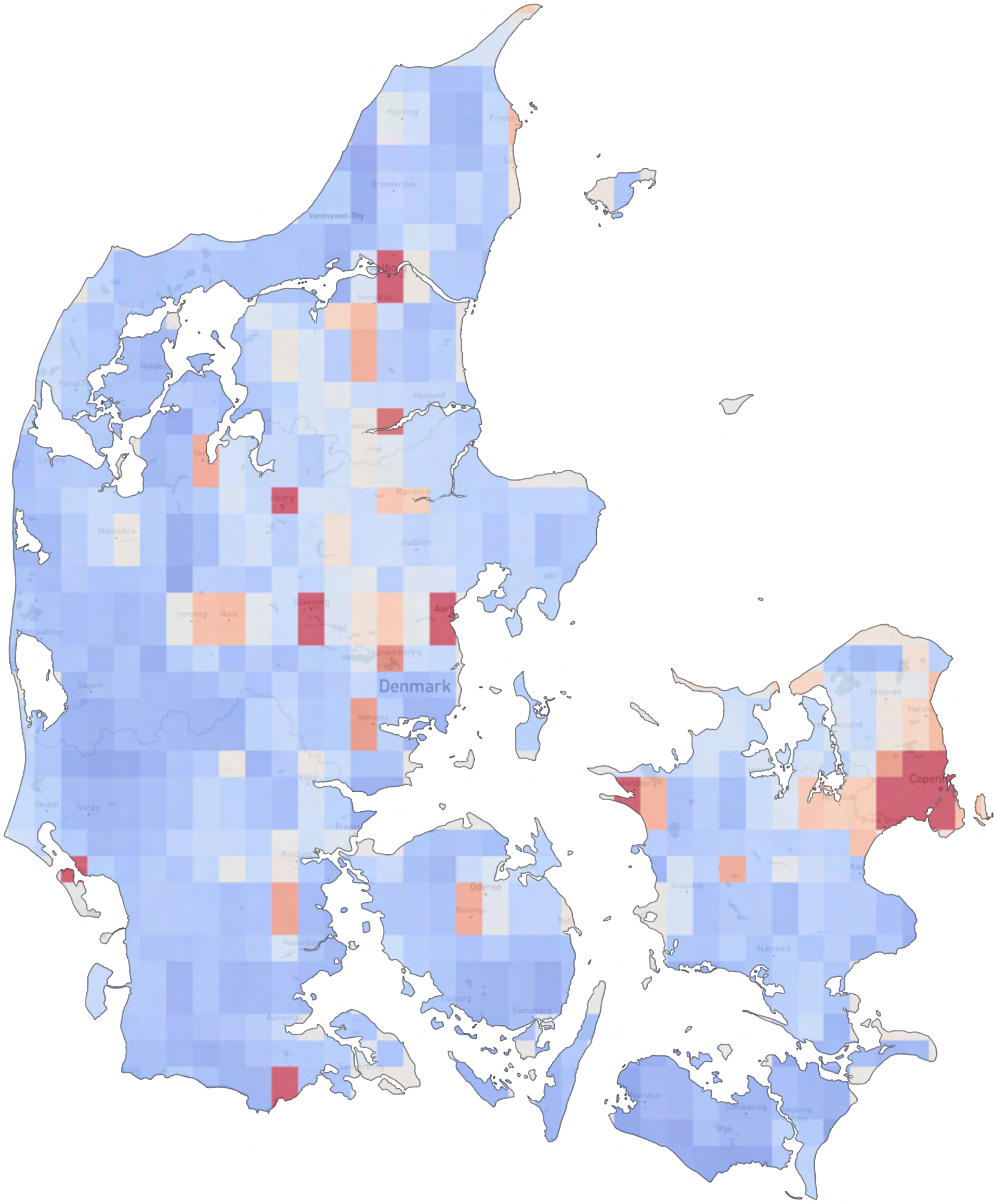
Ud fra det nærværende datamateriale med bl.a. måling af CO_2-flux fra vedvarende græsmarker på lavbundsjord ved Holmegård finder vi ikke evidens for de generelle store udledninger af CO_2 fra lavbundsjorde, som fremføres i dagens politiske debat.

VI ser også, at optaget af CO_2, som forventet, korrelerer fint med mængden af biomasse, der fraføres marken og forventes lagret i jorden. Det underbygger det synspunkt, at en reduktion af den vegetabilske produktion på landbrugsjorden vil være kontraproduktiv i forhold til at sænke CO_2-koncentrationen i den atmosfæriske luft.

Danmarkskortet viser naturligvis også, hvor nettoudledningen er størst, nemlig i de tæt befolkede områder, hvor der afbrændes flest fossile brændstoffer og mest biomasse til transport og energiproduktion.

Fredericia, december 2021

Jens Lund Pedersen, cand. agro.
Jørgen Evald Jensen, cand. agro.
Hans Aarestrup, cand. agro.



Estimation of carbon fluxes in Denmark: 2000-2021

CarbonSpace

This report explores the variations in carbon fluxes of three types of territories:
- Total Denmark territory
- Urban territories
- Agricultural lands

While the total Danish carbon emissions are gradually decreasing, the relative emissions of Copenhagen and Aarhus are growing, with Odense demonstrating a swift decline from mid-2000s peaks.

The agricultural lands of Holmegaard Gods represented three land-use types: croplands, grasslands, forests. All of them consistently serve as carbon sinks (from the CO_2 flux standpoint, without taking into account anthropogenic and methane emissions).

Sustainable agricultural management and reduction of emissions from on-farm operations can contribute to an increase in carbon uptake in the land-use sectors and to further decrease the total national footprint.

Monthly data for emissions of Aarhus and Odense municipalities is a case in point: biospheric uptake during summer months created negative carbon flux over the urban territories.

The estimations were done within the CarbonSpace platform, which is the satellite-powered tool for remote tracking of emissions from land-use. This method can be scaled to estimate the role in balancing carbon of the whole LULUCF (Land-use, land-use change and forestry) sector in Denmark.

Denmark: Total carbon flux

According to the latest national inventory, CO_2 is the most important greenhouse gas contributing to the national total CO_2-eq with 70.3 %, followed by CH_4 with 16.3 %, N_2O with 12.5 %, and f-gases (HFCs, PFCs, SF_6 and NF_3) with 0.9 %.

The largest sources are the energy sector and agriculture, followed by industrial processes and product use and waste.

Estimations in this report represent total CO_2 fluxes over the territory of Denmark, anthropogenic and biospheric sources combined, i.e. the sum of all emissions and uptakes.

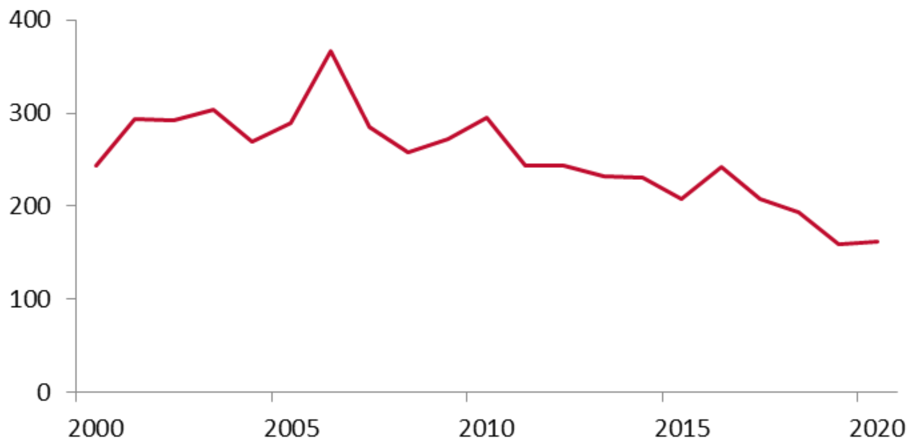
42933 km2

Area

252 t CO2 per km2

Average annual carbon flux

Carbon flux, t CO2 per km2

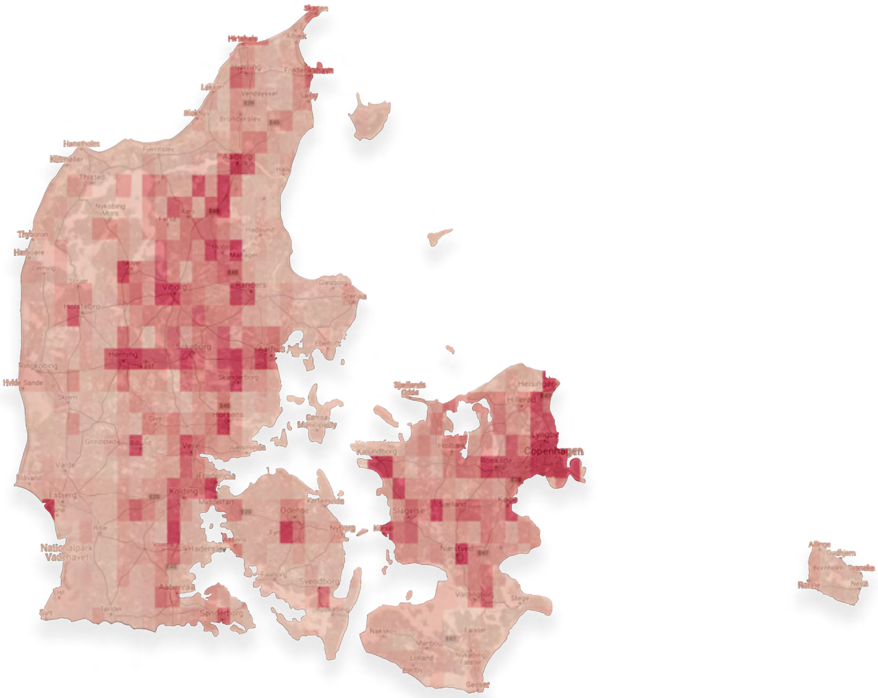


Our estimations witness continuous decrease in CO_2 emission, which is in line with the national inventory.

Carbon flux change vs 2000, t CO2 per km2

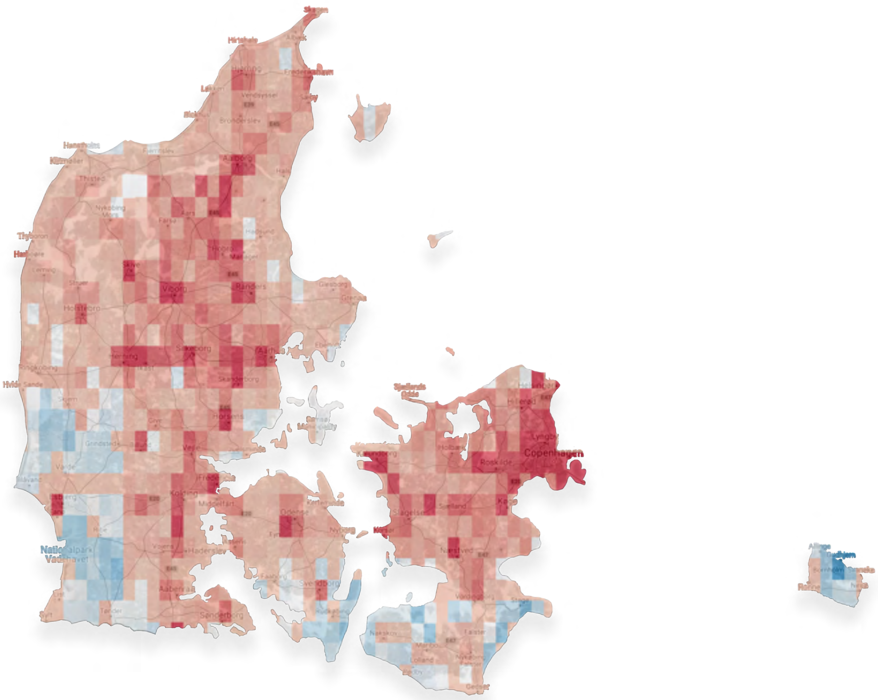
According to the inventory, this trend is mainly caused by decreasing emissions from the energy sector due to the development of renewable energy.

Denmark: Total carbon flux



Carbon flux in 2016, kt CO_2 per km2

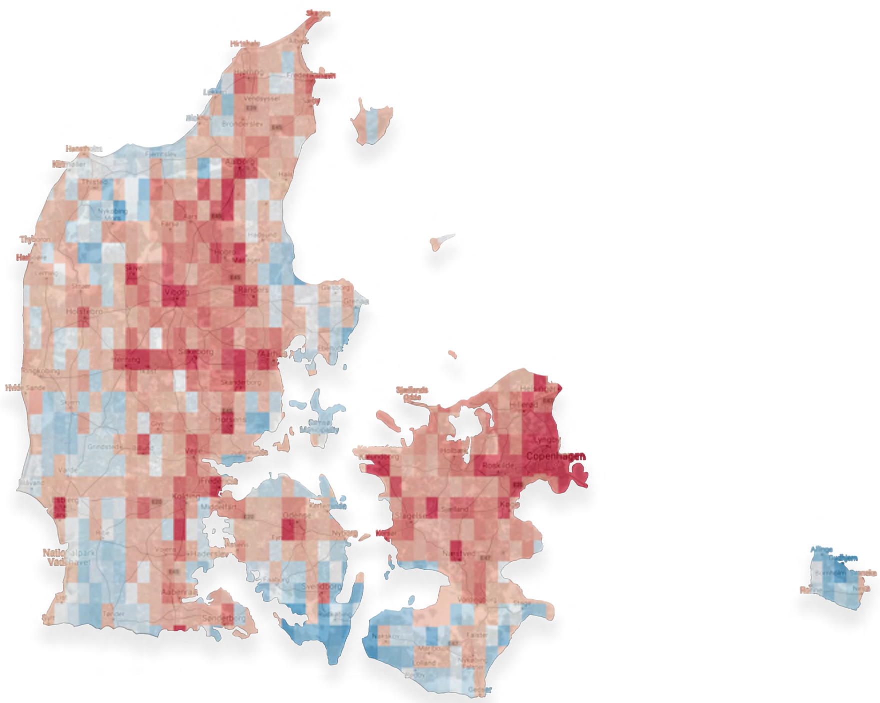
-0.3 40



Carbon flux in 2017, kt CO_2 per km2

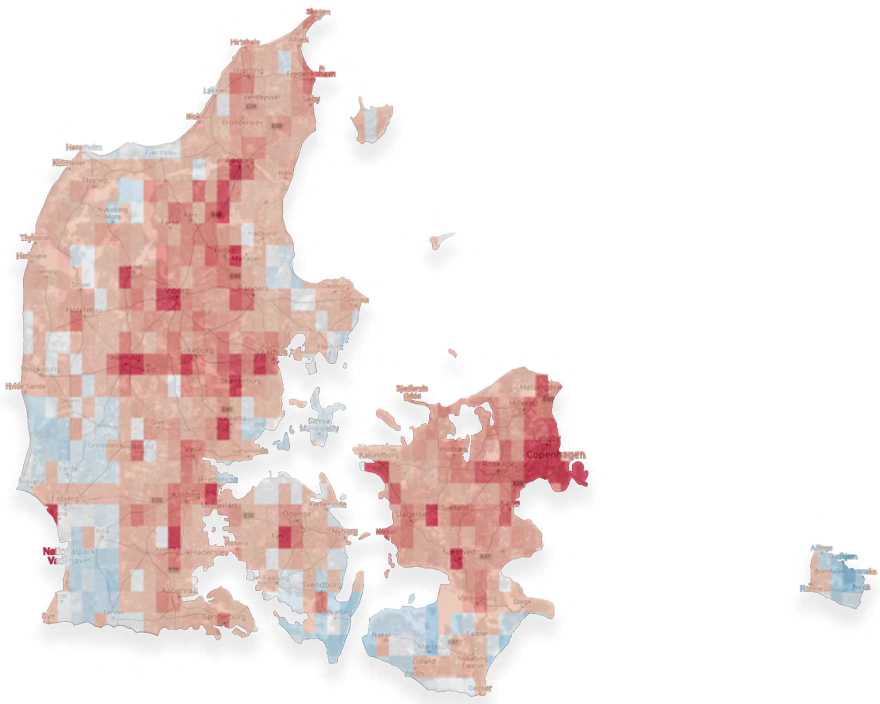
-0.3 40

Denmark: Total carbon flux



Carbon flux in 2018, kt CO2 per km2

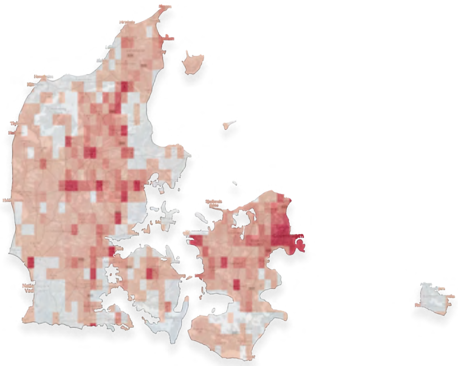
-0.3 40



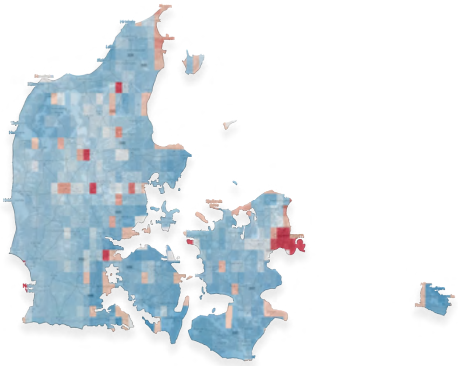
Carbon flux in 2019, kt CO2 per km2

-0.3 40

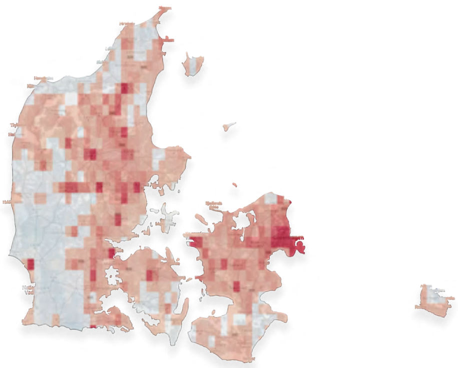
Denmark: Total carbon flux



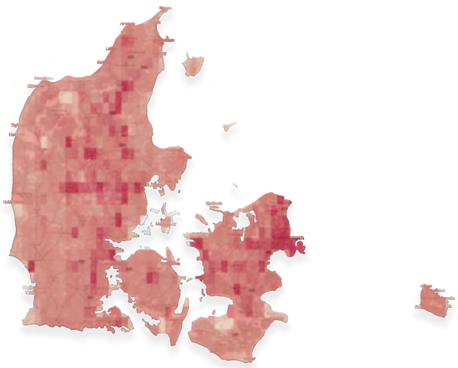
Carbon flux in April 2020, kt CO2 per km2



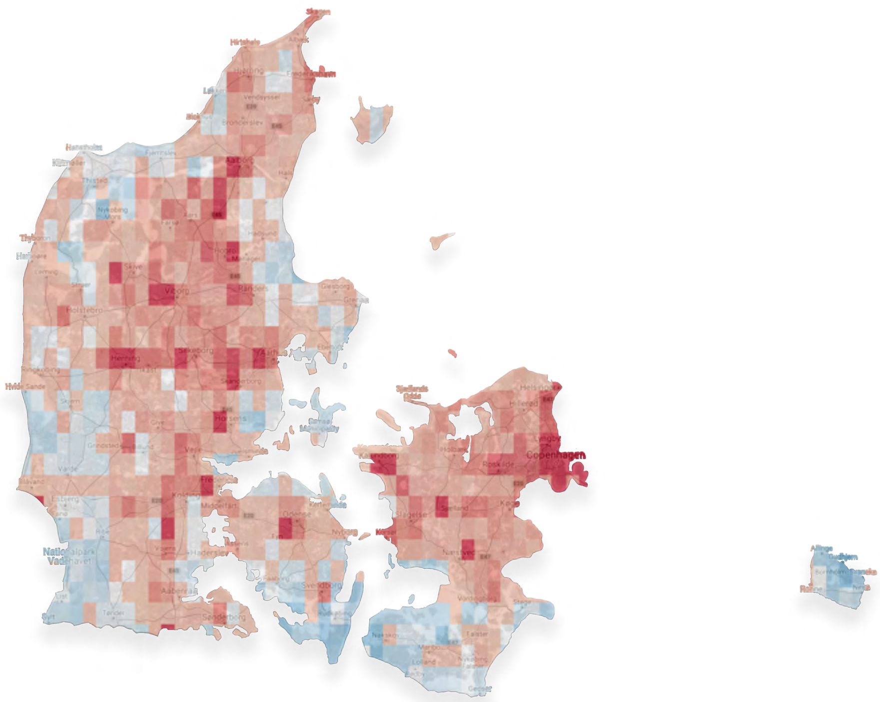
Carbon flux in June 2020, kt CO2 per km2



Carbon flux in August 2020, kt CO2 per km2



Carbon flux in November 2020, kt CO2 per km2



Carbon flux in 2020, kt CO2 per km2

Copenhagen: Total carbon flux

Copenhagen is the largest city in Denmark, a big transport hub and an important contributor to total country emissions.

Its emissions stand out among other cities due to the larger urban area and the lower area of lands, which are capable of uptaking some of the emissions.

Note: Copenhagen area is considered as Greater Copenhagen, and encompasses 18 municipalities (kommunes): København, Frederiksberg, Albertslund, Brøndby, Gentofte, Gladsaxe, Glostrup, Herlev, Hvidovre, Lyngby-Taarbæk, Rødovre, Tårnby, Vallensbæk, Ishøj, Greve, Ballerup, Rudersdal, Furesø.

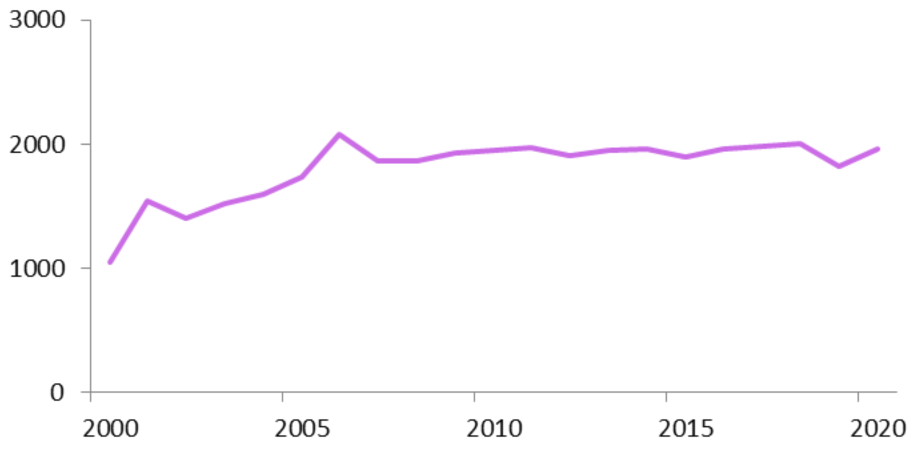
607 km2

Area

1807 t CO2 per km2

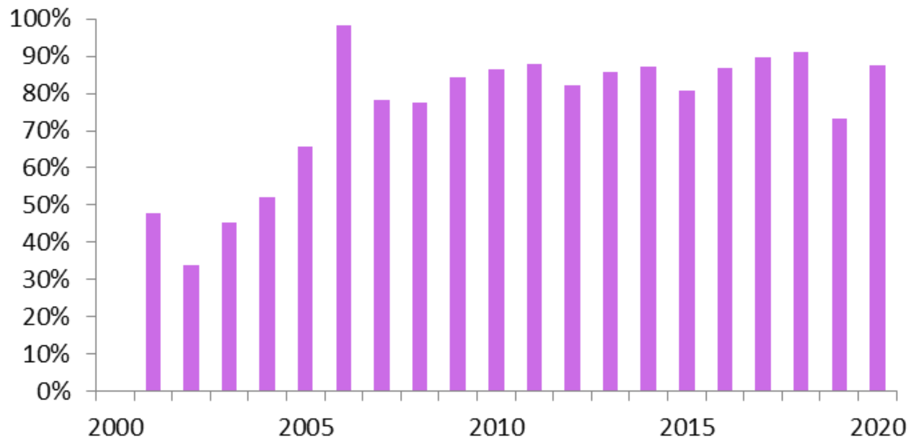
Average annual carbon flux

Carbon flux, t CO2 per km2



Relative (and absolute) emissions have been gradually increasing.

Carbon flux change vs 2000



However, the growth rate has slowed down, and the reverse of the trend can not be excluded.

Aarhus municipality (Aarhus Kommune) is the second-largest and fastest-growing city in Denmark.

The intensity of emissions is significantly lower than that of Copenhagen, however, it's consistently growing during the last 20 years.

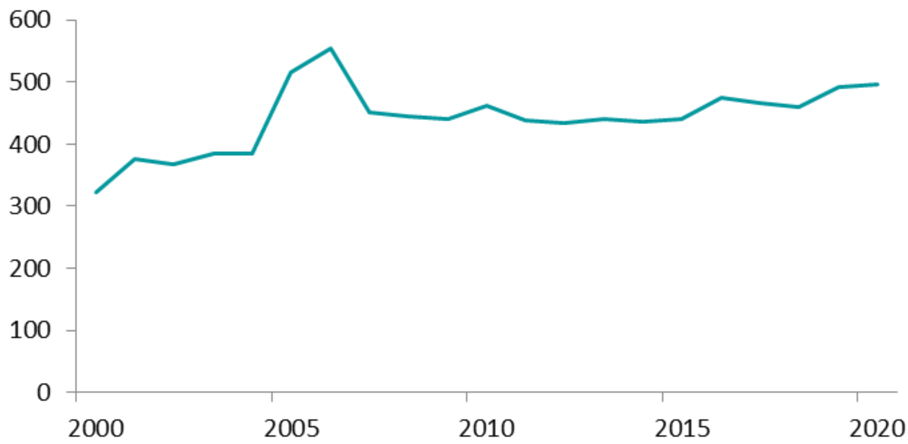
470 km2

Area

442 t CO2 per km2

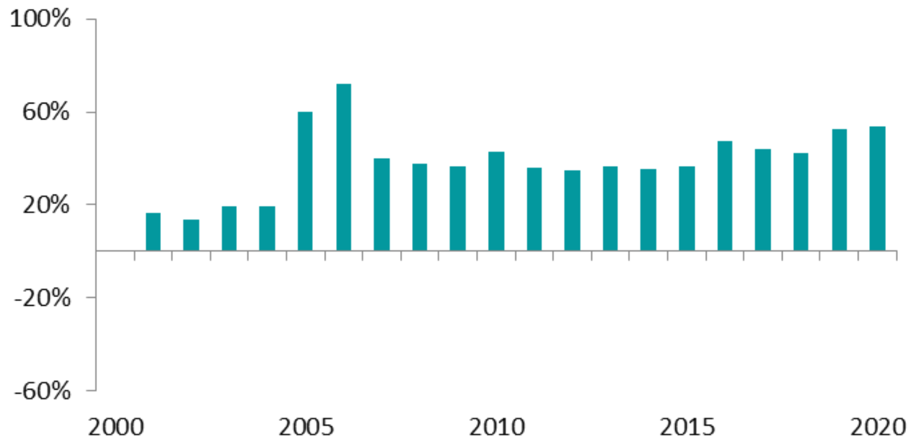
Average annual carbon flux

Carbon flux, t CO2 per km2



In recent history, emissions peaked in 2006 with intensity of 554 t CO2 per km2.

Carbon flux change vs 2000



The overall trend in emissions intensity demonstrates a slight but gradual increase.

Odense municipality (Odense Kommune) is the third-largest city in Denmark.

The intensity of emissions is comparable to the total Danish emissions intensity, however, it has got some local particularities, which are represented on the charts below.

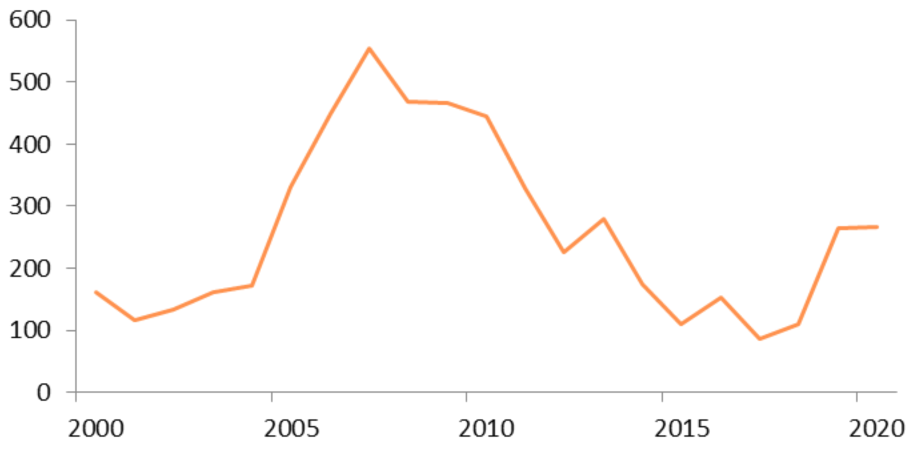
304 km2

Area

260 t CO2 per km2

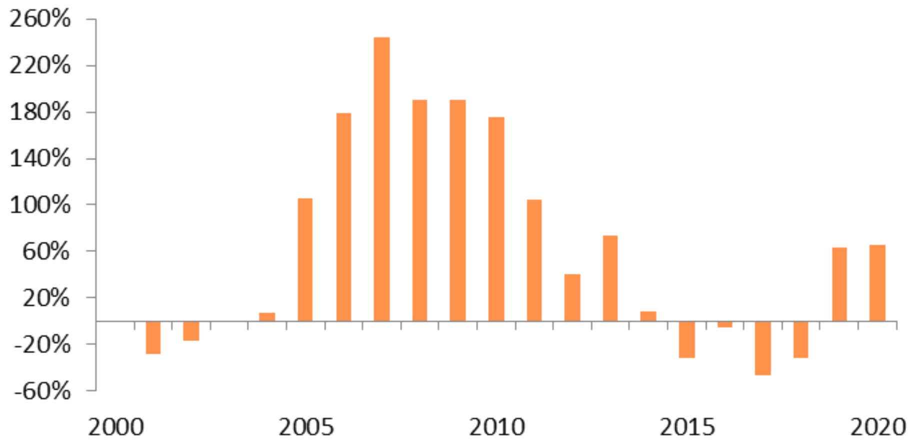
Average annual carbon flux

Carbon flux, t CO2 per km2



Emissions peaked in 2007 with intensity of 554 t CO2 per km2, which is very similar to the story of Aarhus.

Carbon flux change vs 2000

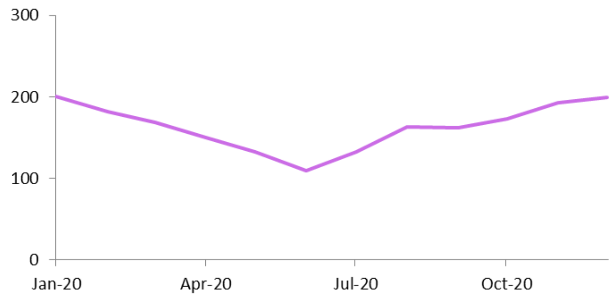


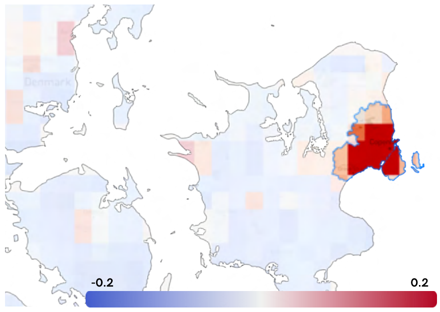
Unlike Aarhus, Odense managed to curb the emissions growth and significantly lower the total intensity.

The charts show the monthly variations in total carbon flux.

The valley in the middle of the charts is explained by biospheric uptake, which is most intensive during summer months. It affects even Copenhagen, which has the lowest area of land.

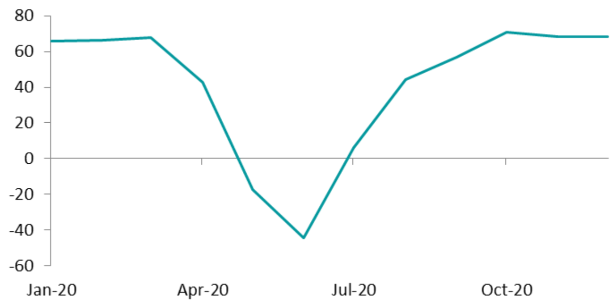
Carbon flux in Copenhagen in 2020,
t CO2 per km2

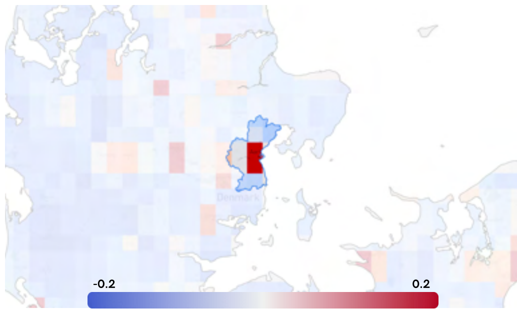




Carbon flux in July 2020,
kt CO2 per km2

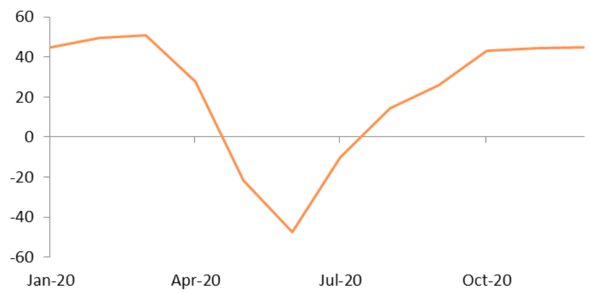
Carbon flux in Aarhus municipality in 2020,
t CO2 per km2

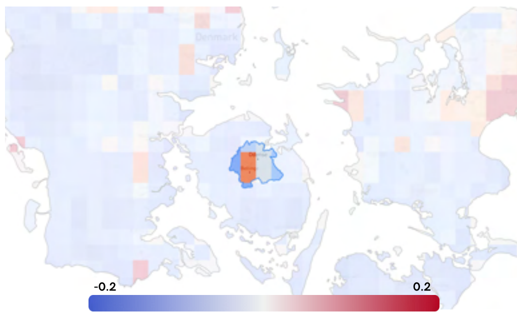




Carbon flux in July 2020,
kt CO2 per km2

Carbon flux in Odense municipality in 2020,
t CO2 per km2





Carbon flux in July 2020,
kt CO2 per km2

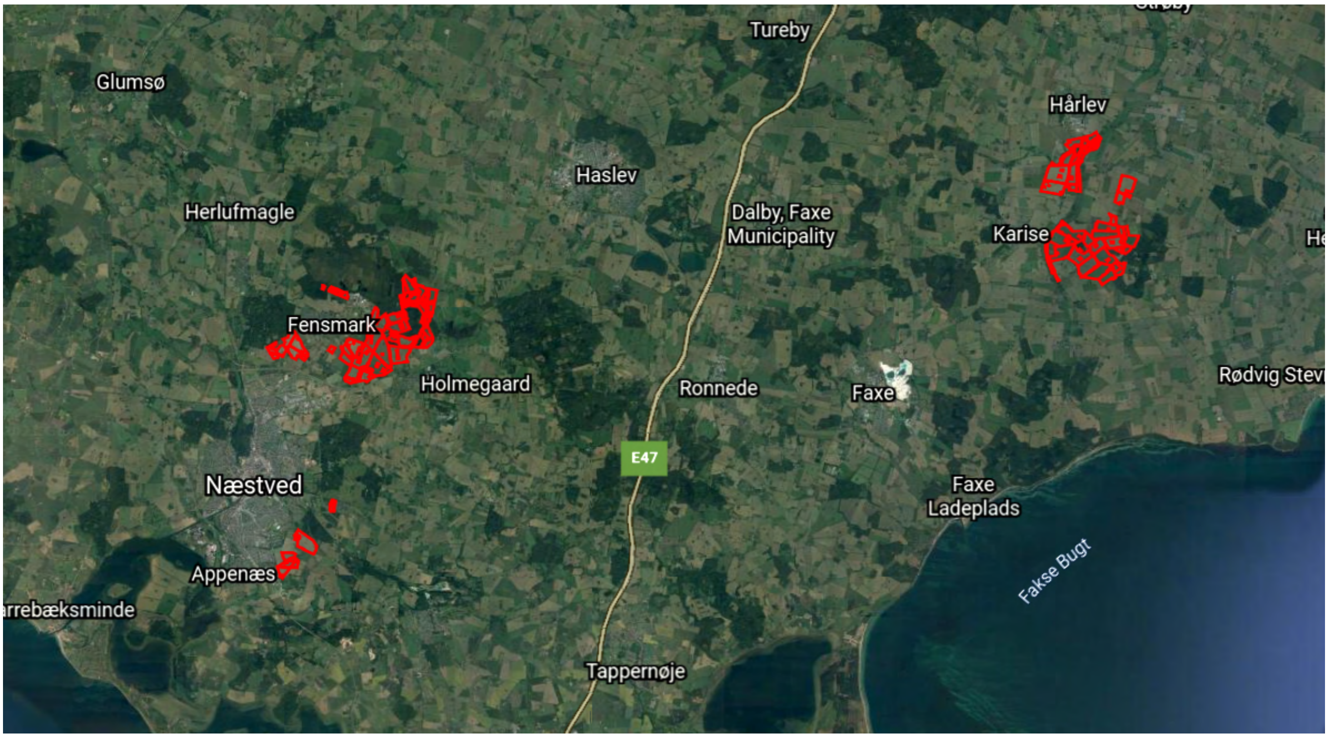
60% of Danish land is cultivated. Keeping in mind that land may serve as a powerful carbon sink, it's important to track fluxes on agricultural lands, because, ultimately, it may show whether the land is managed sustainably and whether it preserves its properties to uptake and store carbon.

In this report, we analyze the carbon fluxes at Holmegaard Gods, which is a number of farms, situated in the Zealand region of Denmark.

The estimated parameter is Net Ecosystem Exchange (NEE), which is a measure of the net exchange of carbon between an ecosystem and the atmosphere and is a primary gauge of ecosystem carbon sink strength.

NEE is a total amount of carbon fixed in the process of photosynthesis by plants in an ecosystem minus carbon losses in respiration (autotrophic + heterotrophic). It effectively represents carbon stock change.

NEE doesn't represent emissions from on-farm operations, including the use of electricity, machinery, fertilizer, methane emission from livestock, etc.



Holmegaard Gods farms highlighted on the satellite image

The total Holmegaard Gods territory consistently serves as a total carbon sink.

The land-use type is mostly croplands (87% of the total area) and grasslands (13% of the total area), with a minor area of forestland (~0.1%).

Note: The following analysis of carbon fluxes includes only lands with an area >1ha. For the analysis of crops performance, all annual data is calculated for the crop year, which is from August of the previous year to July of the reported year.

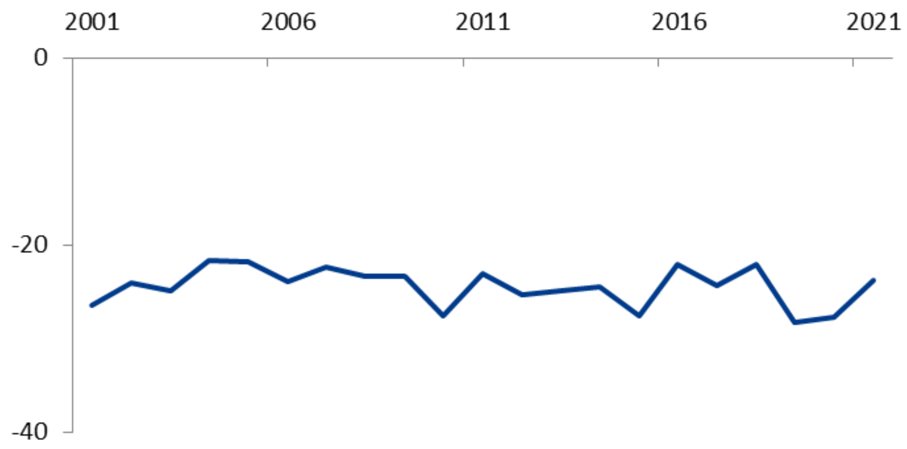
1293 ha

Area

-24 t CO_2 per ha

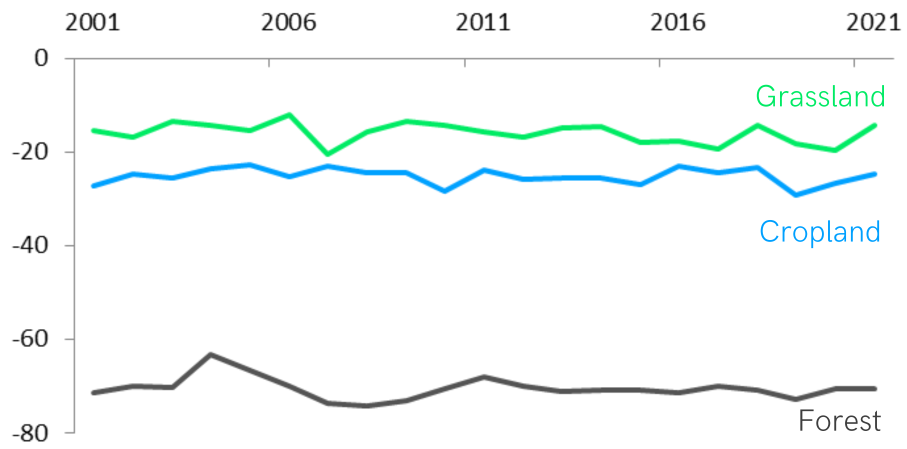
Average annual carbon flux

Carbon flux, t CO2 per ha



The carbon uptake level remains mostly stable over the course of the last 21 years.

Carbon flux from different land-use, t CO2 per ha



Forests generate the best carbon uptake intensity, followed by croplands and grasslands.

Croplands represent the largest land-use type of Holmegaard Gods and define the carbon profile of the whole territory.

While almost all carbon, stored in forests, stays in the ecosystem, most carbon in crops (and grass) is removed during harvesting.

When assessing the sustainability of croplands management, on-farm practices should be taken into account.

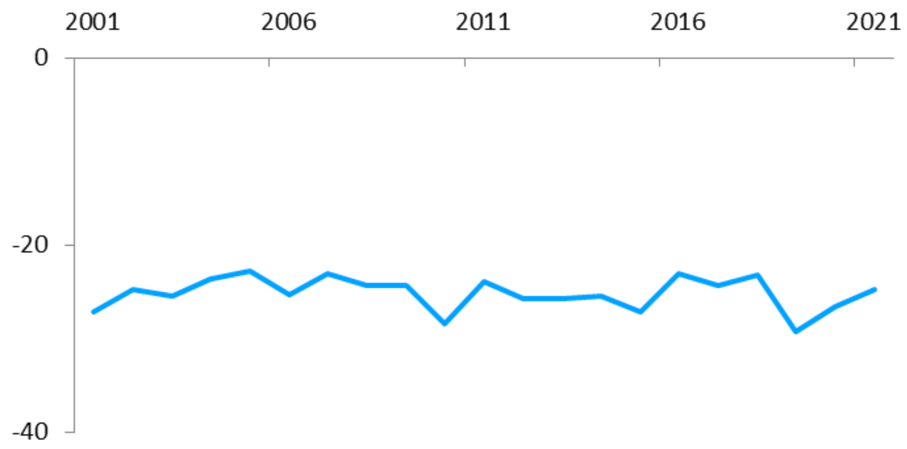
1127 ha

Area

-25 t CO2 per ha

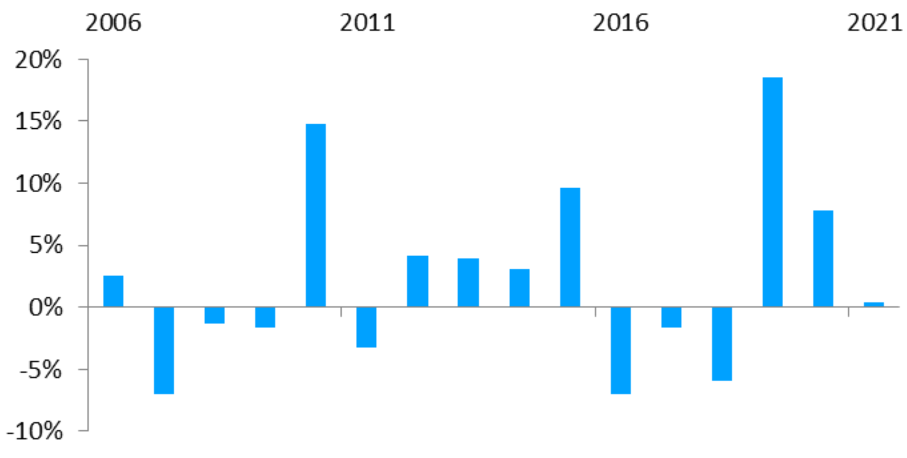
Average annual carbon flux

Carbon flux, t CO2 per ha



The carbon uptake at croplands fluctuates around the average value.

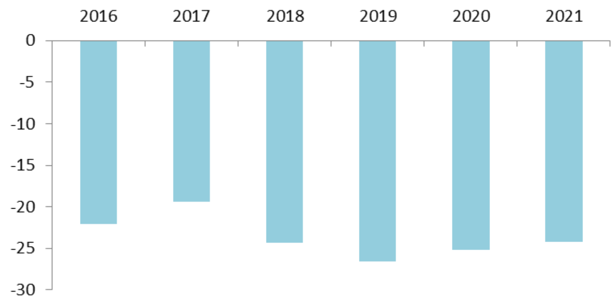
Carbon flux change vs 5-year average (2000-2005)



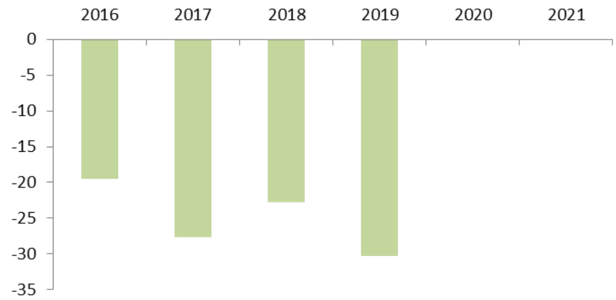
Annual carbon flux change remains mostly within 10%, which is a normal variation due to external factors.

The charts below show the average annual (crop year) carbon flux for selected crops.

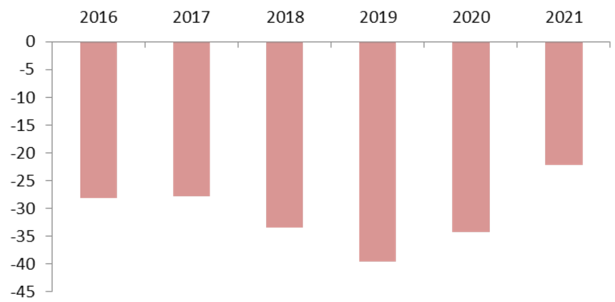
Average carbon flux of Foderhvede, t CO2 per ha



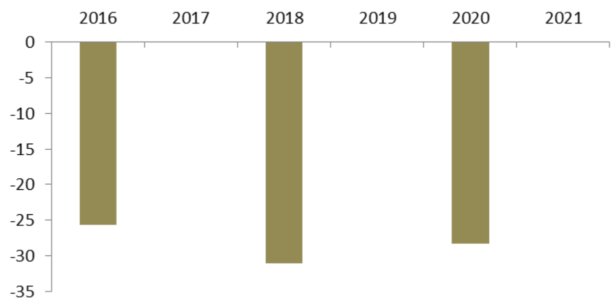
Average carbon flux of Foderbyg, t CO2 per ha



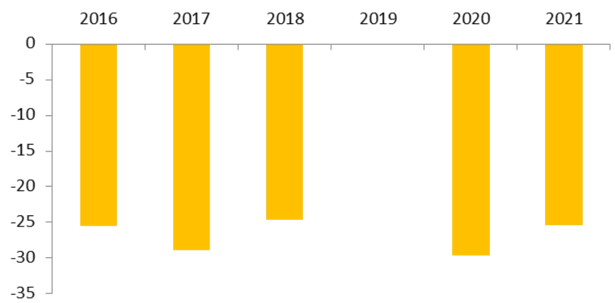
Average carbon flux of Fabriksroer, t CO2 per ha



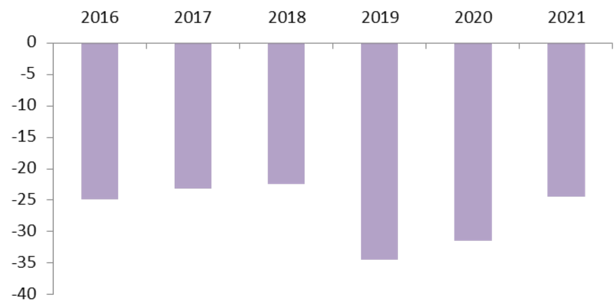
Average carbon flux of Brødhvede, t CO2 per ha



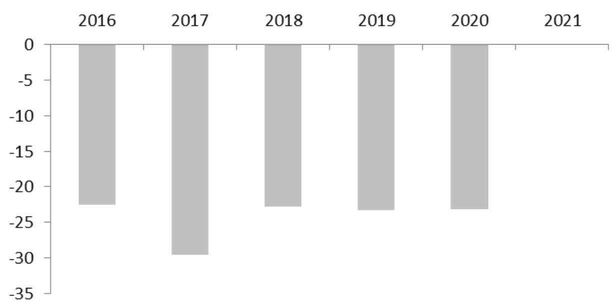
Average carbon flux of Vinterraps, t CO2 per ha



Average carbon flux of Maltbyg, t CO2 per ha



Average carbon flux of Hundegræs, t CO2 per ha

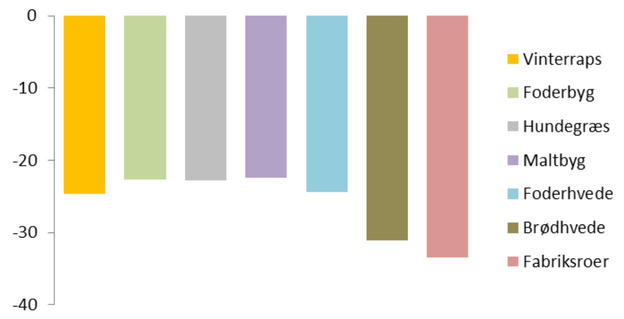


The charts below show the average carbon flux of crops within a crop year.

Average carbon flux of a crop in 2016, t CO_2 per ha

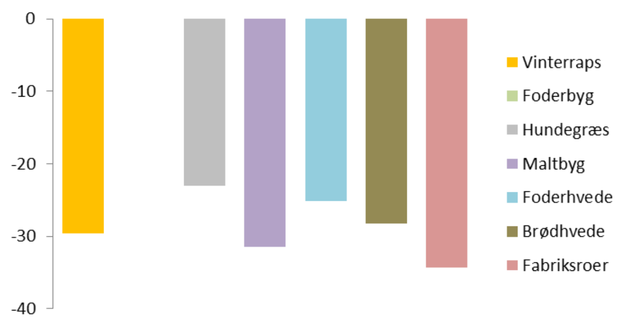
Average carbon flux of a crop in 2017, t CO_2 per ha

Average carbon flux of a crop in 2018, t CO_2 per ha



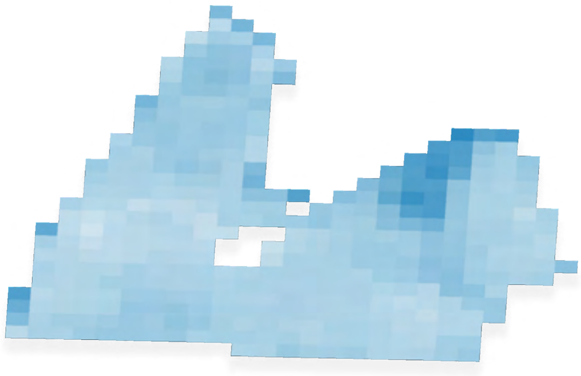
Average carbon flux of a crop in 2019, t CO_2 per ha

Average carbon flux of a crop in 2020, t CO_2 per ha

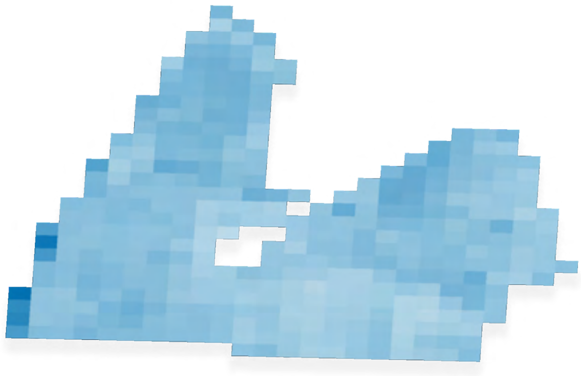


Average carbon flux of a crop in 2021, t CO_2 per ha

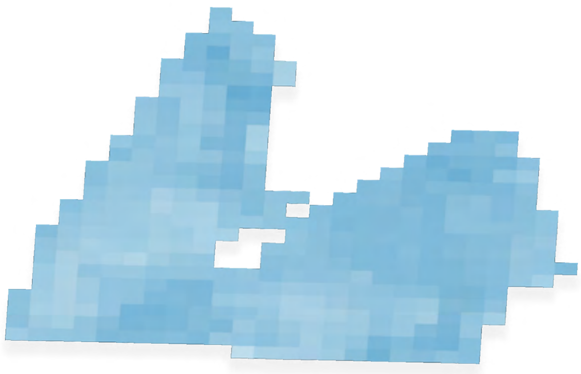
Note: data is presented for calendar year



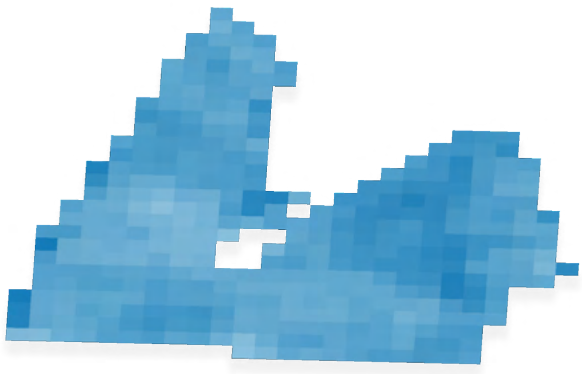
Carbon flux in 2017, t CO2 per ha



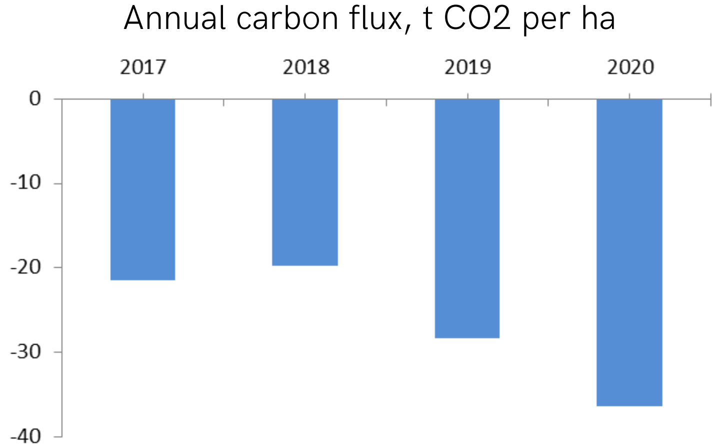
Carbon flux in 2018, t CO2 per ha



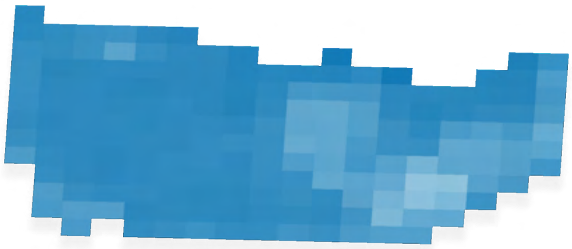
Carbon flux in 2019, t CO2 per ha



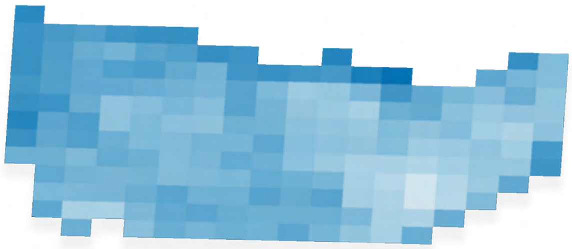
Carbon flux in 2020, t CO2 per ha



Note: data is presented for calendar year

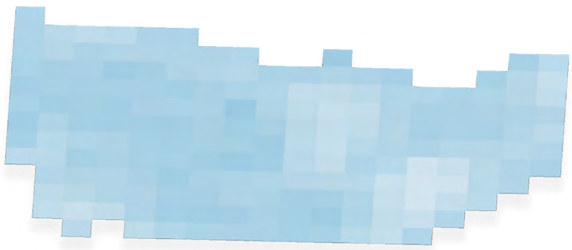


Carbon flux in 2017, t CO2 per ha

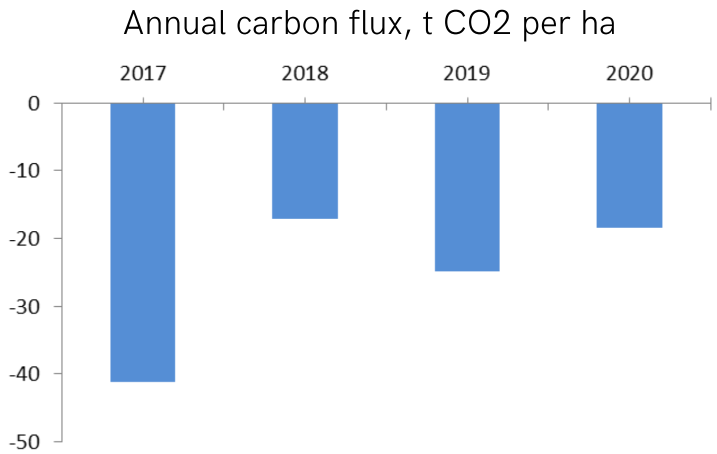


Carbon flux in 2018, t CO2 per ha

Carbon flux in 2019, t CO2 per ha

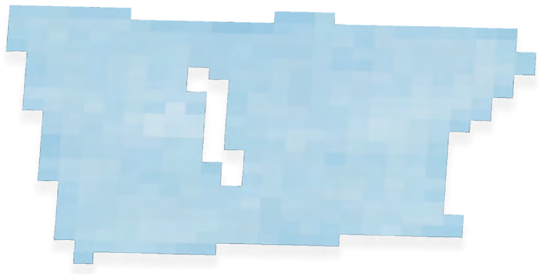


Carbon flux in 2020, t CO2 per ha

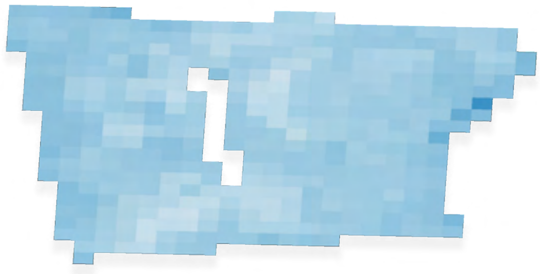


Holmegaard Gods: Carbon flux of field 10-1

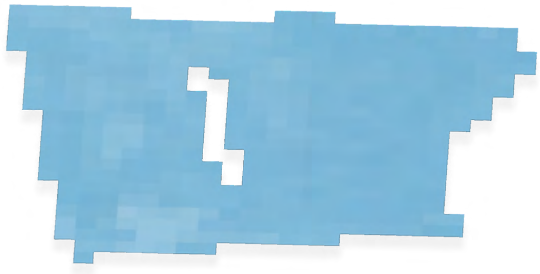
Note: data is presented for calendar year



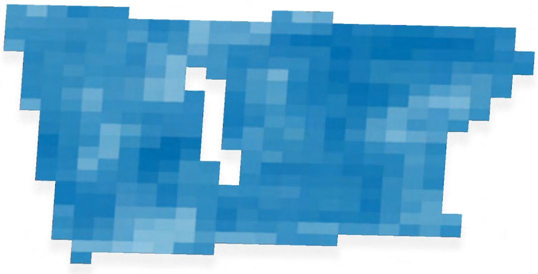
Carbon flux in 2017, t CO2 per ha



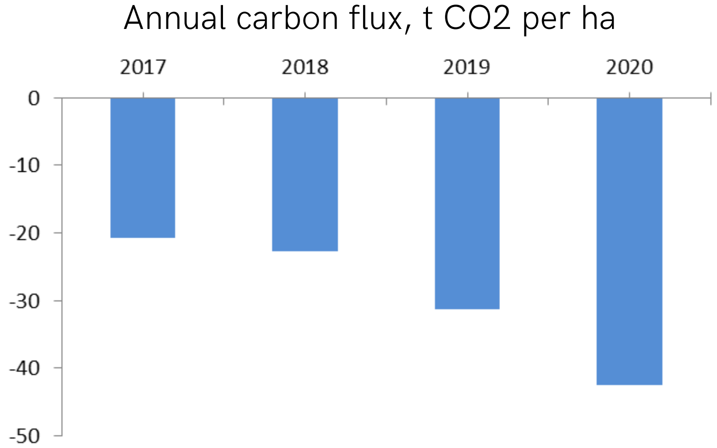
Carbon flux in 2018, t CO2 per ha



Carbon flux in 2019, t CO2 per ha

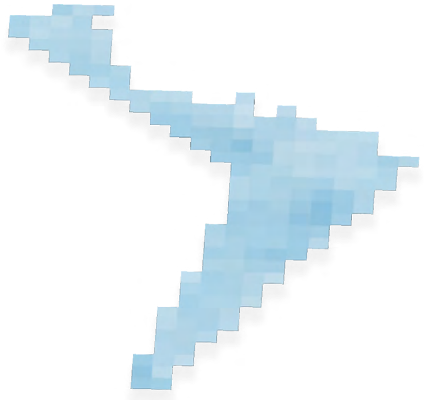


Carbon flux in 2020, t CO2 per ha

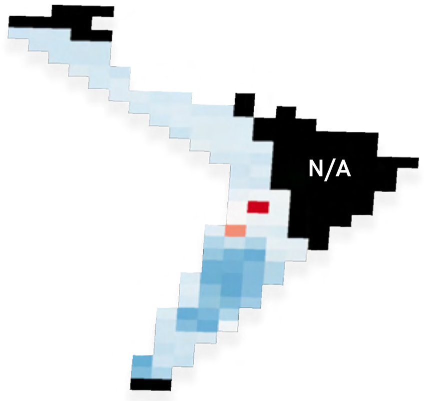


Holmegaard Gods: Carbon flux of field 15-1

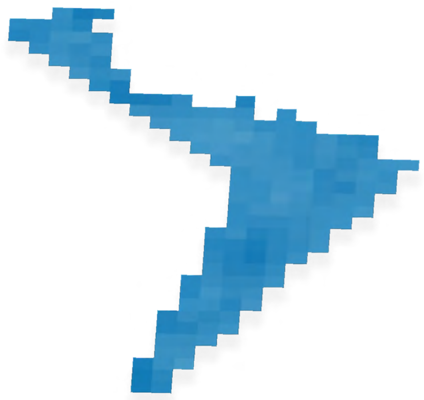
Note: data is presented for calendar year



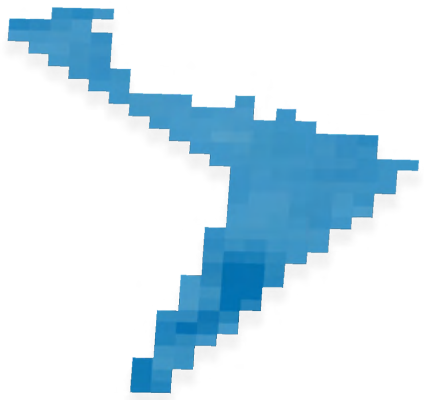
Carbon flux in 2017, t CO2 per ha



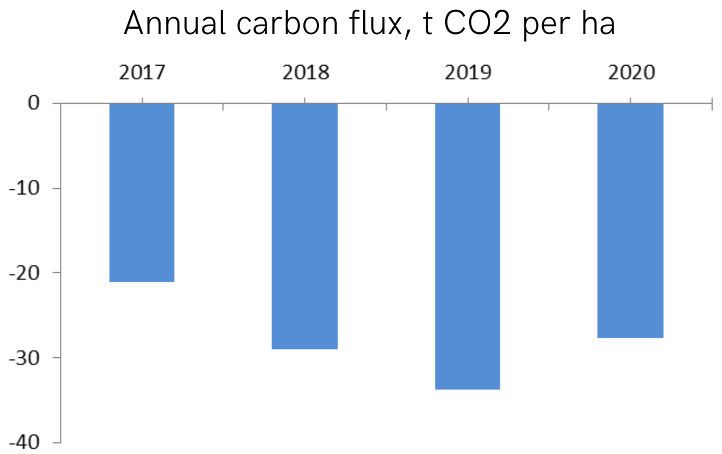
Carbon flux in 2018, t CO2 per ha



Carbon flux in 2019, t CO2 per ha

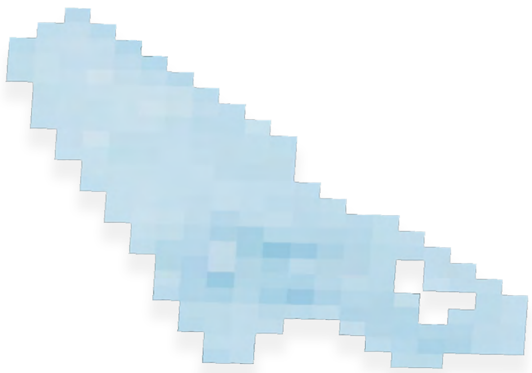


Carbon flux in 2020, t CO2 per ha

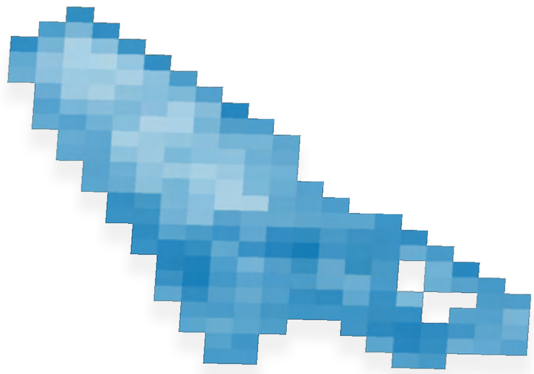


Holmegaard Gods: Carbon flux of field 17-1

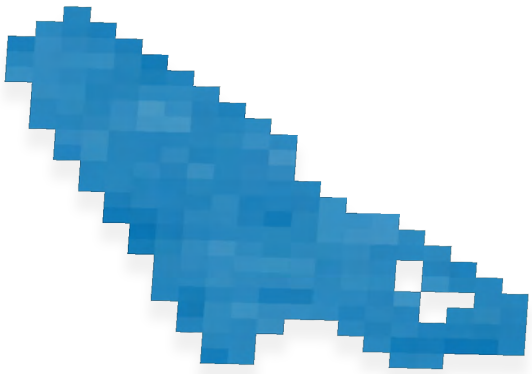
Note: data is presented for calendar year



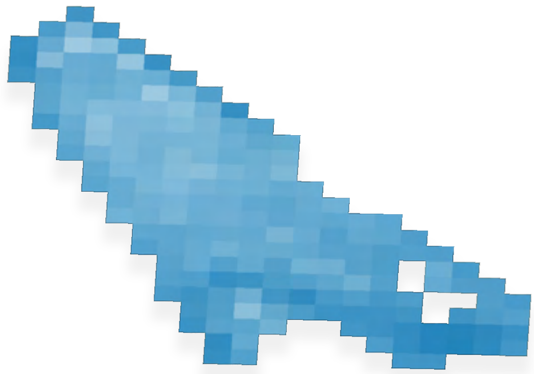
Carbon flux in 2017, t CO2 per ha



Carbon flux in 2018, t CO2 per ha

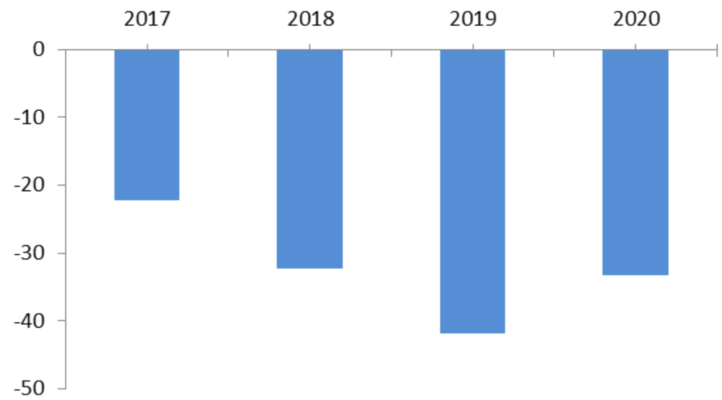


Carbon flux in 2019, t CO2 per ha



Carbon flux in 2020, t CO2 per ha

Annual carbon flux, t CO2 per ha



Grasslands generate the least annual carbon uptake, most probably due to lower biomass. Nevertheless, the areas consistently serve as total carbon sinks.

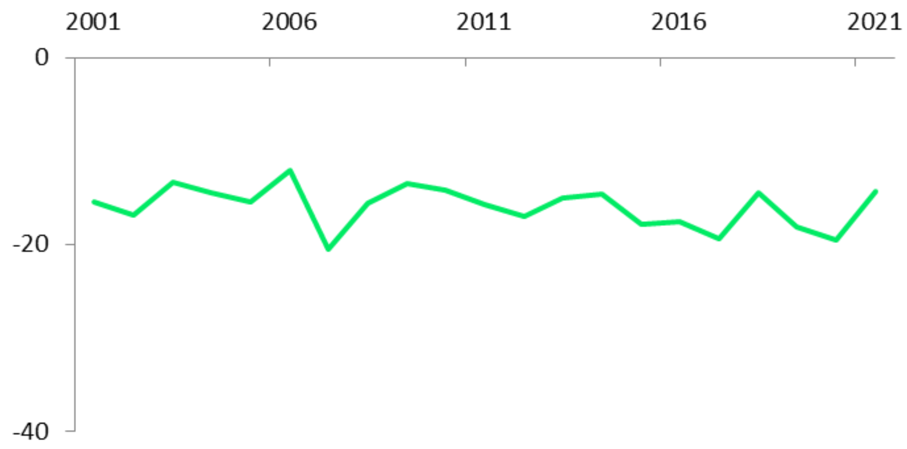
164 ha

Area

-16 t CO2 per ha

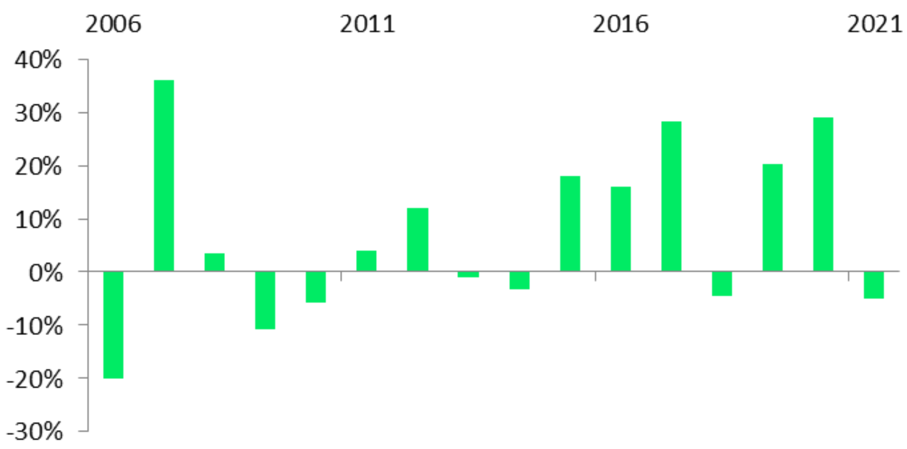
Average annual carbon flux

Carbon flux, t CO2 per ha



The carbon uptake at grasslands fluctuates around the average value.

Carbon flux change vs 5-year average (2000-2005)



Fluctuations in carbon flux from grasslands are more significant than from croplpands and mostly stay within the 20% corridor.

Holmegaard Gods: Carbon flux of forests

Forests represent a marginal share of the territory and marginal impact on the overall carbon performance of Holmegaard Gods, though their relative carbon uptake is the highest among all types of lands.

Continuous sustainable management of forests will preserve this carbon stock.

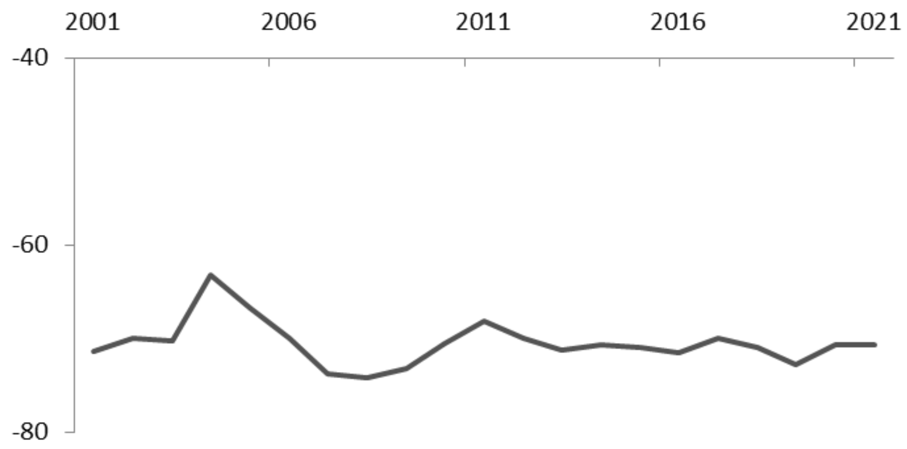
2 ha

Area

-70 t CO2 per ha

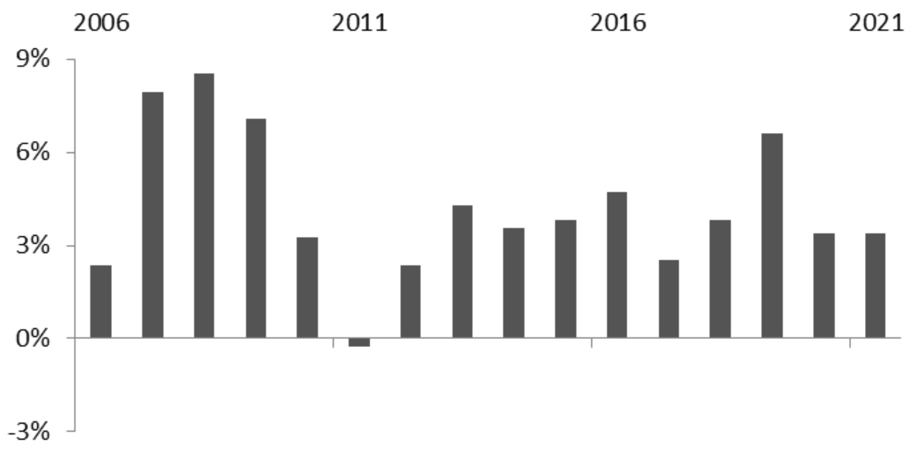
Average annual carbon flux

Carbon flux, t CO2 per ha

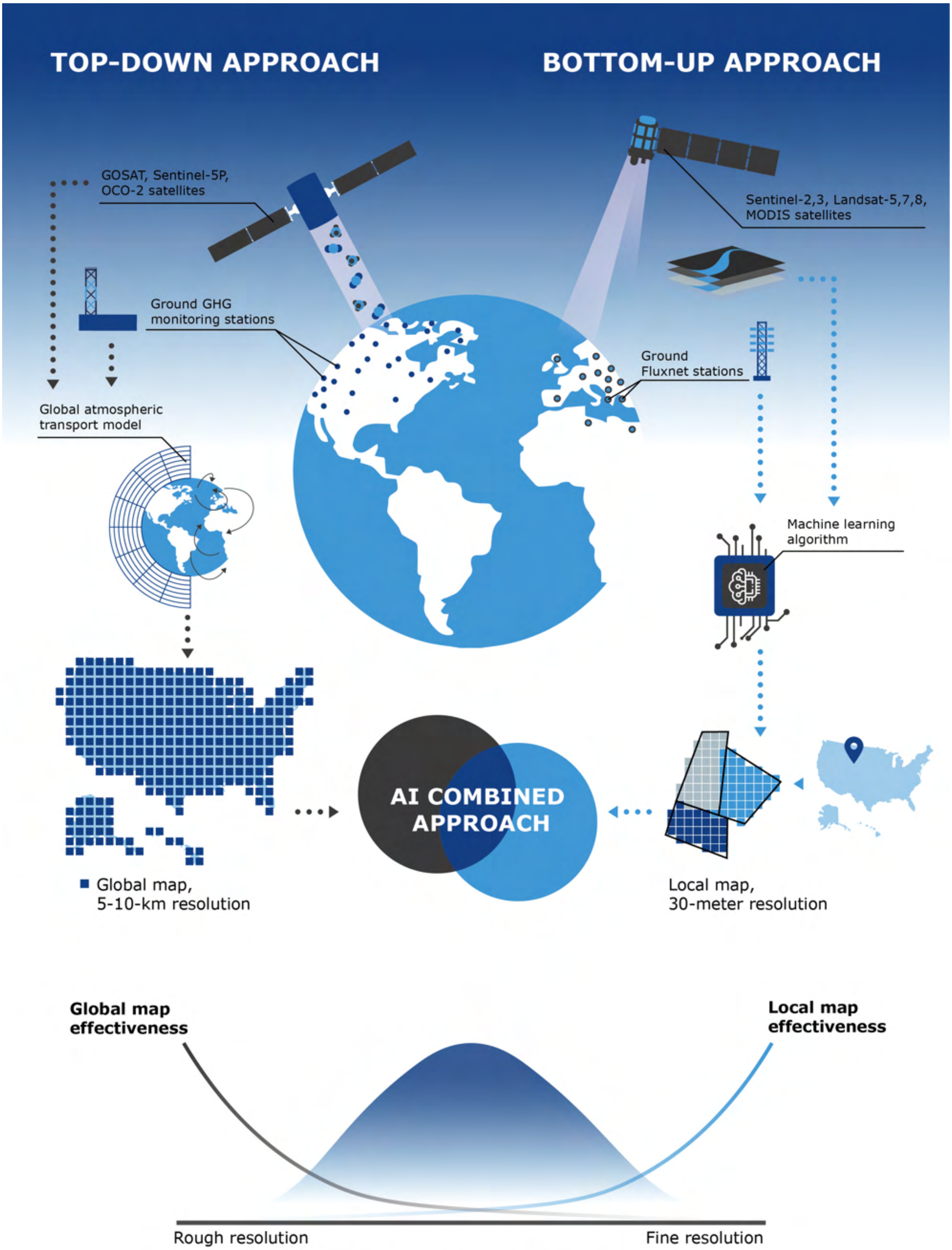


Forests generate an annual carbon uptake of 70 tons of CO2 per ha, which mostly stays in the biomass.

Carbon flux change vs 5-year average (2000-2005)



Carbon flux from forests is most stable compared to grasslands and croplands.



Products and scientific technology core

At the core of the CarbonSpace technology are machine learning algorithms, which are trained on the processing of multispectral satellite imagery and CO2 flux data from the ground stations, which estimate CO2 flux based on eddy covariance method. From this, we derive proprietary models, which allow extrapolating estimations to other areas.

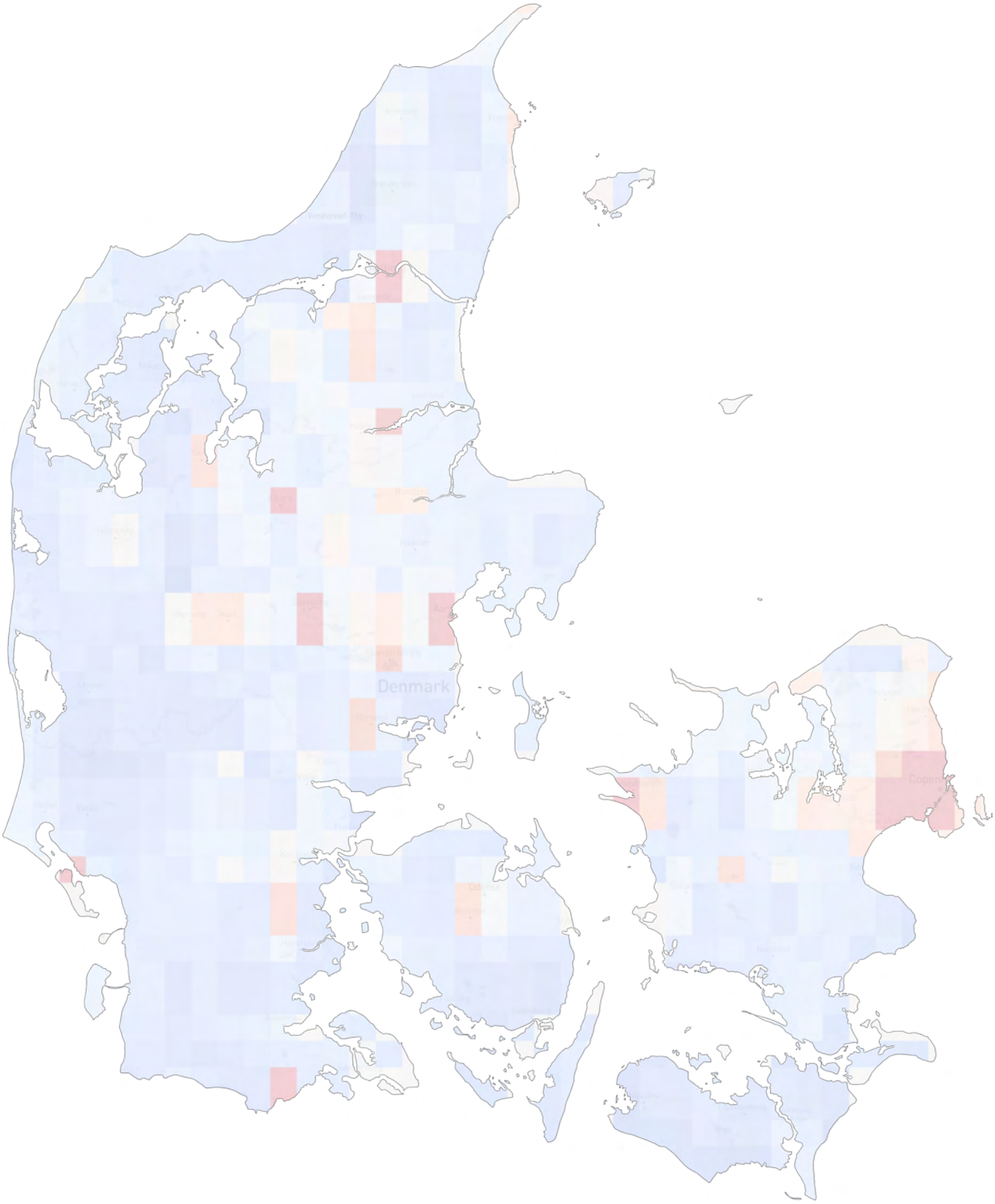
The satellite imagery covers the whole globe - we currently use data from the ESA and NASA satellites with 30-meter resolution. This means we can reliably estimate the land areas larger than 1 hectare.

As a result, the CarbonSpace platform estimates Net Ecosystem Exchange (NEE), which is a measure of the net exchange of CO2 between an ecosystem and the atmosphere. Negative NEE indicates the amount of CO2, which was accumulated in the ecosystem. Positive NEE shows the emission of CO2 in the atmosphere.

However, local estimations are very sensitive to random effects. To balance the local estimations, we use the so-called top-down approach. It is also based on the satellite data, but this time - on total column greenhouse gas concentrations (the column between the Earth surface and the satellite). Using ground measurements of GHG concentrations and data assimilation, we calculate total carbon dioxide fluxes with 0.1-degree granularity (5-10 km, depending on the latitude), which is effective itself at country-level and other relatively big territories.

The benefit of the top-down approach is that the estimated total carbon dioxide fluxes allow us to reconstruct the observed annual CO2 growth rate, which is indicative of the validity of data on the global scale.

All of this makes our estimations reliable and sensitive to various factors, such as crop/forest type, soil type, weather conditions, tillage practices, etc. It helps to estimate carbon fluxes specific to each land area, so it is a huge step forward from current approaches based on industry averages or “yes/no” principle (which accounts whether the good practice, such as cover crops, was formally introduced or not), as it can help quantify actual efficiency of different practices and climate projects in general.



CarbonSpace

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