AARHUS
UNIVERSITET
DCA - NATIONALT CENTER FOR FØDEVARER OG JORDBRUG

Kommentering af udkast til levering af forskningsbaseret myndighedsrådgivning fra DCA, AU-Tech

Titel på produkt	Vidensyntese om anvendelse af biokul i dansk landbrug
Ansvarlig for produktet (projektleder i institut)	Lars Elsgaard, Institut for Agroøkologi, AU
Rekvirent (Kontaktperson hos rekvirent)	Marie Dam, Landbrugsstyrelsen
Deadline for fremsendelse af produkt og deadline for fremsendelse af kommentarer	Udkast til rapport fremsendes af AU til LBST d. 10.06.2022. Kommentarer fra høring fremsendes af LBST til AU d. 30.06.2022. Endelig levering d. 31.08.2022

Skemaet offentliggøres ved levering, men navne slettes, så kun institutionerne fremgår

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Nr	**Ansvarlig for kommentar**	**Side- og linjenr**	**Kommentar**	**Begrundet håndtering af kommentar**	**Ansvarlig for håndtering af kommentar**
1	Landbrugsstyrelsen (LBST)	Generelt	Ville der kunne laves en tabel der – for de parametre, hvor det kan afgøres – viser om biochar har en positiv eller negativ effekt på de fysisk-kemiske egenskaber i jorden, på jordbundsbiologien, på GHG balancerne, på næringsstofsammensætning og på udbytter? Hvis det er mere meningsfuldt så fx differentieret efter feedstocks eller jordtyper.	Udfaldsrummet vil afhænge af feedstock, pyrolysebetingelser, efterbehandling, dosering og jordbundsforhold, så en sådan tabel risikerer at blive for generaliserende. Vi lægger vægt på et effekten må vurderes ud fra et kendskab til den specifikke type af biochar og de forhold hvorunder det anvendes.	AGRO
2	LBST	Generelt	Det ville være rigtig godt med en liste over de forkortelser, der anvendes i videnssyntesen.	Der er indsat en liste over nogle af de hyppigst forekommende forkortelser	AGRO
	Fødevareministeriet (FVM)	Generelt	Nogle af de konklusioner, der fremgår af indholdet i de enkelte kapitler, kan med fordel fremhæves tydeligere i hhv. de enkelte kapitlers "conclusions" samt i opsummeringerne i kapitel 8. Som en service til læser kan det overvejes at henvise til opsummeringsafsnittet (kapitel 8),	Vi har indarbejdet henvisninger til kapitel 8, ligesom rapporten nu er forsynet med et dansk afsnit omkring konklusioner og vidensbehov	AGRO/all

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			hvis konklusionerne fra de enkelte afsnit udfoldes yderligere i kapitel 8.		
3	Dansk Industri (DI)	Generelt	Præcisering: Stiesdal Fuel Technolgies A/S har i maj 2022 ændret navn til Stiesdal SkyClean A/S. Rettes fra "external contributions" på Data sheet og i alt 12 steder.	Tak for præcisering. Navnet er ændret	AGRO
4	LBST	Generelt – Preface	Kan man på baggrund af rapporten antage, at der ikke er nogen stoffer tilbage i biokul efter afbrænding, der kan udgøre en risiko for grundvandet, ud over tungmetaller og evt. PFOS?	Please refer to chapter 5 (section 5.3 - Problematic compounds), where the occurrence of organic and inorganic contaminants in biochar is mentioned. Notably, PAH needs to be considered as possible contaminants. However, there is a lack of studies linking the occurrence of contaminants in biochar to the possible transport of such contaminant to groundwater.	AGRO
5	LBST	Generelt	Er det AUs vurdering, at kun tungmetaller umiddelbart er et muligt miljømæssigt emne i biokullet, og at tungmetaller kun udvaskes ved relativt lave pH? Og er det rigtigt forstået, at lav pH kun forekommer sjældent i dansk geologi, og det derfor kan vurderes, at der ikke er en væsentlig fare for grundvandsforurening fra biokul?	1) As described in Chapter 5, there are more possible environmental items related to biochar than heavy metals. For large-scale application of biochar, we assume that regulation will be implemented, based on standards such as EBC. 2) The present knowledge synthesis is not making an assessment of the general risk of heavy metal contamination in relation to Danish geological settings. Based on the available data for biochar in a Danish context, we can not make such conclusive statements as indicated.	AGRO
6	FVM	Generelt	Findes der tilstrækkelig litteratur/viden om de mest optimale metoder til at at udbringe biokul på landbrugsjord, hvad angår den lavpraktiske udbringning?	Tests of different methods of biochar application are emerging, such as spreading after admixture to slutty, but have not been sufficiently described in the literature.	AGRO

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7	Miljøstyrelsen (MST)	s. 1 linje 26-27	Det bør uddybes, om der snakkes om et vist antal minutter eller om det blot er mindre end en time. Sætningen "Pyrolysis with a retention time in the reactor of more than minutes is considered as slow pyrolysis[…]" er forvirrende at læse, da det er uklart, om der snakkes om et vist antal minutter eller om det skal forstås som mindre end en time.	Langsom pyrolyse kan have betydelige reaktoropholdstider, som afhænger af partikelstørrelse, opvarmningsmetode, opvarmningsrate, om det er en batch eller kontinuerlig anlæg, så det kan være op til timer i simple anlæg som anvendes i mindre industrialiserede lande. Vi har ændret teksten til: *"Pyrolysis with retention times in the reactor with a few minutes and up to a few hours is considered as slow pyrolysis…"*	BCE
8	LBST	s. 1 linje 31	Jeg har tidligere hørt våd-pyrolyseprodukter omtalt som hydrochar etc. – Er det et term, der er anerkendt?	Hydrochar anvendes om en form for biokul der dannes ved hydrothermal carbonisering, dvs. opvarmning af våde biomasser uden ilt. Det dannede biokul er karakteriseret ved at være mere hydrofil end biokul ud fra pyrolyse af tørre råvarer.	BCE
9	LBST	s. 2 linje 55-65	Kan det uddybes hvilken betydning det har, at indholdet af animalske restprodukter skal være mindre end 40 procent? Hvilken potentiel betydning kan det have for den danske biokulsproduktion?	Dette vil potentielt have stor betydning, da det vil betyde at biokul produceret af fibre fra biogasanlæg ikke vil kunne klassificeres efter EBC. Det fremgår imidlertid af en ny online version af EBC guidelines at der arbejdes på retningslinjer for at husdyrgødning, biogasfibre mm kan komme til at indgå bør indgå, hvilket vi også nævner i rapporten.	BCE
10	LBST	s. 2 linje 67-70	Der nævnes typiske H/C_{org} for forskellige typer feedstock biomsse. Kan det uddybes hvilken sammenhæng der er mellem H/C_{org} ratioen for hhv. en given feedstock og den resulterende biochar? Det fremgår først noget senere i syntesen, at de for DK relevante feedstocks	H/C_{org}-forholdet i biokul afhænger især af pyrolyseforholdene, hvor H og O afgasses. Jo barskere pyrolyseforhold, jo mere H og O afgasses og jo lavere H/C_{org}-forhold. The molar H/C_{org} ratio is a biochar property that is related to the degree of thermochemical alteration	BCE/AGRO

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			godt kan opnå en H/C_{org} på under 0,7 efter pyrolyse.	that lead to increasing fused aromatic ring structures resulting in higher stability. Thus, it is the pyrolysis conditions, more than the original biomass, which are decisive for the biochar H/C_{org} ratio. In the highlighted section (1.3) we have now inserted a link to Chapter 6 where H/C_{org} ratios are treated in more detail.	
11	LBST	s. 3 tabel 1.1	Er det korrekt forstået at da tungmetaller ikke er bionedbrydelige, kan de over tid akkumuleres og udgøre et væsentligt problem hvis de udvaskes til grundvandet. Og at koncentrationerne af tungmetaller opformeres i biokul, så de er højere end materialet der var udgangspunktet? Er det ligeledes korrekt at hvorvidt tungmetaller mobiliseres eller bindes i jorden afhænger jordbundsforholdene, således at tungmetaller sorberer og danner komplekser med jordens organiske stof, hvilket betyder en lav risiko for udvaskning. Mens tungmetallerne derimod mobiliseres under sure jordbundsforhold? Hvis ja, er det så AUs vurdering, at da sure jordbundsforhold ikke er udbredt i Danmark, kan problemet med udvaskning af tungmetaller fra biokul vurderes til at være mindre omfattende? Og vil AU i så fald anbefale at tilføre kalk, at såfremt man ønsker at anvende biokul på sure jorde, for at hæve pH'en?	Det er korrekt at en række grundstoffer op-koncentreres i asken i biokul, så hvis man spreder store mængde biokul ud på markene, vil der kunne ske en uønsket ophobning. Men da der vil skulle stilles krav til grænseværdier for indholdsstoffer i biochar på linje med andre jordforbedringsmidler (så som spildevandsslam) anser vi det ikke som et særskilt problem relateret til biochar. Samtidig vil de danske fosfor lofter begrænse den mængde biochar der må udspredes. As mentioned in response to Comment #5, it is outside the scope of this biochar knowledge synthesis to provide the background for general risk assessment of leaching of heavy metals to groundwater under Danish conditions. We expect future large-scale biochar application will comply with regulation that limits the permissible contents of inorganic and organic contaminants.	BCE

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12	MST	s. 4 linje 86-88, s. 27 linje 655, s. 28 linje 690	Det forelås, at begrebet "by-product" udskiftes med begrebet "production residue". Anvendelsen af begrebet "biprodukt" er ikke nødvendigvis i overensstemmelse med affaldsreglerne.	Tak for forslaget. Vi mener at ordet biprodukter er korrekt anvendt her, og vi har ikke forholdt os til affaldsregler.	BCE
13	LBST	s. 4 tabel 1.2	Ift. tilgængelige biomasser fra landbrug står der gylle på. Men hvordan håndteres det i forhold til EBC? (jf. kommentar 9)	Se svar til Kommentar #9. Udover gylle, vil også andre produkter af animalsk oprindelser forventes at kunne indgå på positivlisten.	BCE
14	MST	s. 4 tabel 1.2 s. 98 linje 3016	Er der en grund til at det kaldes wastewater sludge og ikke sewage sludge, som nævnes i resten af rapporten?	Det er det samme. Vi har ændret wastewater sludge til sewage sludge.	BCE
15	LBST	s. 6 linje 150-152	Kan det uddybes lidt hvilken betydning det har, at resultatet af lagring ved brug af H:C på 0,7 er et konservativt estimat?	Det betyder at andelen der bliver indbygget i jorden efter 100 år er lavere, men til gengæld vil vægtudbyttet af biokul ofte være lidt højere. Højere pyrolyse temperatur eller opholdstid giver øgede omkostninger til energi eller en lavere reaktorkapacitet, så det vil afhænge af hvordan systemet optimeres. To elaborate on the significance of H:C of 0.7 as a conservative estimate, we have now added the following to the sentence to the section *"…meaning that high-quality biochars produced*	BCE/AGRO

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				with lower H/C_{org} ratio expectedly will have larger C sequestration potential."	
16	Teknologisk Institut, Agrotech	s. 6 linje 160-162; s. 7 linje 173-175; s. 73 linje 2140-2144	The reference Jensen et al., 2022, is just a DCA report based on the results from other people calculations such as Woolf et al. 2021; Hansen et al., 2021, and bachelor thesis made by Laura Bøgebjerg Poulsen in June 2021 (which was not referenced at all either in DCA report or in here). Therefore, it is not clear if these results are really the work performed by Jensen et al in 2022 using current C-TOOL. I believe there should be clarity here about the estimations, and referred exactly to correct references.	The cited DCA report by Jensen et al. (2022) include a novel model run in C-TOOL under the specific assumptions (as mentioned in the report) for persistence of straw and digestates. For biochar, the method suggested by Woolf is adapted to a soil temperature of 10°C, which is all explained in the report. We are aware of the bachelor report by Poulsen (2021) that tried to include biochar persistence in the C-TOOL model. However, we have not emphasized this preliminary work since it was concluded by the author that the attempt was unsuccessful since fractions of biochar C remaining in the soil after 100 years (cited as BC+100) were modelled to between 1.8-5.9% (whereas the aim was 50-80%). We find the BSc report interesting, but it would potentially be misleading to cite the very low biochar stabilities modelled by Poulsen (2021).	AGRO
17	Miljøministeriet (MIM)	s. 9 linje 260	PFOS har en destabiliserings halveringstid på 100 sek. omkring 500 grader, så til trods for at disse stoffer er relativt varmestabile, er der grænser for hvad de kan tåle. Hvorvidt der er noget PFOS tilbage i biokullet afhænger altså af hvor længe og hvor høje temperaturer man udsætter PFOS for. file:///C:/Users/b178166/Downloads/ez0c00114_si_001.pdf	Tak for artiklen (Xiao et al., 2020: Thermal stability and decomposition of perfluoroalkyl substances on spent granular activated carbon. https://pubs.acs.org/doi/full/10.1021/acs.estlett.0c00114) som viser nedbrydning af forskellige perfluoralkyd-forbindelser opsamlet på granulært aktivt kul. Artiklen viser at PFOS begynder at afgasse fra aktivt kul ved 450°C og at ca. 80% afgasses ved 500°C, hvorefter der ikke afgasses mere.	BCE

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				Hvor meget PFAS (og PAH og dioxin) vil afhænge af råvarer, procesbetingelser under pyrolysen, herunder brug af inaktive gasser til at fjerne disse stoffer og forhindre fortætning på biokul. Nogle af stoffer vil også kunne fjerne ved yderligere en proces nedstrøms. Vi har ikke data og viden nok til at kunne beskrive disse forhold.	
18	FVM	s. 9 linje 268 s. 16 linje 393-396	Er håndtering af risiko for selvantændelse ved bl.a. opbevaring beskrevet yderligere i litteraturen? Vil det være relevant at undersøge nærmere?	Selvantændelse er ofte ikke beskrevet i litteraturen, men er et velkendt problem ved opbevaring af større mængde organisk materialer. Det må være op til producenterne at oplyse om korrekt og sikker opbevaring og håndtering af deres produkter.	BCE
19	LBST	s. 10 linje 280-284	Det beskrives at der i dataekstraktionen fra UC Davis-databesen er filtreret efter "manure" som feedstock. Kan der siges noget generelt om hvorvidt der forventes at være forskel på "manure" som feedstock og så afgassede gyllefibre, som videnssyntesen har defineret som relevant feedstock i DK? Og i så fald hvad disse forskelle forventes at bestå i?	”Manure” i databasen omfatter en række husdyrgødningstyper, hvor der ofte ikke er oplyst tørstofniveau. Men da afgasset gyllefibre omfatter afgasset gødning fra køer, svin og fjerkræ, hvor ca. ¼ af den oprindelig tørstof er omsat til biogas, så giver figurerne stadig et billede af hvilke egenskaber biokul baseret på afgasset husdyrgødning vil kunne have. Afgasset husdyrgødning er heller ikke en ensartet biomasse i Danmark.	BCE
20	LBST	s. 10 linje 286-292	Det er umiddelbart lidt svært ud fra teksten at forstå om et højt askeindhold af biokullet har en negativ eller positiv betydning – Kan det måske gøres mere klart?	Asken skal jo ende et sted. Om det er positivt eller negativt med et højt askeindhold i biokul afhænger af situationen. Men det er vigtigt at kende askeindholdet, herunder tungmetaller, for at kunne anbefale anvendelsesmuligheder.	BCE

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21	FVM	s. 10 linje 287	Kan der tilføjes en enkelt sætning om, hvorfor et højt totalt aske-indhold er ønskværdigt eller ikke er ønskværdigt?	Se forrige kommentar.	BCE
22	LBST	s. 11 linje 305-306	Der kan evt. indsættes en henvisning til afsnit 4.2.1, hvor denne sammenhæng forklares.	Tak. Det er hermed gjort.	BCE
23	MIM	s. 11 figur 2.3	Relativt lave ph'er gør tungmetaller mere mobile.	We are unsure of the intention of this comment. However, the figure (2.3) shows biochar pH, whereas soil pH will be relevant in relation to overall pH effects	AGRO
24	LBST	s. 11 linje 312-314	Skal man forstå det således, at indholdet af hhv. aske og kulstof er omvendt proportionelle?	Ja, indholdet af aske og de organiske kulstof er i nogen grad omvendt proportionale.	BCE
25	LBST	s. 12 linje 326-328	Kan man så tale om at gyllebaseret biokul potentielt har en højere gødningsværdi end halmbaseret biokul, da gyllen har højt indhold af fosfor?	Ja, hvis P kan udnyttes, så har gyllebaseret biokul en højere gødningsværdi.	BCE
26	LBST	s. 14 linje 371-377	Det er lidt uklart i dette afsnit hvad forskellen på carbon yields og fixed carbon yields er?	Tak. Vi har omformuleret teksten til: *"Another interesting outcome of their study was that the fixed carbon yields (the carbon yield based on the carbon content in the feedstock) on dry and ash-free basis were between 22 and 25% for the various process conditions for straw even though the biochar mass yields differed between 24 and 95% on a dry and ash-free basis"*	BCE
27	LBST	s. 17 linje 436	Er der forskel på det i kap. 1 definerede "digested and dewatered sewage sludge" og så det her omtalte "dry sewage sludge". Hvis ja, vil det være godt med en forklaring af forskellen.	Dry sewage sludge betyder at det er tørt materiale. Da vandindhold i slam kan variere meget, så er det ofte mere præcist at opgive råvare som tørre eller også som tørre og askefrie. Vi har tilføjet "100-percent dry" i stedet for "dry" for at understrege dette.	BCE

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28	LBST	s. 18 linje 449	Foreslår at omformulere sætningen, og flytte figurhenvisningen, så det fx hedder "..biochar carbon from the example shown in fig. 2.14…". Som det står nu, læses det som om, man skal kunne læse noget om sequestering i figur 2.14.	Vi har omformuleret teksten, således at det ikke fremgår som om at indbygning af kulstof kan ses i figur 2.14.	BCE
29	LBST	s. 18, 25 og 27	Når jeg sammenligner fig. 2.14, 2.17 og 1.18 undrer det mig, at det kun udgår "Heating"-energi fra "Drying & Pyrolysis"-kassen i fig. 2.14 og ikke de to andre? Er det en fejl?	I figur 2.14 anvendes alt pyrolysegassen til at tørre spildevandsslammet. Ved varmeveksling af de varme procesgasser vil der dannes varmt vand, hvor ellers vil blive anvendt naturgas. For processer beskrevet i figur 2.17 og 2.18 er biprodukterne pyrolyse gas og pyrolyse olie. Forholdene mellem disse vil afhænge af procesforholdene, både under pyrolysen, men også efterbehandling.	BCE
30	Energistyrelsen (ENS)	s. 19 linje 470 s. 26 og s. 28	Der mangler en overvejelse om udledning af CH4 fra selve biokulanlægget, jf. IPCCs standard emissionsfaktor for biokulanlæg. Samme gælder i tabel 2.6 (linje 630) og tabel 2.10 (linje 682).	IPCC standard emissionsfaktor er ikke for anlæg som beskrevet her. Vi går ud fra at CH_4 vil blive udnyttet eller håndteret inden udledning, da danske anlæg vil være avancerede anlæg der skal leve op til gængse miljøkrav fx som i Bekendtgørelse om anlæg, der forbrænder affald (BEK nr 1271 af 21/11/2017). Det er dog uklart for os om CH_4 falder ind under: ”Gasformige og dampformige organiske stoffer udtrykt som total organisk kulstof (TOC), da CH_4 ofte ikke regnes med i TOC. I miljøgodkendelsen til Aquagreen-anlægget i Fårevejle er der stillet følgende krav til udledning: Stof Emissionsgrænseværdi, mg/Nm³ ved et iltindhold i røggas på 11 % Dioxiner og furaner 0,1 ng/Nm3	BCE

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				Summen af Cadmium (Cd) + Titan (Tl) 0,05 Kviksølv Hg 0,05 Total-støv 30 Gasformige og dampformige organiske stoffer udtrykt som total organisk kulstof (TOC) 20 Hydrogenchlorid (HCl) 60 Hydrogenfluorid (HF) 4 Svovldioxid (SO2) 200 Nitrogenmonoxid (NO) og nitrogendioxid (NO2) udtrykt som NO2 200 En række tungmetaller, Sum i alt: 0,5 Carbonmonoxid (CO) 100 Vilkår 15: Virksomheden skal, to gange i efteråret 2021, gennemføre emissionsmålinger på røggasser fra pyrolyseprocessen og skal som minimum analysere for parametre angivet i vilkår 14. Vi går ud fra at danske pyrolyseanlæg vil skulle opfylde krav som ovenfor.	
31	ENS	s. 19 tabel 2.2 (linje 478)	Er der tale om en negativ nettoemission der opgøres i tabel 2.2? I givet fald mangler et minus foran tallet 365… Samme gælder for tabel 2.6 og tabel 2.10. Det er jo substitution af fossile brændsler der er tale om, hvorfor der må være tale om at der tilskrives en tilsvarende reduktion til biokullet…	Ja, der er tale om negative emissioner. Vi har indsat minus foran for at tydeliggøre dette.	BCE

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32	LBST	s. 22 linje 540-545	Kan det tydeliggøres, om der er forskel på fiber-fraktionen fra gylle-digestat og den "solid fraction", der omtales her? Og i så fald hvad forskellen består i?	Det er det samme. ”Solid” er erstattet med ”fibre”.	BCE
33	MST	s. 24 linje 594	I sætningen "climate gas gasses" bør det ene brug af ord "gas" slettes. Ordet "gas" står 2 gange	Tak. Det ene gas er slettet.	BCE
34	ENS	s. 25 tabel 2.5 (linje 626)	Hvordan ser forholdet ud for C efter 10 og 20 år? (tabel 2.5 viser kun 100 år, men en kortere årrække er også relevant ift. målene i Klimaloven). Samme gælder tabel 2.9 (linje 673). Vi ser gerne at rapporten beskriver hvordan fjernelse af halm og biogasdigestat påvirker nettoeffekten af biokul på klimaregnskabet, idet DCE’s C-tool model har indregnet kulstoflagring fra nedpløjning frem til 2035 i KF22. Og her må der også gerne tages hensyn til C-tabet i biokulanlæg (C der bliver til fx CH4, bioolieolie mm)...	C retention after 0-100 years is shown in Fig. 1 in the cited reference by Jensen et al. (2022). We have mentioned this now in section 1.6.3. We will not elaborate on how DCE takes removal of straw or other organic inputs into account in national emission inventories and how C losses from pyrolysis plants will be handled herein. However, the biochar C -yield will clearly be determined by the combined function of %C in the produced biochar, %C in the feedstock, and the biochar yield in percent of the feedstock.	BCE/AGRO
35	FVM	s. 26 linje 633	Det er ikke ganske klart, hvordan net emissionsværdien på 197 i tabellen er beregnet.	Tak. Summen er placeret ved en forkert kolonne.	BCE
36	DI	s. 26 linje 641	«The technology (SkyClean) converts straw into biochar, gas and oil.» bør præciseres til «The technology converts straw into biochar and high temperature heat which will be used to substitute fossil natural gas in the neighbouring biogas upgrade facility.»	Tak for forslaget. Vi vil gerne holde det lidt bredere og kan godt forstille os andre anvendelses-muligheder end erstatning af naturgas til opgradering af biogas.	BCE
37	MST	s. 29 linje 698-699	Sætningen "We have assumed a slower carbon release from manure fibres and sewages sludge compared to the straw, which is an assumption	Vi har omformuleret til: *“Although only few studies are available, we have assumed a slower carbon release from manure fibres*	BCE

	Udfyldes af rekvirent / ekstern institution			AU institut	
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			building on very few studies" giver det indtryk, at den valgte metode er en dårlig ide. Kan det omformuleres?	*and sewages sludge compared to the straw based on the assumption that manure fibres and sewage sludge already have been degraded in previous processes and thus consist of more recalcitrant materials."*	
38	LBST	s. 30	Det ville være godt med en opsummering/delkonklusion på afsnittet.	Vi henviser til Kap. 8 og det danske sammendrag	BCE
39	FVM	s. 33 linje 850	For at øge læsevenligheden kunne man med fordel indlede kapitel 3 med et par sætninger, som forklarer formålet med kapitlet – f.eks. at kapitlet har til formål at kortlægge det nuværende og det fremtidige niveau for tilgængelig biomasse til pyrolysering.	Gjort	AGRO
40	FVM	s. 33 linje 875-876	Hvis årsagen til at landbrugerne beholder halm på marken til formuldning er at forbedre jordbundsforholdene, hvilket biokul også kan bidrage til, vil det så være urimeligt at antage, at hvis biokul bliver tilgængeligt for alle, vil mængden af efterladt halm så også falde?	Det nævnes senere i kapitlet	AGRO
41	LBST	s. 34 linje 901-902	"*It may be that returning biochar can provide similar soil quality support (see Chapter 4), which may release a higher share of straw for pyrolysis if farmers believe in it*." – overvej omformulering, da det ikke er helt klart, hvad det er, landbrugerne skal tro på.	Tak - formulering præciseret	AGRO
42	FVM	s. 35 linje 929	Der beskrives en *"in-depth analysis of the sewage sludge resource in 2018,".* Er der tale om samme henvisning til MST, 2020?	Ja, det er rapporten fra MST, som omtaler denne særskilte analyse for 2018, som vi ikke har kunnet finde en særskilt kilde på.	AGRO

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43	MIM	s. 36 linje 944-945	Der savnes viden om mulig dannelse af klimagasser, der kan dannes, hvis PFAS er tilstede i input-materiale. Der er behov for viden om, hvad der sker med de flourstoffer, der er i PFAS, og om de evt. går i røggassen/udleder potente drivhusgasser. Det er derfor ikke tilstrækkeligt at vide om PFAS fjernes fra biokul, men også at vide, hvad der sker med flourstofferne under pyrolyse.	Vi er enige i at der mangler grundlæggende viden på dette område, hvilket dog ikke tilvejebringes i rammerne af en videnssyntese	AGRO
44	LBST	s. 37 linje 982	Det er ikke helt nemt at følge disse værdier tilbage til afsnit 3.1.1. Kan det gøres lidt tydeligere, hvad det er, der er sammenregnet her?	Afsnittet er omformuleret og tydeliggjort	AGRO
45	FVM	s. 41 linje 1091	Hvad er "wt%" en betegnelse for?	wt% is weight%. This has been added to the text	AGRO
46	MIM	s. 41 tabel 4.1	Kan vi formode at pyrolysen foregår længe nok til at vi er sikre på at PFOS ikke er et problem	Dette må bygge på konkret kendskab til analyser af PFOS ved de pågældende procesbetingelser (e.g., feedstock, temperatur, retention time)	AGRO
47	LBST	s. 44 linje 1156-1165	Det kunne give god mening for læser at sætte tallene ind i et skema, da afsnittet blive en smule taltungt.	The text has been converted into Table 4.2 and revised accordingly.	AGRO
48	LBST	s. 44 linje 1167-1170	Måske kan man uddybe lidt hvilken type biokul der kan have et stort specifikt overfladeareal, overfladekemi og hydrofobe/hydrofile egenskaber, samt hvilken betydning det har?	This goes beyond the scope of this chapter as it will require presenting combinations of biochar feedstock, pyrolysis temperatures and retention time, among other variables. Chapter 2 addresses some of these production conditions	AGRO
49	MST	s. 48 linje 1303	Der mangler et punktum efter "stress".	Done	AGRO
50	FVM	s. 49	Hvor store mængder K skal biokul indeholde for at det kan skabe problemer med salinitet?	Henvisningen til ”ovenfor” var desværre blevet vildledende da den tidligere tekst endte med at blive	AGRO

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		linje 1321-1322 s. 92 linje 2812-2814	Er der sammenhæng med tilgængeligheden af K over tid?	integreret i afsnit 7. Der henvises nu i teksten til Tabel 7.1. hvor der angivet typiske indhold af K i biochar fra forskellige udgangsmaterialer. Ny tekst: *"From the survey on plant nutrient content in biochar (Table 7.1) it appears that K is often the ion present in the largest amounts in biochars based on straw, manure fibre or sludge. Salinity is thus a factor to consider when huge amounts of biochar, e.g., 100 t/ha are added to soils. This would correspond to adding between 2-10 t K/ha and would create a concentration of 200 to 500 mM of K in the soil water solution of the topsoil if applied to a typical Danish coarse sandy soil with limited CEC, exceeding the threshold values for salinity inhibition of crop growth with a factor of 2-10. If a P ceiling of 30 kg P/ha is respected when the allowable biochar amount is determined, it would prevent salinity effects in most cases but could still lead to 1000 kg K/ha being applied (Table 7.1), which far exceeds the crop requirement of typically 50-100 kg K/ha/year".* Generelt er langt størstedelen af K i biochar umiddelbart tilgængeligt, men K kan adsorberes på jordpartikler (humus og ler).	
51	MST	s. 67 linje 1616-1617	Sætningen *"However, the importance biochar as niche for active microorganism should still be*	'of' indsat [der menes s. 57]	ENVS/AGRO

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			better understood" mangler potentielt ordet "of" mellem "importance" og "biochar".		
52	MIM	s. 59 afsnit 5.3 (linje 1703)	Vi savner i afsnittet 5.3 et fokus på andre stoffer end PAH stoffer, der kan dannes i pyrolyseprocessen og ende i biokullet, herunder især dioxiner/furan, der især dannes ved lave forbrændningstemperaturer . POP-forordningen sætter en grænseværdi for indhold af dioxiner/furan, når produkter sættes på markedet samt for hvornår affald kan gå til genanvendelse. Der savnes fokus på stoffer, der kan udledes fra pyrolyseprocessen, f.eks. ved forbrænding af pyrolysegas/olie (f.eks. dioxiner/furan, kviksølv, fluorstoffer dannet fra PFAS), og dermed opmærksomhed på behov for rensning af røggas og opmærksomhed om behov for krav i miljøgodkendelse af pyrolyseanlæg	Andre stoffer, der kan dannes under pyrolysen: Vi nævner i afsnit 5.3 at b.la. dioxiner kan dannes. L. 1757-1759 indeholder et afsnit om PFOS og PFAS, og dette er udbygget. Derudover har vi indført et afsnit om dioxin dannelse under pyrolyse, samt et afsnit om PFOS og PFAS. Fokus på stoffer, der udledes ved pyrolyseanlæg: Denne videnssyntese omhandler biokul i landbrugsjord, hvilket ikke omfatter gasser fra pyrolyseanlæg og miljøgodkendelse heraf. Vi går ud fra at danske pyrolyseanlæg vil skulle opfylde eksisterende miljøkrav, se Kommentar #30 og besvarelse hertil.	ENVS/AGRO
53	LBST	s. 59 afsnit 5.3 (linje 1703)	Vil der ikke være mange af de overvejelser om adsorbtion af fx agrokemikalier eller PAH fra andre kilder, der vil gælde uanset om man øger jordens kulstofindhold med biochar eller ikke-pyrolyseret organisk materiale?	Mange af overvejelserne vil være de samme, men pga. biokuls specielle ladede overflade med høj CEC værdi og pga. forskningsresultater, der problematiserer bindingen af agrokemikalier er det relevant specifikt at nævne det her. Vi har nu Indsat en afklarende sætning: ”(…) *An adsorption capacity that is likely higher than for un-pyrolyzed organic compounds.”*	ENVS/AGRO

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Nr	**Ansvarlig for kommentar**	**Side- og linjenr**	**Kommentar**	**Begrundet håndtering af kommentar**	**Ansvarlig for håndtering af kommentar**
54	MST	s. 60 linje 1732-1737	Afsnittet giver det indtryk, at grænseværdien for spildevandsslam og asker vedrører de samme hensyn som for biokul. Grænseværdierne for spildevandsslam og biokul vedrører anvendelsen af stofferne. Gødningsforordningens grænseværdier vedrører markedsføringen af biokul, men ikke nødvendigvis anvendelsen af biokul. Det forslås at på linje 1733 indsættes sætningen " the marketing of" mellem "for" og "biochars".	Tak for afklaringen. Der er indsat det forslåede: 'the marketing of'.	ENVS/AGRO
55	LBST	s. 60 linje 1732-1737	Det er ikke helt korrekt, at der er fastsat grænseværdier for PAH'er i biokul i Danmark. Den nye EU-gødningsforordning og dens grænseværdier for bl.a. PAH'er gælder udelukkende for CE-mærkede gødningsprodukter. Det er frivilligt om producenter af gødningsprodukter ønsker at markedsføre deres produkter med CE-mærker efter reglerne i forordningen, eller om de i stedet ønsker at markedsføre deres produkter efter nationale regler. Se evt. mere på Landbrugsstyrelsens informationsside om den nye EU-gødningsforordning: https://lbst.dk/virksomheder/salg-af-goedning-og-jordforbedringsmidler-mv/ny-eu-goedningsforordning-20191009-gaeldende-fra-16-juli-2022/ Der er for nærværende ikke fastsat grænseværdier for PAH'er for biokul i nationale	Ok tak for informationen. Afsnit ændret til: *"PAHs should be avoided in agricultural soil ecosystems and in Denmark cut-off values are implemented for soil amendments such as sewage sludge and ashes. This will also be the case for the marketing of CE-labelled biochars (European Commission, 2021). Thus, although studies with PAH contaminated biochars do not always indicate PAHs in biochar as a likely source of short-term ecotoxicity to soil microorganisms (Nissen et al. 2021), there will be a requirement for producers of biochar to comply with PAH cut-off values that will protect soil biological processes for the marketing of CE-labelled biochars. The Danish national legislation does not today require CE-labelling of marketed biochars."* Der findes ikke tilstrækkelige data fra danske undersøgelser til at konkludere, hvorvidt der i en dansk sammenhæng skal fastsættes grænseværdier	ENVS/AGRO

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Nr	**Ansvarlig for kommentar**	**Side- og linjenr**	**Kommentar**	**Begrundet håndtering af kommentar**	**Ansvarlig for håndtering af kommentar**
			regler for salg og markedsføring af gødningsprodukter, jordforbedsringsmidler mv. Landbrugsstyrelsen ønsker præciseret i videnssyntesen hvorvidt der i en dansk sammenhæng er fagligt belæg for og behov for at fastsætte grænseværdier for PAH'er svarende til dem i gødningsforordningen i gødningsprodukter indeholdende biokul.	for PAH'er svarende til dem i gødningsforordningen i gødningsprodukter indeholdende biokul.	
56	MIM	s. 60 linje 1757-1759	Der savnes viden om ved hvilke temperaturer PFAS-forurenet slam bedst behandles for at undgå PFAS i slammet, men også dannelse af klimagasser som følge af flourstofferne. Det nævnes, at der har været fundet PFAS i biokul fra spildevandsslam, men ikke ved hvilke temperaturer spildevandsslammet har været pyrolyseret.	Der er indsat et afsnit i sektion 5.3, men generelt er der ikke tilstrækkelig dokumentation af viden om PFAS i biokul	ENVS/AGRO
57	MST	s. 61 linje 1776-1783 s. 62 linje 1812-1817	Findes der undersøgelser af udvaskning af organiske forbindelser og metaller fra biochar til vandmiljøet? Hvis ikke, kan det være en delkonklusion, at det også skal undersøges, hvad der kan udvaskes fra biochar, når det udbringes på landbrugjord.	Der findes adskillige videnskabelige artikler om biochars evne til at tilbage organiske forbindelser og tungmetaller - både tungmetaller i biochar og forekommende i jord. Og der er ligeledes artikler om frigivelse af uønskede stoffer fra biochar. Der er Indsat uddybende tekst i afsnit 5.4.	ENVS/AGRO
58	FVM	s. 62 linje 1815-1817 s. 104 linje 3222-3233	Der beskrives i kapitel 6 et behov for forsøg, der kan forbedre forståelse. Er der tale om de test, der beskrives i kapitel 8.6? Der kan med fordel i kapitel 6 henvises til, at det fremgår i det senere afsnit.	(Der må menes kapitel 5). Vi har som foreslået indsat en henvisning til Kapitel 8.	ENVS/AGRO

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59	LBST	s. 67 linje 1949	Det kunne være fint med en mere udførlig forklaring på den labile og stabile kulstofpulje – og gerne en opstille et regneeksempel med x mængde biomasse giver x mængde biokul med x indhold kulstof hvoraf x er stabilt og x er labilt. Det vil også give en god forståelse for hvor stor del der indregnes i kulstoflagringen.	Et sådant simplet regnestykke kan sagtens laves, dog kan udbytte af biochar i forhold til biomassen være en særskilt variabel. Men for at imødekomme ønsket har vi indsat følgende regne-eksempel: *A global meta-analysis reported average pool sizes to be 3% for the labile fraction and 97% for the recalcitrant fraction (Wang et al. 2016). This means, e.g., that 1000 Kg of dry mass biochar with a C content of 40% would contain 12 kg labile C and 388 kg stabile C, equal to 0.044 and 1.423 Mg CO2eq, respectively.*	AGRO
60	LBST	s. 68 linje 1997-1999	Kan det uddybes hvorfor H:C er bedre end O:C til bestemmelse af stabiliteten, selvom korrelationen er bedre for O:C?	H/C_{org} ratioen foretrækkes, da den kan bestemmes direkte, mens indholdet af O typisk er en værdi beregnet som en difference (O = 100 − C − H − N − S − aske). Der er derfor større usikkerhed forbundet med at bestemme O/C end H/C ratioen.	AGRO
61	LBST	s. 72 linje 2100-2103	Skal det forstås således at biokul både kan øge og sænke nedbrydningen af SOM?	Ja, der findes studier der finder at biochar øger nedbrydningen af SOM og studier der finder at biochar sænker nedbrydningen af SOM, samt studier der finder ingen eller lille indflydelse på nedbrydningen af SOM. Dette vil bl.a. afhænge af mængden af let-omsætteligt C i biochar (den labile pulje) og ligeledes om der findes hæmmende stoffer i den pågældende biochar	AGRO
62	LBST	s. 86 tabel 7.1	Kunne man måske lave et eller anden form for referencescenarie for næringsstofbehov, så man kan forholde sig til om indholdet er meget eller lidt. For halm er der eksempelvis mængder	Dette er ikke gjort da næringsstofbehov varierer i forskellige afgrøder.	AGRO

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			af fosfor og nitrogen der er i samme størrelsesorden – men hvis man på en eller anden måden kan fremhæve at planterne behøver væsentlig mere N og værdierne dermed er lave for N?		
63	MST	s. 87 linje 2630	Der står "d" i stedet for "days".	OK, er rettet	AGRO
64	MST	s. 87 linje 2638-2648 s. 89 linje 2703	Der står: *"Despite of this content of soluble N, Yuan et al. (2016) found no increase in leaching of inorganic N after application of biochars to soil in a leaching test.* *In international studies, there are observations of both positive and negative effects of biochar on N availability (Hossain et al. 2020). We found relatively few Danish studies with focus on N availability, and therefore more studies of N availability in biochar from low temperature pyrolysis would be useful.* *In conclusion, there is no indication of net N release within the first few months after biochar application to soil in Danish studies and the N in biochar is considered to be in a very stable form. Therefore it is not relevant to set an N utilization percentage on N in biochars. However, we found limited information about N availability in biochar pyrolysed below 500o C."*	Det er vores opfattelse at der ikke er noget der tyder på øget N frigivelse i det første år efter tilførsel af biochar under danske forhold. Vi har dog også taget det forbehold, at for biochar pyroliseret ved under 500^0C findes kun begrænset viden om N tilgængeligheden. Det forventes dog at pyrolyse i praksis især vil ske ved højere temperaturer son fx 500°C. Da indholdet af N er knyttet til meget stabile kulstofforbindelser, kan der heller ikke forventes målbar N frigivelse inden for en 10 års horisont. Vi har dog ikke kendskab til målinger heraf. Vi finder dette er tilstrækkeligt grundlag for ikke at tilskrive nogen N udnyttelse for biochar. Hvis langvarige forsøg senere skulle vise noget andet må man revidere denne opfattelse.	AGRO

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			Er det et tilstrækkeligt grundlag til at komme til ovennævnte konklusion, om at der ikke bør være krav til N-udnyttelse, og at der således ikke vil ske en merudledning af N ved tilførsel af biochar? Dette I sammenhæng med at der i linje 2703 står: *"However, it is still uncertain how the biochar N will be released in the long-term."*		
65	Rådet for Grøn Omstilling (RGO)	s. 89 linje 2702 s. 92 linje 2805-2808	Det fremgår begge steder, at AU finder det irrelevant at medregne N fra biochar i gødningsplaner. Det fremgår samtidig, at mere N forbliver i biochar hvis pyrolyse foregår ved lavere temperatur, men det fremgår ikke, om dette kan medføre at N ved lavere temperatur kan give en gødningseffekt. Hvis ikke, burde AU beskrive konsekvenserne af at lave pyrolyse direkte på husdyrgødning, halm og slam, hvor N går til spilde frem for at kunne anvendes som gødning og substituere kunstgødning – i tilfælde af at man laver pyrolyse *efter* en biogas-proces	Vi har skrevet, at der er behov for flere målinger af N tilgængelighed ved pyrolyse under 500°C. Omvendt er det tvivlsomt om der i praksis vil blive anvendt pyrolyse ved meget under 500°C, idet dette vil give en biochar mede ringere stabilitet af kulstof og muligvis flere uønskede forbindelser i biochar. Vi har allerede beskrevet at kvælstof går tabt ved pyrolysen. Dette vil typisk medføre substitution med kunstgødning.	AGRO
66	RGO	s. 89 linje 2713-2714	Det fremgår, at hvis man doserer biochar baseret på halm med 7-9 t pr. ha, kan man få problemer med for høj kalium-dosering. Men det fremgår ikke hvor stort problemet er – om det anbefales at undlade så høj dosering. Sml. med s. 103 linje 3161-62, hvor der nævnes metoder til at fjerne K fra biochar mhp. at undgå saltskader	Problemet med salteffekt er nærmere beskrevet under Kommentar #50 ovenfor.	AGRO

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Nr	**Ansvarlig for kommentar**	**Side- og linjenr**	**Kommentar**	**Begrundet håndtering af kommentar**	**Ansvarlig for håndtering af kommentar**
67	MST	s. 91 linje 2772-2773	Ordet "overinterpreted" giver ikke mening i den pågældende kontekst. Det foreslås at ordet udskiftes med "overestimated	Ordet er rettet. Betydningen her er at resultaterne ikke direkte bør overføres til danske forhold.	AGRO
68	RGO	s. 92 linje 2809-2817	Det virker uklart, hvorfor det i linje 2815 konkluderes at ”biochar is unlikely to have a significant effect on crop yield”, når det ovenfor konkluderes at biochar har dårlig N-effekt, men en P-effekt på linie med husdyr- og kunstgødning. Så burde konklusionen vel være at man kan nøjes med at tilføre N-gødning, og så *har* biochar en ”yield-effekt”, blot kun i form af P?	Under danske forhold er det vanskelligt at måle en signifikant udbytteeffekt af P tilførsel, undtagen i enkelte afgrøder, som f.eks. majs. Fosfor tilføres mange steder for at vedligeholde jordens niveau af tilgængeligt P. Derfor vil effekten af P i både biochar og anden gødning kun have klare udbytteeffekter på lang sigt.	AGRO
69	LBST	s. 97 linje 2980-2982	I videnssyntesen står: "Harmful biochar constituents, such as volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), heavymetals need to be regulated to prevent accumulation in the soil". Landbrugsstyrelsen ønsker præciseret i videnssyntesen hvorvidt der er fagligt belæg for og behov for at fastsætte grænseværdier for PAH'er, WHO's toksicitetsækvivalenter af PCDD/F, ndl-PCB, chlor, thallium samt tungmetaller i en dansk sammenhæng, svarende til dem i gødningsforordningen i gødningsprodukter indeholdende biokul.	Der foreligger ikke danske undersøgelser af biochar i jord der giver tilstrækkelige data til fastsættelse af grænseværdier for PAH'er, WHO's toksicitetsækvivalenter af PCDD/F, ndl-PCB, chlor, thallium samt tungmetaller i en dansk sammenhæng. Videnssyntesen fastsættelser ikke sådanne af grænseværdier, men der henvises til retningslinjer i internationale standarder som EBC.	ENVS/AGRO
70	LBST	s. 97 linje 3005 - 3008	Landbrugsstyrelsen ønsker præciseret i videnssyntesen, hvorvidt der i en dansk sammenhæng er fagligt belæg for og behov for at implementere krav om, at biokul skal have	For at kunne definere et produkt som biokul vil det være nødvendigt at produktet overholder nogle minimumskrav og her vil en parameter som at H/C forholdet er under 0,7 være med til at sikre at biokul	BCE

	Udfyldes af rekvirent / ekstern institution			AU institut	
Nr	**Ansvarlig for kommentar**	**Side- og linjenr**	**Kommentar**	**Begrundet håndtering af kommentar**	**Ansvarlig for håndtering af kommentar**
			H/C_{org} ratio på under end 0,7 svarende til kravet i gødningsforordningen.	har en stor effekt på kulstoflagring. Da både gødningsforordningen og EBC anvender 0,7 vil det være mest enkelt at anvende den samme værdi.	
71	RGO	s. 98 linje 3021-22	Som supplement til beregningen af CO2e effekt af biochar fra pyrolyse af halm savner vi beregning af hvad det ville give, såfremt man sendte halmen først gennem biogasanlæg og dernæst pyrolyse på digestat (eller fiberfraktion). Her ville man måske få mindre C-lagring, men til gengæld større produktion af grøn gas (idet der produceres biogas, som har betydeligt højere metanindhold sammenlignet med pyrolysegas), som kan substituere fossile brændsler	Dette er en relevant diskussion, da der er en forventning om at en stigende mængde halm vil blive anvendt til biogas. Det må forventes at hvis halmen først anvendes til biogas, vil der produceres mindre biochar per ton oprindeligt halm, da en stor del af kulstoffet er blevet omdannet til metan. Hvorvidt den samlede klimagevinst bliver bedre eller dårligere ved først at producere biogas af halmen og derefter pyrolysere restmaterialet kræver en grundig beregning og dette scenarie har ikke være en del af denne videnssyntese.	BCE
72	RGO	s. 100 linje 3059-63, samt tabel 8.1	Beregning af potentiale for pyrolyse på halm tager ikke højde for mindre produktion fremover af korn/halm som følge af 1) nedgang i landbrugsareal pga. mere skov, natur, udtagning af lavbundsjord, urban vækst og infrastruktur, 2) nedgang i produktion af korn til fordel for græs (jfr. dog linie 3094-95) og fødevareafgrøder (hvoraf kornsorter og raps formentlig kun vil udgøre en mindre del). Øgning af græs vil være nødvendigt, både for at erstatte ubæredygtig import af soja og for at beskytte vandmiljøet. Der tages heller ikke højde for, at mere halm bør gå til biogasanlæg, jfr. nedenfor	I scenarierne for 2030 *er* taget højde for nedgang i landbrugsareal som følge af lavbundsudtagning, byer, veje og skov. Mere natur er medtaget i ekstensiveringsscenariet. Der er også i forskelligt omfang udlagt mere græs, primært på bekostning af majs, men også korn og raps. Til gengæld er estimeret en 15% øget opsamling af halm og brug af halmsorter med 15% højere halmudbytte. Hvorvidt halmen skal gå direkte til pyrolyse eller først til biogas har vi med vilje ikke taget stilling til.	AGRO

	Udfyldes af rekvirent / ekstern institution			AU institut	
Nr	**Ansvarlig for kommentar**	**Side- og linjenr**	**Kommentar**	**Begrundet håndtering af kommentar**	**Ansvarlig for håndtering af kommentar**
73	MST	s. 100 linje 3066-3067	Der mangler et komma efter "included" da det virker til at være en indskudt sætning.	Komma indsat	AGRO
74	RGO	s. 100 linje 3072-77	Korrekt at undgå dobbelttælling af halm, men jfr. ovenfor kunne en større del af halmen sendes til biogasanlæg, hvorved mere biogas-fiber vil være til rådighed for pyrolyse	Korrekt, men hvilke konverteringsspor, der vil blive implementeret, tager vi med vilje ikke stilling til i dette kapitel	AGRO
75	RGO	s. 101 linje 3094-95	Her nævnes græs, jfr. kommentar nr. 74 – men igen ser vi det som potentiale for biogas – hvorfra fiber kan være potentiale for pyrolyse. Denne mulighed burde også nævnes	Vi nævner, at teknologiintegration bør analyseres nærmere, fx mellem grøn bioraffinering, biogas og pyrolyse, ligesom vi i hovedafsnittet har nævnt, at græsfiberen kan anvendes til pyrolyse.	AGRO
76	MST	s. 101 linje 3111	Ordet "the" efter "on" skal slettes, da det er overflødigt.	Done	AGRO
77	RGO	s. 102 linje 3132-33 s. 103 linje 3172	Linje 3132-33 : «...biochar usually does not effect the rewetting ability of soils....», sammenholdt med linje 3172: "…might increase the water holding capacity…". Vi savner forklaring på forskellen på de 2 udsagn. Kan en forklaring være opfyldning af porer i jorden med biokulpartikler? Nævnes i kap. 4: Biokul ændrer iflg flere studier ikke på jordbundens 'wettability' (befugtningsevne/optagelse af vand – dvs proces). Dette forklares med at pyrolysen skete mellem 300 og 750 g celcius resulterende i biokul med hydrofil (letopløselig) karakter – linje 1214. Kan opfyldning af porer undgås ved at opnå større partikelstørrelse i biochar, og kan dette	There is no difference or contradiction between the two statements. They rather complement each other. Concerning water holding capacity, biochar does increase water holding capacity or water retention as presented in Section 4 (Table 4.2), and this is dependent on soil type. Regarding rewetting/wettability/hydrophicility of soils, the current literature does not report any negative effect. Thus soils in which biochar is added do not become water-repellent and rather increases the water holding capacity. It is, however, true that the pyrolysis temperature that was used in the studies contributing to the synthesis were at temperatures that produce hydrophilic biochar.	AGRO

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			opnås ved at anvende lavere temperatur i pyrolysen? Vi er klar over, at man i ovennævnte betragtning skal skelne mellem jordtyper, idet man for at øge vandbindingsevne i grus skal tilføre finkornet materiale, mens man omvendt skal tilføre mere grovkornet materiale for at skabe en pore-struktur i leret jord – og dermed øge vandbindingsevnen her. Vi har også sammenholdt med Miljøstyrelsens præsentation af BioAdapt – et AU/KU projekt som undersøger biokul til opblanding i underjorden af sandjord, mhp. at forbedre vandhusholdningen af disse jorde, hvor man forventer en god effekt af biochar: https://mst.dk/service/nyheder/nyhedsarkiv/2020/dec/nedmuldet-biokul-skal-goere-sandet-jord-mere-robust-over-for-fremtidens-klima/) Endelig er vi klar over at såfremt det ved visse jordtyper vil være en fordel at lave en biochar med større partikelstørrelse, og såfremt dette kan gøres ved *lavere* temperatur i pyrolyseanlægget – så skal det afvejes ift. at stabiliteten af C i biochar øges, hvis den er produceret ved *højere* temperatur. Men vi savner i det hele taget en belysning af disse forhold i videnssyntesen	Secondly, the biochar particle size may play a role in the water retention dynamics, depending on the feedstock used for producing biochar and the soil in which is added to. There is no literature in Denmark that compares different particle sizes for different soils. The global literature presents conflicting results on the effect of particle size on soil water retention. While some studies report no effect of different biochar particle sizes on a sandy clay loam (https://link.springer.com/article/10.1007/s42729-021-00597-8), other studies show an increased water retention for coarse biochar particles compared to ground biochar (https://www.mdpi.com/2571-8789/3/1/14) Due to the lack of studies on biochar particle size that fit Danish conditions and the inconsistencies in the results from other countries, no conclusions could be drawn and included in this synthesis. But this remains a topic of interest in future research.	
78	MST	s. 104 linje 3201	Ordet "tetm" skal rettes til "term".	Done	ENVS/AGRO

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Nr	**Ansvarlig for kommentar**	**Side- og linjenr**	**Kommentar**	**Begrundet håndtering af kommentar**	**Ansvarlig for håndtering af kommentar**
79	MIM	s. 104 linje 3222	Det bør tilføjes, at der er behov for øget viden om POP og MFS i biokul, især med slam som input. Det bør tilføjes, at der er behov for øget viden om hvordan pyrolyseprocessen, driftstemperaturer, samt evt. undertryk i pyrolysereaktor påvirker dannelse og udledning af stoffer fra anlægget samt indhold af stoffer i biokul. Det bør tilføjes, at der er behov for øget viden om udvaskning af stoffer til miljøet, der har været bundet i biokul, når/hvis biokul nedbrydes, f.eks. Cd og PAH.	Vi har tilføjet yderligere vidensbehov i mere generelle vendinger	ENVS/AGRO
80	FVM	s. 98 linje 3013-3033	De estimerede størrelser for CO2e-lagring efter 100 år fremgår ikke tydeligt af kapitel 2.	Tallene fremgår af tabel 2.1, 2.5 og 2.9	BCE
81	FVM	s. 110 linje 3389	Hvilke temperaturer menes der med "høje temperaturer"? Er det over 500 grader eller højere?	Rettet og præciseret. Der burde i stedet stå at P tilgængelighed falder med stigende (increasing) temperatur	AGRO
82	FVM	s. 110 linje 3390	Det fremgår, at *"However, it is generally found that P-availability in biochar decreases at high pyrolysis temperatures. Also, the immediate P availability in biochars is low, which means that biochar is not a suitable start P fertilizer."* Vil det være relevant at undersøge nærmere, om dele af P-indholdet i nogle former for biokul ikke er plantetilgængelige på kort eller mellemlangt sigt?	Vi har omformuleret teksten her. Vi ved at en del af P indholdet er hurtigt tilgængeligt, men der er også en del af P indholdet der har en lav tilgængelighed. Nogle forsøg har vist at P i biochar havde lille effekt på den tidlige vækst af vårbyg, men senere på vækstsæsonen var der en høj P optagelse efter tilførsel af biochar til vårbyg. Det vil være relevant at kigge nærmere på den del af fosfor der ikke er tilgængeligt i det første år. Rent	AGRO

	Udfyldes af rekvirent / ekstern institution			AU institut	
Nr	Ansvarlig for kommentar	Side- og linjenr	Kommentar	Begrundet håndtering af kommentar	Ansvarlig for håndtering af kommentar
				metodisk er det dog vanskeligt at adskille de forskellige P former.	

AARHUS
UNIVERSITET
DCA - NATIONALT CENTER FOR FØDEVARER OG JORDBRUG

Ekstern fagfællebedømmelse af levering ifbm. forskningsbaseret myndighedsbetjening fra DCA, AU

Titel på produkt	Vidensyntese om biokul, kapitel 1 & 2
Tovholder	Lars Elsgaard, AU-AGRO
Fagfællebedømmer	Tobias Pape Thomsen, RUC
Deadline for fagfællebedømmelsen	11-05-2022

Efter aftale offentliggøres den eksterne fagfællebedømmelse sammen med kommenteringsarket fra interessenthøring.

	Udfyldes af fagfællebedømmer:			**Udfyldes af forfatter:**
	Linje-nummer	**Kommentar**	**Angiv hvis tilbagemelding ønskes***	**Begrundet håndtering af kommentar**
1	General	**Disclaimer** reg. the fractionated nature of the thesis section and review material. Only having one chapter makes it difficult to determine if there are relevant aspects missing or they may be present in other parts of the compiled thesis. I have therefore mainly focused on what is in the chapter and not on what is missing. The purpose of the chapter is not completely clear, but the focus seem to be on climate impact aspects of production and (field) application of biochar. For this reason I have not focused on any aspects related to other social, economical or environmental impact categories.		We agree that it would have been easier if the entire report has been present for the review and therefore it is good that the review have been focused on what is in the chapters and not what is missing. We have tried to make the purpose more clear. We will not cover social, economical and other environmental impact besides GHG. This will be covered in another chapter that will be finished after the main report.
2	General	A chapter title and a short chapter intro/meta text would make the reading easier and more coherent. Type of study. Main goal and purpose. Context.		We have changed the title to "Selection of feedstock, scenarios and estimation of carbon sequestration"

	Udfyldes af fagfællebedømmer:			Udfyldes af forfatter:
	Linje-nummer	**Kommentar**	**Angiv hvis tilbagemelding ønskes***	**Begrundet håndtering af kommentar**
		Would make it more clear how the different sections relate and where they lead to.		
3	General	Related to the development of scenarios and references: Will the different parts of the calculations be compiled together and discussed/ concluded on at a later stage? Or in a later section/chapter? Is there someone else reviewing these parts? With a quantitative sustainability study as this, it can be problematic to divide the review of the different phases (goal and scope, inventory, impact assessment, conclusions and recommendations) between different reviewers as these parts are heavily related – and dependent, on each other.	X	The scenarios and references will be compiled together at a later stage where economic and environmental impacts will be evaluated in another chapter. We are still not sure if this will be a chapter that is part of the main report or an additional document. We will not be responsible for this but the document will use some of the data from our chapters. We agree that it is difficult to review individual chapters and divide it between reviewers but since it has been decided to have different reviewers to different chapters it has not been possible to avoid.
4	General	Does the thesis contain a sensitivity assessment of uncertain parameters and assumptions or can such an assessment be included? There are several parameters and assumptions related to the scenario development and calculations with none or uncertain references behind them. This is an indication of potential sensitivity and a sensitivity analysis should be conducted to investigate the impact of such sensitivity on the results and conclusions. If a quantitative assessment of the sensitivity is not possible, then there should be a discussion and qualitative evaluation of these matters.	X	A sensitivity assessment will not be included due to time constraints. It will be added to the knowledge gaps
4a	General	The structure of the chapter is somewhat confusing. It is both descriptive while also developing a set of scenarios and reference systems for biomass management. There are some mixing of the two parts. The structure makes it difficult to separate the	X	Thanks for the comments. A better intro will be added explaining the structure. We will not cover environmental impact besides GHG and it is not the purpose of this chapter to do any LCA or similar analysis. Socio-economic analysis will be covered in another

	Udfyldes af fagfællebedømmer:			Udfyldes af forfatter:
	Linje-nummer	**Kommentar**	**Angiv hvis tilbagemelding ønskes***	**Begrundet håndtering af kommentar**
		knowledge compliment and the climate impact assessment. This is made more difficult by the absence of an introduction and a results section on the climate impact assessment and a discussion/conclusion. IF it is the purpose of this chapter to provide both background information AND an assessment of the climate impact of biochar production and use in 3 difference cases, I suggest to reconsider the structure to make the distinction between the two parts and the flow more transparent and easy to follow. I recommend to start with an overall, common introduction stating the purpose of the chapter in the compiled thesis and the overall design of the chapter. I would then keep the first part of the chapter (which would become the main part with regard to length) strictly descriptive and divide into descriptions of e.g. 1) the pyrolysis process, 2) the feedstocks and 3) products and product use. In the second part of the chapter I would structure more like a classic LCA or climate footprint accounting with the four phases I) goal and scope, II) (life cycle) inventory, III) impact assessment (here the compiled results from the calculations are presented), IV) conclusions and recommendations. And very importantly - include a sensitivity assessment in phase IV along with a critical reflection that you already have some of ☺ In the goal and scope it should be clearly stated what systems and effects are assessed and which are not. Only the very		chapter that will be finished after the main report. We will not be responsible for this and this will be covered in another chapter/document that will be finished after the main report.

	Udfyldes af fagfællebedømmer:			Udfyldes af forfatter:
	Linje-nummer	**Kommentar**	**Angiv hvis tilbagemelding ønskes***	**Begrundet håndtering af kommentar**
		straight forward effects are included in the study and this limitation should be transparent and clear. State e.g. that char use is assumed limited to direct soil amendment even though more advanced systems may yield more value and also state how all potential effects related to below-ground impact of biochar amendment (and biomass amendment) is limited to C-sink decay and persistence only. Describe preferably how the boundaries are set, how it will influence the results, the type of model (attributional >< consequential), the common functional unit for the 3 different sub-studies, to which extent they will be evaluated and discussed in comparison etc. The second part of the chapter would be the shortest with regard to length but most likely require the most work. IF it is NOT the purpose of this chapter to provide a consistent assessment of the climate impact of biochar production and use in 3 difference cases but instead only background information and fractionated calculations on selected parts of the systems, then this should be stated somewhere very clearly and the benefits and drawbacks compared to a more consistent study should be discussed.		
5	53	A dry matter content of at least 85% is not a prerequisite for thermochemical conversion. At least not in a technical sense. However, if biomass with higher moisture content is fed to a pyrolysis plant, then part of the retention time in the reactor will be spend drying the material. This prolongs the required		We think that in full-scale modern plants that this is a prerequisite, but agree on changing the sentence accordingly.

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	Linje-nummer	**Kommentar**	**Angiv hvis tilbagemelding ønskes***	**Begrundet håndtering af kommentar**
		retention time and thus limit the capacity of the plant. This is expensive. But establishing drying capacity is also expensive and if the material is e.g. 20% moisture then it may be a better option to "dry in the pyrolysis plant". it is a context dependent decision if one approach or the other is superior.		
6	56-57	I find it a stretch to state that torrefaction produce oils and char. It produce a water phase with some simple organic molecules and a heat treated, super-dry biomass.		We have deleted "torrefaction",
7	64	+ "under extremely high pressures. Goes for hydrothermal liquifaction as well."		We have changed the sentence to: Hydrothermal carbonisation and hydrothermal liquefaction are processes where wet biomass is heated up and converted into biochar, bio-oil and gases at high temperature and pressure.
8	83-85	In a recent online version of the positive list it is stated that ""The pyrolysis of non-plant biomasses such as sewage sludge, livestock manure, manure containing biogas digestates or bones and slaughterhouse wastes may also produce valuable raw materials that could be used in the interests of the bioeconomy and climate protection. It is planned to include these raw materials mid 2022 in the EBC feedstock list following a key review publication about the product safety and conditions of use." https://www.european-biochar.org/media/doc/7/version_en_10_1_track-changes.pdf		Thanks for the information we will include this.

	Udfyldes af fagfællebedømmer:			Udfyldes af forfatter:
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9	88	Elaborate the abbreviations in table 1.1 e.g TGA, DM, WHC, EPA EFSA PAH		It has been elaborated
10	98	All biomass can be pyrolyzed, but it is not possible to feed all types of biomass to all types of pyrolysis processes		We agree, it has been changed
11	99-101	Where does this recommendation/opinion originate from? Is there a reference or an in-house analysis behind it? Are these the most important characteristics based on a set of parameters and a weighting scheme or are they just some of the important ones? I agree that they can all be very relevant, but there may also be others e.g. low wear and tear (corrosivity, fouling etc.), simple exhaust gas cleaning (low levels of Hg, Cd, S, Cl etc.), suitable particle size distribution, high density and heating value etc. What the most crucial set of characteristics is will depend on the context.		We don't have a reference and agree with your suggestions on other factors, that we now have included in the text.
12	102	Wood is generally not considered a by-product while there may definitely be by-products from wood-production		With residues we mean by-products garden waste will be mentioned.
13	105	Table 1.2: Add a section on industrial organic residues? e.g. spent grains, yeast sludge, residues from vegetable oil production, residues from pectin production and many others. Add the woody fraction from garden and park waste somewhere as this is one of the more commonly considered feedstocks for municipal pyrolysis		Industrial wastes and garden waste is now in the table
14	113	Table 1.3: Language – change all sentences to "incorporated into agricultural soil"?		Has been done.

	Udfyldes af fagfællebedømmer:			Udfyldes af forfatter:
	Linje-nummer	**Kommentar**	**Angiv hvis tilbagemeldin g ønskes***	**Begrundet håndtering af kommentar**
15	115	Table 1.4: The values listed for dewatered sewage sludge is on basis of the sludge as received (with 75 wt% water), but the unit used is kg/t DM. The corresponding values on dry matter basis can be found in the 2018 reference in appendix 1 in the column "Værdi I TS". From the same reference, sludge HHV per kg TS: 16.75 in undigested sludge and 13.0 in digested sludge.		Thanks. This has been changed. HHV depends on the ash and water content. Will be clarified
16	123	The gas "**can be**" cooled instead of "is cooled". This is important as most pyrolysis plants today do not have oil condensation and this is by many considered next phase development. Perhaps change the text around accordingly.		OK
17	127	The climate impact value of the natural gas substitution is not very recent. In the BioGrace II database a value for EU mix natural gas of 66 g CO2e/MJ is proposed. This is also an average value and thus suited for attributional modelling. Perhaps include a note on volatility of recent gas market? The effect of recent changes is that substitution values are less robust and other substitution options/values may be relevant from now on.		Thanks for referring to the BioGrace II database. We assume that natural gas is substituted and we will use the 68 g CO2e/MJ from the BioGrace II database for an EU mix of natural gas, which is a little different from the value you suggest.
18	126-132	It seems that an attributional modelling approach is taken applying average values. This has benefits and drawbacks. In such a model, it is indirectly assumed that there is no influence of the initiative on		Correct but we do not include this kind of modelling

	Udfyldes af fagfællebedømmer:			Udfyldes af forfatter:
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		the form/behavior/performance of the existing system		
18 b	134	To section 1.6: This is a highly debated and intensely investigated topic. I do not expect you to be able to include all the different approaches that can be taken using lab, field or modelling methods. However, it would be good to mention that there are many different approaches that all have their benefits and drawbacks and that you have focused on 2 methods related to the biochar carbon persistence and a range of sources related to biomass carbon persistence. For an overview on the matter (related to biochar carbon persistence) see eg https://doi.org/10.1111/gcbb.12266 https://doi.org/10.1016/j.biortech.2018.09.030 https://doi.org/10.1016/j.geoderma.2020.114184 https://doi.org/10.3389/fenvs.2020.514701 https://doi.org/10.1016/j.scitotenv.2021.150789	X	This will be described and discussed in a later chapter. We should have informed you on the structure of the knowledge synthesis.
19	135	Two options: 1) The current interest for biochar is mainly caused … or 2) The main interest for biochar in relation to Danish agriculture is caused …		We choose option 2
20	137	Re-phrase: thus preserving the carbon in the soil and avoiding re-emission of CO2 back into the atmosphere where it contributes to climate change.		Thanks, we will use this.
21	145	Based on the **molar** H/Corg ratio		Correct, we have changed this
22	148	"and" not "are" (5 and 10)		Correct, we have changed this
23	150-152	This is a critical aspect of the assessment and should be regarded as such. At least a note on the uncertainty of such a simple model should be provided. Also, when the calculation use worst-case	X	Thanks for the comment and the valuable reference. We haven't studied the Laghari et al. as the title focuses on the post-process treatment.

	Udfyldes af fagfællebedømmer:			Udfyldes af forfatter:
	Linje-nummer	**Kommentar**	**Angiv hvis tilbagemelding ønskes***	**Begrundet håndtering af kommentar**
		H/C molar ratio of limit threshold biochar (0.7) the effect of such an assumption should be discussed. In reality most EBC certified biochars would have much lower H/C ratios. In a study by Laghari et al from 2021 DK sewage sludge, DK cereal straw and DK biogas fibers were pyrolyzed at 600 C yielding biochars with molar H/C ratios of 0.38, 0.33 and 0.30 respctively. Using these values instead of threshold value 0.7 would increase permanence to 0.88-0.96 and 92-99 at 5C and 10 C respectively for the 3 chars. Thus, the results generated using H/C 0.7 is a highly conservative/ worst-case estimate and the the impact of this assumption should be tested. This could be done using the same method with other representative H/C values or using other proxies/ persistence measures. In all cases, the impact of this assumption on the overall results should be quantitatively evaluated.		We think that the low H/Corg values found in the lab scale were done under very optimal conditions. Our experiences are that full-scale production seldom gives the same yields and quality as in the lab. When the Danish operators have data from full-scale production, these can be used for better calculations. We will use the cut-off value of 0.7 for the three scenarios. The text has been changed to: Lower H/Corg ratios can be found in the literature, e.g. Laghari et al. (2021) found H/Corg ratios less than 0.4 for sewage sludge, biogas fiber, cattle manure, poultry manure, woodchips and wheat straw pyrolyzed in lab scale at 600 ° and retention time of 60 minutes. However, full scale production is a trade-off between reactor capacity, dry matter and particle size of feedstock resulting in ratios lower and lab scale results. In the estimations in the study, an H/Corg ratio of 0.7 will be used.
24	159-162	If there are one or more references for this argumentation it would stand stronger.		It will be elaborated in other chapters
25	171-172	Suggest to re-phrase to something like: "In our calculation, we assume that 10 percent of the carbon amended to soil with the digestate fibers still persist in the soil after 100 years".		Thanks, we will use this re-formulation.
26	181-184	If the focus of this chapter is only climate impact, then this short section may be re-written to fit that purpose. With regard to emissions from the pyrolysis proces, other environmental impact categories may be more relevant than GWP. While these processes		We acknowledge that there can be many kinds of emissions from the process, but maintain that we assume that the plant will produce according to their environmental approval. The text has been changed to:

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	Linje-nummer	**Kommentar**	**Angiv hvis tilbagemelding ønskes***	**Begrundet håndtering af kommentar**
		generally only emit significant amounts of the GHG CO2, there may be emissions in exhaust and residue/by-product/waste streams relevant to investigate with a focus on e.g an air quality, terrestric tox, aquatic tox, acidification etc. instead of climate impact		It is assumed that production of biochar in Denmark fulfils the current regulations with respect to emission of gas, wastewater and solids, and these emissions are very dependent on the degree of gas cleaning.. For gas emissions, the Legal order for waste combustion plants (MST, BEK nr 1271 of 21/11/2017) can be used as a guideline.
27	199	+ use of in-situ catalyst, char beds or partial oxidation reactors		We have added the suggestions, deleted types of precursors and the reference.
28	202	Include a note that while slow pyrolysis is often chosen with a biochar focus, a fast or flash pyrolysis could be applied to optimized oil yield and a biomass gasifier could be applied to optimize gas yield.		See comment to the next note.
29	203-205	Can also be left in an inert (N2 flushed) char collection compartment to cool more slowly. To optimize char quality and avoid PAHs in the char it is crucial to separate the pyrolysis gases from the biochar at the highest possible temperature. Cooling the char in the proximity of the pyrolysis gases may lead to re-condensation of tar species onto the active biochar.		Thanks for the suggestion. We have changed the text to: For biochar production, slow pyrolysis is often chosen, whereas fast or flash pyrolysis is applied when the focus in on optimisation of oil or gas yields. The hot biochar will leave the reactor at high temperature and need to be cooled by using a water mantled cooler, generating warm water or, in some cases, directly cooled by adding water directly on the hot char to minimize the risk of self-ignition. Alternately, the cooling can be done by use of inert gases. To optimize the biochar quality and reduce contamination with toxic polycyclic aromatic hydrocarbons (PAH), it is crucial to flush the pyrolytic gases away from the biochar before cooling (Madej et al. 2016). Cooling the biochar in the proximity of the pyrolysis gases may lead to the re-condensation of PAH and other tar species onto the biochar.
30	207-289	A critical reflection on the use of the US Davis biochar database should be included. It is a unique dataset	X	We have added the following text:

	Udfyldes af fagfællebedømmer:			Udfyldes af forfatter:
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		and as such very interesting. But the consistency and quality may be up for discussion and the results as a whole should be regarded with case as they are influenced by massive uncertainty and underlying variations. This induce more scattering of the results and they are super scattered. Only the very global and robust correlations can be found. But there are also a lot that cannot. For example: there will almost always be a strong correlation between P content in the char and temperature but such a correlation require a more consistent setup that does not involve variation of everything at once. It should be mentioned that more consistent experimental campaigns are required to identify and analyse such correlations and interdependencies and that there are many of such studies being conducted as well. Also, to be placed in this part of the chapter the charts and results e.g. through correlations or spans or average values should be applied in the quantitative assessment. Otherwise the charts and data could be moved to the descriptive section of the chapter?		As the database are based on inputs from many sources with various feedstock, process conditions and analyses of biochar, the figures can only be used to illustrate general trends and the variations.
31	224+	There is an inconsistency in the methods description. The method for determining the volatile matter is described. But not for determining the ash content, pH, surface area? Are the first two charts on basis of dry char? are the measurements standardized or is it up to the user (as with phyllis)? how is ash and volatile content related in this method. determination of volatile content at 900 C for 7 minutes - is that a	X	More text has been added. The analysis of volatile matter was added as is different from other methods to determine volatile matter.

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		biochar standard? or for fossil coal? if the volatile matter is all that volatilizes in a flash incineration, then it could also be extracted from the determination of the ash content except that 900 C incineration will vaporize certain inorganic elements as well?		
32	228	7 minutes <u>in manure</u>? maybe in air instead? Or in N2?		Has been changed to "in air"
33	232	In char? Versus temperature, not versus HC ratio?		Corrected.
34	239	Ash content or pH versus temperature? Axis says pH, legend says ash content. Add a comment that it is related. Ash content increase with temperature and pH increase with ash content as pH is measured in a slurry on weight basis and CHONS does not contribute as e.g. ash constituents KMgCa etc does		Corrected. This text has been added: The pH of a slurry of biochar increased with increasing pyrolysis temperatures (figure 2.3) and ash contents (figure 2.3).
35	244	Figure 2.4 is presumably not relevant in this chapter. If the purpose of the chapter is climate impact assessment and char use is limited to soil amendment and soil enhancement effects of biochar are not included then surface area correlations are redundant to investigate. The chart is not referred to in the text and should as such be omitted.		The figure has been deleted.
36	252-253	Nitrogen recovery/loss may be more interesting than content? perhaps the aim should even be to release/loose all N in the pyrolysis? residual N in biochar has little or no fertilizer value and it is unknown if the farmer still has to account for it? Important to optimize N utilization across the whole value chain and not focus only on the thermal process. This may include digestion and dewatering		We have added an paragraph with: It is of importance that nitrogen and phosphorus can be used as nutrients for plants when applied on agricultural fields. The availability of these nutrients is also of importance is of similar importance. Also the losses (emissions) of nitrogen during the processing of feedstock, where ammonium-nitrogen will

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		to mineralize N and move it to the water phase as well as use steam drying to re-condensate volatilized N in the drying process.		follow the water fraction during separation (dewatering), and ammonia can be emitted during drying.
37	262	i guess this chart illustrates well the volatility and uncertainty of the results in the database. this wild scatter is unexpected and it makes it impossible to decifer that there will be an increasing trend with temperature. Grass biochar samples with 5-7.5% P is to me highly counter-intuitive??		We agree on the comment, but have decided to keep the figure.
38	270	and its **related carbon** sequestration potentials in soils.		Added.
39	273	Very important to include that: "Many biochars **produced at temperatures below 500 C** in the Biochar database cannot fulfil this criterium as it is shown in figure 2.8**, while almost all biochars produced above this temperature comply with the HC ratio threshold.**		Thanks for the comments. We have added the the suggested text.
40	278+	Change "Hydrogen carbon" and "Oxygen carbon" to "Hydrogen-carbon" and "Oxygen-carbon" or "Hydrogen/carbon" and "Oxygen/carbon"		We have added dashes between the mentioned species.
41	288-289	The caption and the legend does not fit "Symbols: blue square, sewage sludge, green triangle, manure, and red dots, straw."		The symbols are from an earlier version and are deleted as the symbols are shown in a box in the the figures.
42	290	Change header to "Impact of pyrolysis proces retention times"?		Done
43	291	Ronsse et al (2013) is missing in the bibliography. https://onlinelibrary.wiley.com/doi/full/10.1111/gcbb.12018		Ronsse et al. is added to the reference.
44	291	Chang pyrolysis times to "pyrolysis proces retention times"?		OK

	Udfyldes af fagfællebedømmer:			Udfyldes af forfatter:
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45	292	For straw **there** was a clear difference **with the applied retention time** at the low		Added.
46	294-299	A bit confusing. And needs precision. The chart show huge difference in carbon yield at low temperature and the 22-25% C yield is only true for temp > 400 C. The "biochar" yield of 95% is at 300 C, but it is not really possible to produce biochar at 300 C unless you apply massive pressure. Regardless of retention time you would get a highly torrefied biomass but never a char. In the reference the effect is described as "In proximate analysis, it was found that the fixed carbon content (expressed in wt% of dry and ash-freebiochar) in the biochar samples strongly depended on the intensity of the thermal treatment (i.e. higher tempera-tures and longer residence times in the pyrolysis process). The actual yield in fixed carbon (i.e. the biochar fixed carbon content expressed as wt% of the dry and ash-free original feedstock biomass weight) was practically insensitive to the highest treatment temperature or residence time." The main THM is that carbon in char made at sufficiently severe process conditions is thermally stabile in an inert atmosphere even though temperature or retention time is increased further. At low temperatures the biochar yield is very high as it contains volatile carbon and more HNOS than the biochar produced at higher temperatures.	X	We have rewritten the text: In a study by Ronsse et al. (2013), pyrolysis temperatures varied between 300 and 750 °C with pyrolysis process retention times of 10 and 60 °C minutes for wood, straw, green waste and dry algae. For straw, there was a clear difference with the applied retention times at the low pyrolysis temperatures of 300 °C. However at 450, 600 and 750 °C the hydrogen-carbon ratio did not differ a lot between 10 and 60 minutes (figure 2.10). Another interesting outcome of their study was that the fixed carbon yields on dry and ash-free basis were between 22 and 25 percent for the various process conditions for straw even though the biochar yields differ between 24 and up 95 percent on a dry and ash-free basis (figure 2.11). The high yields obtained at pyrolysis temperatures at 300 °C wereoffset by a corresponding reduction in carbon contents in the biochar, thus resulting in a similar fixed carbon yields (e.g. figure 2.12). It should be noted, that the carbon yields from this study is somewhat lower than other studies, where e.g. 40 percent was found for straw (Laghari et al., 2021). The hydrogen-carbon ratios decreased with increasing temperatures, which will affect the carbon sequestration potentials of the biochar (figure 2.11).

	Udfyldes af fagfællebedømmer:			Udfyldes af forfatter:
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		I am puzzeled by the carbon yields in the char product as these are very low compared to what i have determined/measured myself. I usually see 40-45% for straw biochar which is almost double this study. There is no analysis of the untreated biomasses in the paper and it is impossible to reproduce the calculatins . I advise that care is taken using this reference. It is also a bit confusing that the carbon recovery rates you use in the calculations later on are all higher than these results (27, 35 and 40%).		
47	300	Figure 2.11 and 2.13: for temperatures >400 C there is no significant difference in neither total carbon yield, fixed-C yield or biochar yield. There is only a difference at 300 C which is too low temperature for pyrolysis unless high pressure is applied.		The figures illustrate that the carbon yields are dependent on the process temperatures, below 400 °C, but the H/C rations decrease with increasing temperatures, which is of importance if the H/C ration is used for calculation of the carbon sequestration potential in agricultural soils.
48	321	or storing it in an inert atmosphere		We have added the suggested text, but I think that using an inert atmosphere is less practical, if the biochar is produced for use in agricultural fields.
49	323-324	reference missing. can also be an issue in handling and storing. pelletization or briquetting, mixing with e.g. manure or compost or simply wetting with water solves this issue. wetted biomass retain water and does not dry up easily if covered.		Reference added. Text expanded with: Spreading of biochar as a powder can generate huge emission of dust (e.g. Gelardi et al., 2019). Methods to spread and incorporate or inject the biochar into the soil should be tested and documented. Addition of water and incorporation into the soil is a possible solution (Gelardi et al., 2019). The biochar could also be mixed with manure slurry and applied with slurry tankers with trailing hoses, - shoes or injection. These technologies should be tested under Danish conditions. Dust can also be a problem during handling and storage of biochar.

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50	3327-328	Or mineralized in reed beds as eg WSP Danmark A/S (formerly Orbicon) facilitates the development, deployment and maintenance of. FORS just established a new reed bed for sludge mineralization. There are quite a few in DK.		This text has been added: Another fraction is mineralised in reed beds.
51	329	Interesting instead of interested.		Corrected.
52	341-342	+ wastewater treatment method, catchment area and in the sludge has been digested or not		Text with dependence on wastewater treatment method has been added. This includes whether the sludge has been digested.
53	346	Not easy to verify if they are in accordance as figure 2.1 is ash content in biochar?		The reference to figure 2.1 has been removed.
54	351	Figure 2.15: You should add a description about where the data is collected from. Is it mainly from AquaGreen or the previous descriptions or something third? Comment on the quality and robustness of the applied parameters. Which are strong and which are uncertain? Comment on the expected criticality of the H/C ratio of 0.7. If a quantitative sensitivity assessment is conducted, then mention which of the applied parameters that are investigated in the sensitivity assumption. Biochar DAF, not Blochar DAF Ash-free or ash free not ashfree	X	The source of the data is added in the figure legend.

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55	362	Perhaps "also influenced by severe uncertainty" instead of "similar dodgy"?		Thanks for the suggestion. Text added accordingly.
56	364	"a very" instead of "very a"		OK
57	364-365	Sentence is difficult to read. I understand that lignin content is 16% in straw, but what is it in the sludge and how does it relate to carbon persistence levels?		The whole sentence is deleted.
58	367	Relevant to describe sensitive parameters. Does the 268 kg C in the sludge amended to soil account for the losses in the storage? I find it relevant to elaborate the note on uncertainty and I will just mention here that the carbon balance i did for a similar study was very different. I found 5% losses in storage and a long term C-sink of <6% of the sludge C amended to soil. This would give 60 kg of CO2 seq in this regard. Similarly, (as mentioned) i think the HC ratio of 0.7 may be substantially higher than i have seen in experimental studies on pyrolysis of various Danish sludge types.	X	We agree. No. We have reduced the carbon with 10 percent due to mineralization. We miss data on H/C ratio for sludge on Danish condition on full scale, The used 3% EF is based on Larsen et al. (2018) calculated for 180 days, which we assume is the average storage time in the reference.
59	403-406	This is a very simple approach and it should be discussed. In general it is a rule that the systems should be consistent and equivalent with regard to the services they provide. In the 2018 study i did, the estimated cost of nutrient losses were at least 10 times greater than the energy saved by reduced transportation. The P loss used in the calculation is around 6/31=20%. This is high. and should be accounted for	X	We thank for the comments. We agree on that the systems should be consistent. However, it is not a LCA we carry out in this chapter. Re N loss. It is outside the scope of this chapter to evaluate the values of P and N. We assume this will be covered in a later chapter on socio-economic evaluations.

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		by replacing the lost P. The climate intensity of P production vary but for quick estimates the https://www.biograce.net/biograce2/ database standard values can be used. here it is 0.54 kg CO2eq per kg P2O5 equivalent to approximately 1 kg CO2e per kg P. The climate impact hereof is limited (6 kg CO2 ish) as is any minor losses in K, Ca, Mg etc. However, the discussion about N is more crucial since more N is lost + synthetic N replacement is more climate intensive than mineral P fertilizer. However, a lot of the N that is lost has little fertilizer value. You assume an N-loss of 37 kg. According to https://www.biograce.net/biograce2/ the average cost of mineral N fertilizers are 4.5 kg CO2 eq per kg N. However, it is not all the lost N that should be substituted with new mineral N because the farmer cannot supply as much N in a biochar + mineral N combination as he can in sludge alone due to the use-efficiency factor (fri oversættelse af udnyttelses%). If this factor is 40% (is it?), then the reference farmer will distribute all N in the sludge (= 44 kg) while the farmer in the scenario can only distribute something like the 3 kg he has left in the biochar + 15 kg mineral N fertilizer, giving a cost of 67 kg CO2-eq (if the 40% use-efficiency factor apply to both sludge and char). This also means that there		

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		is a difference in total N application in the field (44 kg >< 18 kg) which influence N2O loss and leaching. In this regard it seems like you have included N2O emissions from N application in the reference but not in the scenario? This should be corrected as there will still be N applied and there will still be N2O emissions, but it will be different types of N and different amounts and thus different emission levels. This is somewhat on the edge of my expertise so please let me know if i am completely wrong in this regard.		
60	411-420	It is not clear if the results from Willen 2017 are used subsequently in calculations/conclusions of this thesis? The figure text is quite elaborate if the results are not used and could be shorted . And if the results from Willen are used, it should be discussed where and how representative it is since the two studies/ data sets differ.		The results are not used later. We think it is necessary to explain the figure, which is the reason for the big figure text.
61	428-429	**The emissions of methane** from storage and application of wet, biologically active biomasses **can be mitigated by production of biogas through anaerobic digestion (AD) of manure**.		We have added the suggestion to the text.
62	430-433	is this relevant when only addressing the establishment of pyrolysis plant capacity? or is it to evaluate the effect of establishing either AD capacity OR pyrolysis capacity OR a combination compared to a do-nothing reference?		We agree that the sentence is not needed and much of it has been deleted.
63	434	this is true for a Stiesdal pyrolysis unit, but may not be the case with other plant types. AquaGreen develop systems with integrated drying – also for manure and		We agree. The sentence has been changed and it is mentioned pelletizing is part of the solution from Stiesdal.

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		digestate, and possibly also without the need for pelletization. Systems from e.g. PyREG, ETIA, BioGreen etc typically do not require pelletization. It will often be a benefit as it increase thermal capacity and reduce feeding issues but it is also expensive		
64	439	Is Phosphorous ceiling the right term in English? Maybe Phosphorous application limits?		The text has been changed.
65	441-444	This will also happen if the digestate is stored un-separated and untreated.		We agree, but our reference is the solid fraction
66	455-457	What is the dry matter content of this fiber product?	X	The dry-matter concentration of the fibre fraction varies but is often around 30%. We have included this.
67	460	Figure 2.17: Part of the figure is missing on both sides? This makes it difficult to read.		The full figure has been included
68	467	It is not completely clear to what extent the data in the table are used in the scenario development and climate impact calculations? This carbon recovery in biochar is a lot higher than the study used in the discussion on page 15-16 (Ronsse 2013). The difference should be explained somewhere because the levels described on p 15-16 seem very stabile across different biomass types and temperatures. As mentioned previously there is biomass composition data missing from the study and the calculations cannot be reproduced which makes it difficult to find the differences. My own experience show carbon recovery levels closer to those in table 2.4 than to those determined by Ronsse et al.	X	The table is based on information from Stiesdal.

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		it is also a bit confusing that the system in figure 2.17 only has a high temperature heat product (Thermal oil to biogas upgrading = amine scrubber heat supply) whereas there is an oil and a gas product in table 2.4. Perhaps this should be briefly mentioned/discussed somewhere?		
69	473-480	I think it is a bit problematic to apply this type of drying technology. At least it should be discussed what the impact of applying alternative drying technology would be. In modern, pressurized heat pump based steam drying systems, the energy use will be even lower. Systems with energy consumptions as low as 0.5 MWh to produce one ton of fibers with 10% moisture is under development according to Stiesdal. In addition, around 2/3rds of the applied energy can be recovered as 90 C heat. In smaller modern, atmospheric pressure heat pump based drying systems, the energy requirement would be 0.25 MWh per ton water with the possibility to reduce it even further according to the company drying matter (https://www.dryingmatter.com/) however, in such a low temp process there would not be a residual heat source for other uses.		We agree that the energy balance can improved by using more efficient drying systems. We will mention this but still use the high energy consumption in our calculations since this is how it is done with the biogas fibres today.
70	480	2 GJ is more than 10% of biomass HHV which is at least twice as high as typical estimations of 4-5%?		We agree and will use 5% of 15.9 GJ=0,8 GJ
71	490-494	Perhaps mention that AU is investigating GHG emissions from separated and non-separated pig manure and biogas digestate samples and results		We have added a sentence with the work in the STABIL project.

	Udfyldes af fagfællebedømmer:			Udfyldes af forfatter:
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		from bench/pilot scale experiments will be published as part of the GUDP project STABIL in the coming 1-2 years?		
72	491-494	How about emissions from the liquid phase after separation? Especially in cases where screw pres is applied and subsantial amounts of organic material will go with the liquid fraction? I guess that especially Methane is crucial to monitor in this regard?		It is correct that there will also be emissions from the liquid fraction but since we assume the same separation in both the reference scenario and the pyrolysis scenario, the emissions from the liquid fraction can be ignored.
73	495-496	I cannot find this table? Is the energy balance related to table 2.4 = 2.2 + 5.6 GJ minus parasitic losses (eff 80 in figure 2.18 = 1.56 GJ loss?) minus drying energy (4.6 GJ) = … 1.56 GJ? Also, a substantial part of the energy from the drying could probably be usable for DH production. I guess the drying air temperature is quite high and there should be a potential in the enthalpy of evaporation even though it is air drying with relatively low net efficiency. And where do the 499 kg CO2e per tonne biomass originate from?	X	The table was by mistake taken out and is now inserted again. Some of the figures has been changed due to new assumptions.
74	503	Again, I recommend to make it more clear what parameters are used for this calculation and where they originate from. Also, preferably discuss the quality and robustness hereof.	X	We have added the H/C ratios are assumed and the data not mentioned elsewhere are from Stiesdal.
75	508	Table 2.5: In table 2.4 you show a carbon recovery of 51%, but in table 2.5 you use a recovery rate of just 27%. This is	X	We know use a carbon recovery of 51%.

	Udfyldes af fagfællebedømmer:			Udfyldes af forfatter:
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		almost a factor 2 difference and the difference should be discussed. If figure 2.18 and table 2.4 differ on other aspects, they should be discussed or one of them omitted. One row is "Sludge" – should it be "Digestate"? Where does the Fperm of 0.18 come from? It is much higher than the 10% stability discussed on page 7 and also higher than any other estimates i have seen? This should be described. Again, i expect that losses (mainly storage) are not included in the carbon balance for the reference value chain? The sequestration result 223 / 238 kg CO2e in 100 years is a controversial result that should be discussed. The carbon recovery in the biochar seem very low to me while the C-sink rate for the amendment of the raw fibers seem very high. In addition the carbon loss in fiber storage does not seem to be included?		We agree that Fperm should be 0.10 and it has been changed. In the other calculations the right Fperm has been used. After changing the Fperm value the carbon balance should be in the expected range. We assume that the carbon lost in the fiber storage anyway would be in the C pool that would be very fast degraded.
76	513	Table 2.6 EF = 0.013: In the described system, the surplus energy will be used to supply heat to amine scrubbers at a biogas plant. Amine scrubbers are heated with fossil methane. On page 6 you wrote "It is assumed that the methane substituted is of fossil origin with emissions of 0.057 CO2 kg MJ-1 (Møller et	X	Now the surplus energy substitutes natural gas.

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		al., 2008)." i guess the emission factor of the surplus energy should reflect this?		
77	518	Table 2.6: As with the sludge case, the total N balance should be considered to make sure that the systems are equivalent. Some N should be applied in the biochar scenario to give the same net application as in the reference when taking into account the use-efficiency factor of N in the digestate and char?	X	The N balance should now fit. It is not the scope of this chapter to evaluate the fertilizer values.
78	538	In table 2.3 you show a carbon recovery in straw biochar off 44%. Therefore, the choice of 35% has to be discussed?	X	APA (write that the data from Stiesdal is different from literature (REF) in this respect and we have chosen to use values closer to what is find in literature.
79	541	Figure 2.4: As with the previous scenario: Why are the data from table 2.3 not used in the calculations/assumptions behind figure 2.4? Or are they? This is quite confusing. If you use a better/more representative source for the data, then it should be described. Otherwise the Stiesdal data should be used or deleted? As a minimum there must be a discussion why the selected parameters are used. Where the parameters originate from and the quality of the data is also important and should be included.	X	The figure is based on the assumptions in the top-left corner and based on data from Stiesdal.
80	548	Why 0.6 and not 0.7 as in the other cases? A globally assumed HC ratio of 0.7 for all biochars in the study was assumed on page 7? However, according to Figure 2.4 the HC ratio in the char is 0.58 and if the C-balance data from table 2.3 is used it will become much lower.	X	We have changed to 0.7. The thinking was that straw-based biochar was easier to produce.

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81	552	Table 2.4: This HC ratio and Fperm do not correspond. The Fperm correspond to HC ratio 0.7. If 0.6 is used it should be Fperm = 0.746?	X	The H/C has been changed to 0.7.
82	558	Table 2.5: heat from straw pyrolysis will rarely be used for district heating as it is very high temperature and may be used for industrial purposes instead. In the early sections you wrote that "In our calculations we assume that the energy output will displace natural gas or heating. It is assumed that the methane substituted is of fossil origin with emissions of 0.057 CO2 kg MJ-1 (Møller et al., 2008).". In the straw case and the digestate case i find natural gas substitution more relevant than average district heating. However, it is possible to establish both systems and ideally you should calculate the results with both substitution values and discuss	X	Thanks, we agree about this and we have now used natural gas substitution in all scenarios.
83	561	There should be a section here about with a summary of the results where the system impacts are aggregated/compiled and discussed/investigated up against each other. To compliment this discussion, a sensitivity assessment of the most uncertain parameters and assumptions should be conducted. This can include some of the aspects discussed in 2.8 but should also include a quantitative assessment that indicate how much the uncertainty/sensitivity of a given parameter influence the overall results.	X	We will add a section which summaries the findings.
84	568-569	the impact of this assumption/parameter use on the results should be tested using alternative sources. E.g. https://docplayer.dk/29384551-Halm-skal-da-i-biogasanlaeg-julie-houge-hansen-phd-studerende-syddansk-universitet.html for the manure fibers and	X	We still think it is right to mention that there are only few studies and in the knowledge gap we don't think it is needed to refer to the scarce literature.

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		e.g Yoshida H, ten Hoeve M, Christensen TH, Bruun S, Jensen LS, Scheutz C. Life cycle assessment of sewage sludge management options including long-term impacts after land application. J Clean Prod 2018. doi:10.1016/j.jclepro.2017.10.175. for the sewage sludge		
85	572	if the product has an EBC certificate then there will be valuable information in this regard that follows the biochar product.		Thanks, we have included this
86	574	Important to mention in this regard that you only applied one of many different approaches to biochar carbon persistence and you only investigated the most conservative scenario for threshold biochar products. Many biochar products will have lower HC ratios than 0.7 and (if the method is valid) similarly longer persistence. You should ideally test the effect of applying other persistence/ sequestration levels to investigate the importance of this parameter on the final results. A simple approach could be to try to change the HC ratio as proposed using the experimental data on char from sludge, straw and digestate from https://link.springer.com/content/pdf/10.1007/s12649-021-01358-5.pdf According to recent experimental data from Stiesdal and AquaGreen even the above results by Laghari may underestimate persistence through HC ratio overestimation. Especially the C-content of the	X	Thanks for the comments. We have rewritten the section: Carbon storage of biochar is one of the most important parameters for the carbon dioxide reduction by using the pyrolysis technology. The impact on climate gas emission reduction depends both on the biochar and what is happening in terms of carbon sequestration if the biomass is used on farmland without pyrolysis. We have assumed a slower carbon release from manure fibers and sewages sludge compared to the straw, which is building on very few studies. For the biochar several factors affect the fraction of biochar carbon remaining (un-mineralised) after 100 years. According to IPCC this is very dependent on the temperature used in the process but the time will also be an important factor. This is however not clear and these information will usually not follow the biochar product. If the product has an EBC certificate there will be valuable information in this regard that follows the biochar product. However If more precis information on carbon storage over long time should

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		digestate has been found to be quite low compared to other danish digestate samples		be calculated more information about process conditions are important. The estimated carbon sequestration values in this chapter is based on a hydrogen-carbon ratio of 0.7 which is the threshold limit set by the EBC certificate. Lower values will result in higher sequestrations. A more detailed description of the various methods and parametrisation is provided in chapter 6.
87	590	Section 284. it probably is to some extent? is this relevant in a section on knowledge gaps and uncertainty? I think both Stiesdal, AG and others measure for NOX, unburned hydrocarbons etc in the exhaust?		We have changed this.
88	601-603	I agree than HC ration is a better proxy than temperature. even temperature and retention time may be insufficient and under certain conditions highly misleading as it is the particle core temperature that is governing for the global severity. If particles are very large or the reactor is large and externally heated then the temperature gradient into the center particle core will be very long. Veryfying the particle core temperature profile will require extensive experiments and modelling. And it will be easier to measure HC ratio :) An even simpler proxy that everyone with a muffleoven can do is residual volatile organics measured by conducting a very severe pyrolysis (e.g. 650 C for 2 hours) on pre-produced char. If the thermal mass losses doing this second pyrolysis are substantial then there is a large risk that the material was not completely pyrolyzed in the first process.		Thanks for the information. We agree, but have not included it since the chapter with knowledge gab don't need too many details.

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89	**601-603**	Suggestion for re-phrasing: The hydrogen-organic carbon **molar composition** factor is independent of the biochar production parameters and is a better way to characterize biochar **with regard to carbon persistence and C-sink potential.**		Thanks we agree and re-phrased the sentence.

* Ved afkrydsning i denne kolonne angiver fagfællebedømmer at fagfællebedømmeren ønsker at se hvordan kommentaren er håndteret i produktet *inden* endelig levering.