

Bioenergipotentialer - geografisk fördelning och påverkan av hållbarhetskrav inom EU

Slutrapport för projekt 36090-1 inom Bränsleprogrammet Hållbarhet

Julia Hansson IVL Svenska Miljöinstitutet och Göran Berndes, Chalmers

Författare: Julia Hansson, IVL Svenska Miljöinstitutet och Göran Berndes, Chalmers

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IVL Svenska Miljöinstitutet AB, Box 210 60,100 31 Stockholm

Tel: 08-598 563 00 Fax: 08-598 563 90

www.ivl.se

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Sammanfattning

Det övergripande målet med projektet är att utifrån ett resursperspektiv undersöka hur bioenergisystemet påverkas av hållbarhetskrav. Syftet var att kartlägga bioenergipotentialens geografiska fördelning och undersöka hur olika regioners möjligheter att producera biomassa och fasta/flytande biobränslen för EU påverkas av hållbarhetskriterier för biobränslen, samt översiktligt analysera konsekvenser för den svenska biobränslemarknadens utveckling. Projektet är ett samarbetsprojekt mellan Julia Hansson på IVL och Göran Berndes på Chalmers och har resulterat i ett flertal vetenskapliga publikationer. Resultat och slutsatser presenteras kortfattat i efterföljande extended summary.

Summary

The overall objective of the project is to assess how sustainability requirements influence the bioenergy system, from a resource perspective. The purpose was to assess the geographic distribution of the bioenergy potential and to investigate how the possibilities to produce biomass and solid/liquid biofuels for the EU in different regions are influenced by sustainability requirements. The analysis also includes how the Swedish bioenergy market might be affected. The project was a co-operation between Julia Hansson, IVL and Göran Berndes, Chalmers and resulted in several scientific publications. Results and conclusions are briefly presented in the extended summary below.

Inledning

Efterfrågan på biobränslen förväntas fortsätta öka (se t ex Smith et al. 2014). Användningen av bioenergi berör i stor utsträckning miljömålet *Begränsad klimatpåverkan* och berör även flera andra svenska miljömål som *Levande skogar*, *Bara naturlig försurning*, *Ingen övergödning*, *Ett rikt odlingslandskap*, *Ett rikt växt- och djurliv*, *Giftfri miljö*, *God bebyggd miljö*, samt *Levande sjöar och vattendrag*.

Hållbarhetskriterier för biodrivmedel och andra flytande biobränslen har utformats inom ramen för EU:s förnybarhetsdirektiv (direktiv 2009/28/EG) och har införlivats i svensk lag. Kommissionen förväntades föreslå motsvarande bindande hållbarhetskriterier även för fasta biobränslen. Arbetet med att ta fram hållbarhetskriterier för fasta biobränslen avstannade i slutet av 2013, men på sikt är tvingande EU-krav för fasta biobränslen däremot fortfarande möjligt. Flera initiativ pågår kring hållbarhetskriterier även för fasta biobränslen (t ex har några EU länder infört eller överväger att införa egna kriterier).

Den internationella handeln med biobränslen förväntas fortsätta att växa som följd av att den geografiska fördelningen av biomassaressurser inte sammanfaller med efterfrågemönstret (Junginger et al., 2014). Politiska mål och hållbarhetskrav kan komma att få stor påverkan på framtida bioenergimarknader eftersom kriterierna kan påverka hur styrmedel utformas och vilka bränslen som gynnas eller missgynnas av det.

Det är angeläget att förstå hur hållbarhetskrav i olika utformningar kan komma att påverka såväl internationell handel som förutsättningarna för den svenska bioenergimarknaden. Det finns ett behov av studier kring hur hållbarhetskrav påverkar utbudet av biomassa för den europeiska marknaden inklusive i Sverige. Detta projekt bidrar till bättre förståelse för hur miljörestriktioner i form av EU:s hållbarhetskriterier påverkar den möjliga produktionen och handeln med biobränslen. Projektets ansatser tar till skillnad från många tidigare studier explicit utgångspunkt i EU-relevanta hållbarhetskrav för bedömningar av bioenergipotentialen på global och regional nivå och möjlig påverkan på bioenergimarknaden, med fokus på den svenska.

Med hållbarhetskrav avses i detta projekt inte bara EU:s hållbarhetskriterier för biodrivmedel och biobränslen. Det finns en mängd initiativ kring hållbarhetskrav för biomassa, bioenergi och/eller biobränslen, både på nationell och regional nivå, exempelvis ISO/PC 248-Sustainability criteria for bioenergy, CEN/TC 383 Standard for sustainably produced biomass for energy applications, RSB Sustainability Standards. Flera av de svenska miljömålen är i hög grad relevanta för bioenergi, liksom regleringar t ex kopplat till EU:s vattendirektiv. Vilka hållbarhetskrav som analyseras och i vilken utsträckning redogörs för i respektive delstudie.

Projektet vars titel är "Bioenergipotentialer - geografisk fördelning och påverkan av hållbarhetskrav inom EU" har finansierats inom ramen för Energimyndighetens Bränsleprogram Hållbarhet. Projektet har pågått under perioden 2012-12-03–2015-05-31 med en total budget på 2 000 000 kr och Julia Hansson på IVL Svenska Miljöinstitutet har varit projektledare. Denna rapport är projektets slutrapport. Inledningsvis beskrivs projektets mål, genomförande, måluppfyllelse och kort projektets huvudresultat. Därefter följer ett avsnitt med mer utförlig beskrivning av resultat, slutsatser och diskussion. Denna del skrivs på engelska för att kunna spridas även internationellt och därmed nå en bredare publik.

Projektets mål och genomförande

Det övergripande målet med projektet är att utifrån ett resursperspektiv undersöka hur bioenergisystemet påverkas av hållbarhetskrav. Syftet var att kartlägga bioenergipotentialens geografiska fördelning och undersöka hur olika regioners möjligheter att producera biomassa och fasta/flytande biobränslen för EU påverkas av hållbarhetskriterier för biobränslen (utöver faktorer som mark- och vattentillgång, konkurrerande markanspråk och möjliga avkastningsnivåer för odlade grödor), samt översiktligt analysera konsekvenser för den svenska biobränslemarknadens utveckling. Projektets delmål var:

- En review-publikation över vetenskaplig litteratur som analyserar den globala och regionala bioenergipotentialen.
- Egen inventering och analys av bioenergipotentialens storlek och globala geografiska fördelning baserad på uppdaterad metodansats och aktuella databaser. Tidsperspektiv 2020-2050 och med beaktande av biofysiska produktionsförutsättningar kombinerat med tekniska data för olika produktionssystem för biomassa för energi.
- Analys av hur hållbarhetskrav relevanta för EU påverkar möjligheterna för regioner med avsevärda biomassaresurser att exportera till EU-länder.
- Identifiering av de mest begränsande hållbarhetskraven och hur olika ansatser till implementering av hållbarhetskrav påverkar tillgången på "EU-godkänd" biomassa.
- Analys av implikationerna av de resultat som erhålls när det gäller efterfrågan på svenska biobränslen och utvecklingen av den svenska bioenergimarknaden.

Projektet är ett samarbetsprojekt mellan Julia Hansson på IVL och Göran Berndes på Chalmers. Oskar Englund, som är doktorand för Göran Berndes, har deltagit och projektet utgör en del i hans doktorandarbete. Även Yvonne Jans, doktorand vid Potsdam Institute for Climate Impact Research (PIK), som har varit gästforskare hos Berndes på Chalmers, och Roman Hackl, IVL, har bidragit till projektet. Samarbetet har fungerat mycket väl under hela projektiden.

För att nå projektets delmål har en mängd olika delstudier genomförts. Dessa delstudier inkluderar:

- En genomgång av vetenskaplig litteratur som analyserar den globala och regionala bioenergipotentialen.
- En kartläggning av standarder och certifieringssystem för hållbar bioenergi har genomförts som ett samverkans-projekt inom IEA Bioenergy.
- En kartläggning av hur biodiversitetsfrågan hanteras inom ramen för olika hållbarhetsrelaterade standarder och certifieringssystem för biomassaproduktion inom jordbruk och skogsbruk.
- Modellering av biomassapotentialen med hänsyn till globala vattenresurser och andra faktorer som biodiversitetsskydd och skydd av områden med stora biosfäriska kolförråd, främst skogar.

- Analys av hur potentialen för biobränsleproduktion kan påverkas av styrmedel med mål att förhindra markomvandling med stora CO₂-utsläpp. Biodieselproduktion från palmolja i Brasilien användes som fallstudie.
- Analys av den institutionella kapaciteten i relation till hållbarhetskrav i världens länder.
- Syntes av forskning kring hur bioenergimarknaden kan påverkas av hållbarhetskrav.
- Analys av växthusgasprestanda för el och värme producerat från pellets för den svenska marknaden.
- Kompletterande inledande analys av hur den svenska pelletsmarknaden kan påverkas av införandet av hållbarhetskrav för fasta biobränslen med fokus på krav för växthusgasminskning och hållbart skogsbruk. Analysen inkluderar en specifik analys av betydelsen av torrefiering.
- Analys av hur definition och hantering av "highly biodiverse grasslands" kan komma att påverka det möjliga bidraget av bioenergi från världens gräsmarker.
- Kartläggning av möjligheterna att integrera ekosystemtjänstbegreppet i LCA-metodik genom en fallstudie på pelletsproduktion (examensarbete).

Projektgruppen har valt att driva delar av projektet med anslutning till IEA Bioenergy Task 43 som leds av Berndes. Vi har också samverkat med andra relevanta forskningsprojekt. Detta har gett tillgång till data och analyskapacitet som varit till stor nytta för projektet. Ett par seminarier har genomförts med koppling till projektet. Eftersom flera av delmålen överlappar bidrar vissa analyser till mer än ett delmål, vilket vi har försökt förtydliga i rapporteringen nedan.

Genomgången av vetenskaplig litteratur som analyserar den globala och regionala bioenergipotentialen är delvis en utveckling av arbetet som genomfördes inför IPCC:s rapport om förnybar energi 2011. Modelleringen av biomassapotentialen sker i samverkan med PIK och fokuserar på vattentillgång som begränsande faktor för biomassaproduktion för energi men inkluderar även andra påverkansfaktorer såsom biodiversitetsskydd och skydd av områden med stora biosfäriska kolförråd, främst skogar. Denna analys visade sig vara mer komplicerad än förväntat. Delstudien som specifikt analyserar hur potentialen för biodieselproduktion baserat på palmolja i Brasilien påverkas av styrmedel som syftar till att förhindra markomvandling som medför stora CO₂-utsläpp bidrar till andra, tredje och fjärde delmålet ovan. Potentialen för biodiesel från oljepalm i Brasilien har analyserats som första tillämpning av nyutvecklade GIS-baserade metoder.

Undersökningen av hur hållbarhetskrav kan påverka möjligheten till EU-export i olika regioner baseras på inventeringen av standarder och certifieringssystem för hållbar bioenergi. Som del i analyserna av hur hållbarhetskrav påverkar förutsättningarna för olika länder att exportera så har vi bland annat undersökt hur olika hållbarhets relaterade standarder hanterar biodiversitet. Vi har även undersökt den institutionella kapaciteten att "garantera" hållbarhetskrav i olika länder.

Analysen av hur definition och hantering av "highly biodiverse grasslands" kan komma att påverka det möjliga bidraget av bioenergi från världens gräsmarker utförs för att illustrera

betydelsen av olika hållbarhetskrav och hur olika ansatser till implementering av hållbarhetskrav påverkar tillgången på "EU-godkänd" biomassa. Flertalet studier bidrar emellertid till målet om att identifiera de mest begränsande hållbarhetskraven och hur olika ansatser till implementering av hållbarhetskrav påverkar tillgången på "EU-godkänd" biomassa. Analysen av påverkan på den svenska biobränslemarknaden utgår från en syntes av forskning kring hur bioenergimarknaden kan påverkas av hållbarhetskrav och baseras främst på växthusgasbalanser för olika pelletsdjor och kriterier för hållbart skogsbruk men betydelsen av länders institutionella kapacitet ingår också liksom situationen när det gäller inhemsk produktion av biodrivmedel.

Enligt genomförandeplanen i Energimyndighetens beslut ingår en uppskattning av möjlig efterfrågan på biobränsle inom EU till 2020 utifrån de enskilda EU medlemsstaternas handlingsplaner för förnybar energi och efterföljande lägesrapporter. Eftersom detta sammanställts av andra, till exempel i Beurskens et al., 2011, har vi valt att inte själva upprepa denna uppskattning utan har refererat till redan utförda studier. Mer tid har istället lagts på den egna analysen. Eftersom projektet har pågått under lång tid har vi löpande genomfört litteratursökningar för att hålla oss uppdaterade inom vetenskaplig publicering och har relaterat våra studier till andra studier inom området.

Måluppfyllelse och huvudresultat

Projektet har resulterat i ett stort antal främst vetenskapliga publikationer. Samtliga av projektets mål har uppfyllts. Ett urval resultat sammanfattas nedan, en utförligare beskrivning (på engelska) återfinns i efterföljande avsnitt. En lista över de publikationer som producerats inom projektet återfinns i slutet av rapporten. De flesta publikationer bifogas rapporteringen till Energimyndigheten som separata bilagor och kan erhållas från projektdeltagarna.

Arbetet med att sammanställa och analysera vetenskaplig litteratur som analyserar den globala och regionala bioenergipotentialen har bidragit till ett par publikationer som även delvis kopplar till det andra delmålet (med egen analys av bioenergipotentialens storlek och fördelning). Smith et al. (2013) analyserar hur stor växthusgasutsläppsminskning kopplat till markanvändning som kan nås utan att äventyra matsäkerhet och miljömål. Creutzig et al. (2014) inkluderar resultat från en omfattande granskning av litteratur kring bioenergipotentialer och klimatnytta av bioenergi. Berndes et al. (2012) och Berndes (2014) diskuterar tillgången på biomassa i stort samt vad som påverkar tillgången. Ytterligare en artikel är under utformning och kommer att färdigställas efter att projektet är slut.

Man noterade i ovan studier att uppskattningar av hur mycket bioenergi som skulle kunna produceras globalt i framtiden varierar inom ett stort intervall beroende på antaganden och metodval i beaktandet av en rad faktorer, vilka i sig själva är osäkra. För flera av dessa är det tydligt hur de påverkar bioenergipotentialen och också vilka åtgärder som kan påverka i gynnsam riktning. Andra faktorer, som till exempel klimatiförändringarna, är dock mer osäkra både vad gäller påverkan i sig och gällande konsekvenser av olika åtgärder för att minska klimatiförändringarna och dess negativa effekter. Sammantaget innebär detta att osäkerheterna kring bioenergipotentialens storlek är stora. Grovt sammanfattat fann genomgången av studier som bedömer den globala bioenergipotentialen: en hög enighet för en hållbar teknisk global bioenergipotential på upp till 100 EJ, medelgod enighet för 100–300 EJ och låg enighet för en potential över 300 EJ (1 EJ motsvarar ungefär 278 TWh).

En slutsats från sammanställning och analys av befintlig vetenskaplig litteratur är att frågan hur vattentillgång och vattenutnyttjande påverkar den globala och regionala bioenergipotentialen är bristfälligt undersökt. Av denna anledning genomfördes egna analyser i samverkan med Potsdam Institute for Climate Impact Research (PIK). En central del av de egna analyserna bestod i (i) uppdatering av databaser och representation av odlingssystem samt vattenanvändning inom jordbruket, och (ii) scenario-baserad modellering med LPJmL som är en dynamisk global vegetationsmodell som har använts i ett stort antal studier för att studera kolflöden och hydrologiska flöden för olika rumsliga och temporala skalor.

Analyserna av hur bioenergipotentialens storlek och fördelning bestäms av vattenresurstillgång och användning visade att vattenresursernas storlek, konkurrerande vattenanvändning (inklusive för att säkerställa bevarande och kvalitet hos akvatiska ekosystem), val av energigrödor och utformning av bevattningssystem har stort inflytande på bioenergipotentialen. Till exempel, i ett antal scenarier varierades parametrar som representerar (i) bevattningssystemens effektivitet, (ii) begränsningar av vattenuttag för att upprätthålla livskraftiga och artrika akvatiska ekosystem, samt (iii) vattenfördelning längs avrinningsområden. Om produktiva gräsarter (C4-växter där möjligt) odlas på marker som i dagsläget inte används inom jordbruket - och som inte består av skog, våtmark, skyddad mark eller har allvarligt degraderade jordar - så motsvarar den uppskattade biomassapotentialen 450-

600 EJ primärenergi per år. Om istället C3-växter odlas så blir totala biomassapotentialen betydligt lägre, motsvarande cirka 180-250 EJ primärenergi per år.

Det är viktigt att notera att ekonomiska och andra begränsningar inte beaktas i studier som syftar till att uppskatta så kallade tekniska potentialer. Å andra sidan så har i studien ovan hänsyn inte tagits till att produktivitetsutveckling inom jordbruket kan reducera markbehovet betydligt, speciellt när det gäller mjölk- och köttproduktion. Likaså kan förändringar i dieter kraftigt påverka hur mycket land som behövs. Men en otvetydlig slutsats är att vattentillgång samt prioriteringar - och former - för dess användning har stor betydelse för hur mycket biomassa som kan produceras i framtiden, för mat, bioenergi, och andra biobaserade produkter. Vi ser behov av ytterligare analyser inom området, inklusive fördjupning inom specifika regioner.

Som en annan del av vår analys av bioenergipotentialens storlek och fördelning, kopplat till vår analys av hur hållbarhetskrav påverkar möjligheterna för regioner med avsevärda biomassaressurser att exportera till EU, har vi specifikt analyserat hur potentialen för biodieselproduktion baserat på palmolja i Brasilien påverkas av styrmedel som syftar till att förhindra markomvandling som medför stora koldioxid-utsläpp. I Englund et al., (2015) och Englund et al. (2014) fann vi att palmolja för biodieselproduktion i Brasilien kan vara lönsamt på betydande ytor inklusive områden med naturlig vegetation där etablering skulle leda till stora utsläpp från förändrad markanvändning (LUC). 40-60 Mha, motsvarande 10% av global dieselefterfrågan, bedöms kunna användas för lönsam biodieselproduktion utan att orsaka direkta LUC-utsläpp och utan att inkräkta på skyddade områden. En kostnad för LUC-utsläpp på \$125/tC eller högre skulle göra palmoljeproduktion olönsam på de flesta marker där omvandling skulle påverka kolstockar och naturliga ekosystem.

I en annan studie, som genomfördes inom ramen för IEA Bioenergy Task 43, undersöktes möjligheten att använda skogsbiomassa skadad av insektsangrepp som råvara till pellets i Brittish Columbia, Kanada (Lloyd et al., 2014). Man fann att volymmässigt utgör insektsskadad ved en betydande potential, men att relativt höga kostnader för detta veduttag kan utgöra ett hinder. Studien understryker vikten av att fortsatt utveckla systemen för utnyttjande av avverkningsrester som över tid förväntas utgöra den viktigaste bioenergiråvaran i Brittish Columbia.

Som grund till undersökningen av hur hållbarhetskrav kan påverka möjligheten till EU-export i olika regioner ligger en omfattande inventering av standarder och certifieringssystem för hållbar bioenergi i Goovaerts et al., (2013), Stupak et al. (2012); Goh et al. (2013), Stupak et al. (2015). Analyserna av hur hållbarhetskrav påverkar möjligheterna för olika regioner att exportera till EU, samt vilka hållbarhetskrav som är mest begränsande, har delvis också genomförts med anslutning till IEA Bioenergy, där följande möten har arrangerats:

- Joint Workshop on Developing a Binding Sustainability Scheme for Solid Biomass for Electricity & Heat under the RED, Arona, Italy, 1-2 juli, 2013.
- The Transatlantic Trade in Wood for Energy: A Dialogue on Sustainability Standards, Savannah, USA, 23-24 oktober, 2013.
- IUFRO 2014 Conference session "Forest Biomass Supply Chains: Practice, Economics, and Carbon Balance", Salt Lake City, USA, Oct 5-11, 2014.

- Forests, bioenergy and climate change mitigation, Köpenhamn, 19-20 maj, 2014 (arrangör IEA Bioenergy Task 38, 40, 43, JRC och EEA).

Som en annan del i analyserna av hur hållbarhetskrav påverkar förutsättningarna för olika länder att exportera så har vi bland annat undersökt hur olika hållbarhetsstandarder (11 skog, 9 jordbruk, 6 biobränsle) hanterar biodiversitet (se Englund och Berndes, 2015a). De biodrivmedelsrelaterade standarderna uppvisade högst ambition vad gällde biodiversitetsbevarande. Kopplat till samma mål samt till målet om att identifiera de mest begränsande hållbarhetskraven har vi undersökt den institutionella kapaciteten ("quality of governance") att tillgodose hållbarhetskrav i världens länder. Resultatet av denna undersökning ger ett kompletterande perspektiv genom att visa i vilka länder med avsevärda bioenergipotentialer som bristande institutionell kapacitet kan innebära svårigheter att garantera hållbar produktion. Analysen, publicerad i Englund och Berndes (2015b) och Englund och Berndes (2014), visar att statliga hållbarhetssystem kan bidra effektivt till att främja hållbar biomassaproduktion, men att utmaningar med både lagstiftning och verkställande kan vara ett problem, främst i ett antal afrikanska och asiatiska länder. Privata internationella hållbarhetssystem verkar kunna ha en roll i de flesta länder, men statliga hållbarhetssystem behövs också.

Vidare kopplat till analyserna av (i) hur hållbarhetskrav påverkar möjligheterna för olika regioner att exportera till EU, (ii) vilka hållbarhetskrav som är mest begränsande, samt (iii) hur olika ansatser till implementering av hållbarhetskrav påverkar, genomför vi specifikt en studie av hur definition och hantering av "highly biodiverse grasslands" kan komma att påverka potentialen för bioenergi från världens gräsmarker (se Hansson och Berndes, 2015). I studien undersöks hur gräsbevuxna områden med hög biodiversitet beaktats i uppskattningar av den globala bioenergipotentialen som inkluderar biodiversitetshänsyn. Som jämförelse kartläggs i studien också hur gräsmarker beaktas i studier och initiativ som syftar till bevarande av biodiversitet.

Studier av biomassapotentialer utesluter vanligtvis biodiversitetsrika gräsmarker som "no-go areas" utgående ifrån olika naturskyddsprioriteringssystem. Studier som diskuterar strategier för biodiversitetsbevarande i allmänhet använder vanligtvis mer förfinade metoder, t ex för att mer noggrant avgöra vilka gräsmarker eller vilka delar av gräsmarkerna som bör bevaras och för hur man kan förena biomassaproduktion med åtgärder som är positiva för biodiversiteten. Det finns dock ingen globalt vederatagen metod för att bedöma och kvantifiera mängden gräsmarker som kan vara tillgänglig för bioenergi från ett biodiversitetsbevarandeperspektiv. Avsaknaden av klara definitioner och vägledning kopplat till förnybarhetsdirektivet leder till godtycklighet och osäkerhet kring möjligheterna för biobränslen från gräsmarker. Den vetenskapliga artikel som redogör för resultaten i denna studie (Hansson och Berndes, 2015) kommer att slutföras efter projektets slut.

Kopplat till målet att analysera implikationerna av de resultat som erhålls för svenska biobränslen och utvecklingen av den svenska bioenergimarknaden har vi bidragit till en syntes av forskning kring hur bioenergimarknaden kan påverkas av hållbarhetskrav (se Pelkmans et al., 2013 och Hansson et al., 2015b). Fortsatta analyser inkluderar främst växthusgasbalanser för olika pelletskedjor (som inledningsvis utförts i samverkan med ett annat Energimyndighetsfinansierat projekt (projekt P36099-1 som finansierats inom ramen för AES-programmet) och kriterier för hållbart skogsbruk men betydelsen av den institutionella kapaciteten ingår också (se Hansson et al., 2014, Hansson et al., 2015a, Hansson et al., 2015b).

Analysen visar att många pelletskedjor potentiellt tillgängliga för den svenska marknaden (inklusive svenska kedjor) ser ut att kunna nå strikta krav vad gäller växthusgasbalans. Det faktum att en del potentiella pelletsproducentländer kan ha svårt att införa och förverkliga hållbarhetskrav innebär en betydande affärsrisk för importörer och detta skulle kunna stärka marknaden för pellets från länder som Sverige. En artikel med scenarier för utvecklingen av inhemsk biodrivmedelsproduktion baserat på en kartläggning av befintlig och planerad produktionskapacitet för biodrivmedel i Sverige (som bygger vidare på tidigare arbete) och som kompletterar analysen av fasta biobränslen i form av pellets har också publicerats (Grahn och Hansson, 2015).

För att bredda analysen kopplat till fler potentiella framtida hållbarhetskrav har en kartläggning av möjligheterna att integrera ekosystemtjänstbegreppet i LCA-metodik utförts i form av ett exjobb (Nordin, 2014). Detta har genomförts som en fallstudie på pelletsproduktion som bl.a. identifierat berörda ekosystemtjänster och möjligheten att kvantifiera dem, vilka ekosystemtjänster som i nuläget går att studera med LCA, samt möjliga sätt att analysera påverkan på ekosystemtjänster med LCA.

Vidare försvarade Oskar Englund sin licentiatexamen "Towards Sustainable Bioenergy - Governance, Resource potentials and Trade-offs" den 28 mars, 2014 (se Englund, 2014). För mer utförlig beskrivning och diskussion av projektets resultat och slutsatser hänvisas till avsnitt Resultat och diskussion samt till de vetenskapliga publikationer som har producerats.

Resultatspridning

Viktiga målgrupper för projektet resultat utgörs av myndigheter, beslutsfattare, miljö- och certifieringsorganisationer, forskare samt företag och aktörer inom bioenergiindustrin och i anslutande sektorer. Forskargruppen har spridit sitt resultat till ovan nämna målgrupper via vetenskapliga publikationer och konferenspresentationer samt via medverkan på seminarier. Genom gruppens medverkan i IEA bioenergy (främst Annex 43) och i flera expertgrupper (t ex ISO, Roundtable for sustainable biofuels, GBEP och European Biofuel Technology Platform) har forskargruppen också aktivt spridit sina forskningsresultat till intresserade aktörer som inte främst söker information genom vetenskapliga publikationer. Projektets analyser bidrar härigenom till att nationella och internationella regelverk och styrmedel om bioenergi baseras på god kunskap och styr mot hållbara lösningar och till att kunskapen i samhället om olika biobränslets miljö- och klimategenskaper förbättras.

Framtida forskningsfrågor

Projektets har sin utgångspunkt i ett antal breda frågeställningar vilka har adresserats genom mer avgränsade delstudier kring specifika forskningsfrågor som bedömts vara centrala. Det finns skäl till ytterligare studier kopplat till dessa specifika forskningsfrågor och vi har även identifierat nya forskningsfrågor som motiverar studier.

Hållbarhetskrav kan potentiellt sett ha stor betydelse för bioenergimarknadens utveckling. Det är därför viktigt att fördjupa kunskaperna om hur utformning av olika hållbarhetskrav påverkar bioenergimarknaden och förutsättningarna för bioenergi i Sverige och utomlands generellt - och svenska biobränsleaktörer specifikt. Detta är kunskap som är värdefull för Energimyndigheten och andra myndigheter, inte minst i arbetet med att påverka utformningen av styrmedel inom

EU. Det är viktigt att även fortsättningsvis följa utvecklingen inom EU och globalt vad gäller hållbarhetskrav och att analysera de frågeställningar som följer av detta.

Specifika aspekter som behöver studeras vidare inkluderar:

- betydelsen av (direkta och indirekta) markförändringar för olika biobränslens växthusgasbalanser samt sociala, ekonomiska och miljöeffekter i övrigt, hur dessa markanvändningsförändringar och växthusgasbalanser kvantifieras inom ramen för hållbarhetskrav, och hur styrmedel kan utformas för att stödja önskvärda markanvändningsförändringar och samtidigt minska omfattningen av markanvändningsförändringar med oacceptabla konsekvenser, t ex växthusgasutsläpp som överstiger uppsatta acceptansnivåer;
- förutsättningarna för nya bioenergiråvaror;
- hur definitioner och metoder för gränsdragningar kopplat till hållbarhetskrav (t ex no-go areas) påverkar tillgängligheten till biomassaressurser i Sverige och runt om i världen. T ex behövs fortsatta analyser av betydelsen på globalt och nationellt plan av krav kopplat till gräsmarker med hög biodiversitet och hur dessa implementeras; och
- hur integrering av bioenergisystem i skogs- och jordbrukslandskap kan bidra till att skapa bättre ekonomiska förutsättningar samt minska negativ miljöpåverkan inom näringarna.

Det är motiverat med ytterligare analyser av hur olika hållbarhetskrav kopplat till bioenergi (EU:s kriterier såväl som andra hållbarhetsaspekter) påverkar förutsättningarna för biomassaproduktion i den svenska skogen. Sådana analyser har giltighet även relativt andra skogliga produkter eftersom produktion av skoglig bioenergi är integrerad med annan skoglig produktion. Det finns också skäl att fördjupa analysen av olika länders förmåga att verkställa och upprätthålla hållbarhetskrav, t ex via fallstudier i olika länder.

Resultat och diskussion (in English)

Global and regional bioenergy potentials

Selected results from the studies on global and regional bioenergy supply potentials are described below (see also Smith et al., 2013; Creutzig et al., 2014; Berndes et al., 2012; Berndes, 2014a, b). Figure 1 shows estimates of the global technical bioenergy potential in 2050 by resource categories. Ranges were obtained from assessing a large number of studies based on a food/fiber first principle and various restrictions regarding resource limitations and environmental concerns but no explicit cost considerations. Many studies agree that the technical bioenergy potential in 2050 is at least approximately 100 EJ per year with some modeling assumptions leading to estimates exceeding 500 EJ per year. Different views about sustainability and socio-ecological constraints lead to very different estimates, with some studies reporting much lower figures.

In summary, the review by Creutzig et al. (2014) found: Sustainable technical potential as up to 100 EJ: high agreement; 100–300 EJ: medium agreement; above 300 EJ: low agreement. The wide range is both due to methodological differences and varying expectations about development for critical determinants, not the least dietary changes and agriculture productivity (especially meat and dairy production). There are also subjective choices in model implementations of "sustainability constraints" that can have a large influence on the outcome. One example of this, which is further discussed below, concerns greenhouse gas (GHG) balances associated with land use change (LUC) to make place for bioenergy. Studies that include as a sustainability constraint that GHG emissions caused by LUC for bioenergy should be kept at very low level naturally exclude larger areas from use compared to studies that set a higher LUC emission limit. Studies also add restrictions on land availability with reference to other aspects such as status of water resources and biodiversity. Also here, subjective choices and/or use of different databases cause large variations.

The share of bioenergy in the future energy mix depends not only on whether large volumes of biomass can be produced without causing unacceptable impacts, but also depends on the attractiveness of other energy options, both fossil and non-fossil, since this strongly influences demands for bioenergy. Figure 2 shows a magnitude comparison of biomass outputs in forestry and agriculture with prospective biomass demands for energy (see the figure caption for a more detailed description). Models indicate that, if technological and governance preconditions are met, large-scale deployment (>200 EJ), together with BECCS, could help to keep global warming below 2° degrees of preindustrial levels.

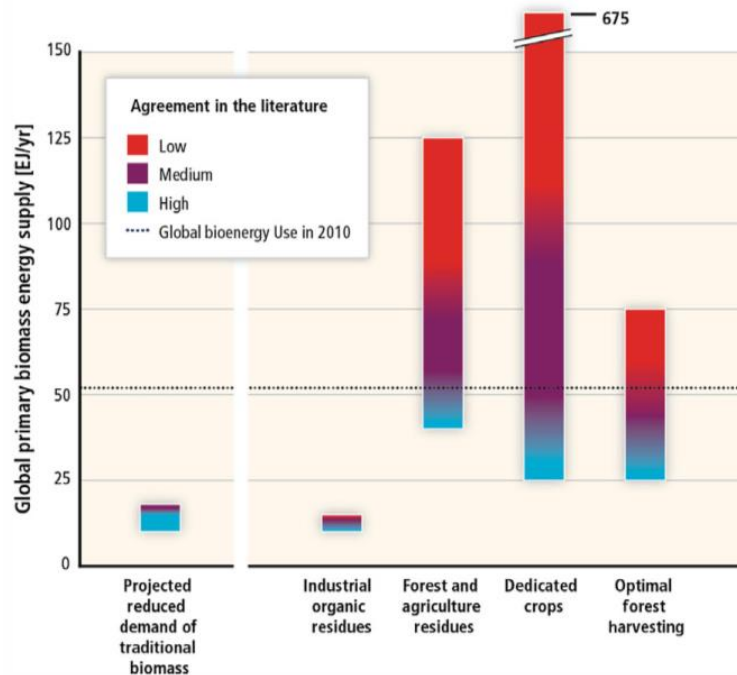


Figure 1. Estimates of the global technical bioenergy potential in 2050 by resource categories. Optimal forest harvesting represents the fraction of harvest levels (often set equal to net annual increment) in forests available for additional wood extraction if the projected harvest level resulting from the production of other forest products is taken into account considering both biomass suitable for other uses (e.g., pulp and paper production) and biomass that is not used commercially. Source: Creutzig et al. (2014).

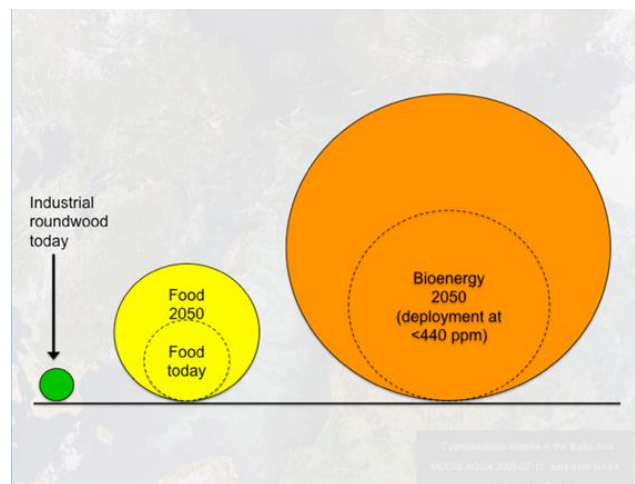


Figure 2. Comparison of the food and agriculture sectors with the prospective bioenergy sector. The energy content of today's global industrial roundwood production is about 15–20 EJ per year, and the global harvest of major crops (cereals, oil crops, sugar crops, roots, tubers and pulses) corresponds to about 60 EJ per year. The large orange circles show the range (25th and 75th percentiles) in biomass demand for energy, as given in a recent review by the IPCC of 164 long-term energy scenarios to meet concentration targets of <440 ppm CO₂eq (corresponding to 118– 190 EJ per year of primary biomass). Source: Berndes (2014a).

We conclude that the high variability in pathways, uncertainties in technological development and ambiguity in political decision render forecasts on biomass supply potentials, deployment levels and climate effects very difficult. It is also important to note that studies that assess biomass supply potentials far into the future have limited relevance to discussions of the present-day consequences of bioenergy expansion. Assessments that start from food/fibre-first principles and set limits on resource availability should not be understood as providing guarantees that a certain level of biomass can be supplied for energy purposes without competing with food or fibre production, or without resulting in impacts on soil, water, and other resources. These assessments quantify the bioenergy that could be produced in a certain future year based on using resources that are defined as being available and not required to meet food and fibre demands, given a specified development in the world or in a region. However, they do not investigate how bioenergy expansion towards such a future level of production would or should interact with food and fibre production or how it affects resources and the environment.

At the same time, studies of future bioenergy supply potentials help improve our understanding of availability and competing uses of various resources and how these can be optimized to meet multiple demands while reducing impacts. It has been proposed that biomass supply for energy should be restricted to a "safe" or "sustainable" level, implying that a sustainable bioenergy potential can be defined and quantified. However, the magnitude of the biomass resource potential depends on the priority assigned to bioenergy products over other products obtained from the land, notably food, fodder and materials such as sawn wood and paper, and on how much total biomass can be mobilised in agriculture and forestry. This in turn depends on natural factors and on how society understands and prioritises nature conservation and the protection of soils, water, and biodiversity in relation to the climate issue, as well as on how agronomical and forestry practices are shaped to reflect these priorities. Further, the notion of determining a sustainable level of bioenergy supply assumes that impact risks increases more or less linearly with the total level of biomass harvest for energy. But the consequences of bioenergy expansion are determined in large part by the deployment strategy and the environmental, socioeconomic, and institutional conditions (including considerations and adaptations) where the deployment takes place. Bioenergy production also interacts in complex ways with food and fibre production, which makes the assessment of bioenergy impacts challenging.

While supply-side mitigation measures, such as changes in land management, might either enhance or negatively impact food security, demand-side mitigation measures, such as reduced waste or demand for livestock products, should benefit both food security and greenhouse gas (GHG) mitigation. Demand-side measures offer a greater potential (1.5–15.6 Gt CO₂-eq. yr⁻¹) in meeting both challenges than do supply-side measures (1.5–4.3 Gt CO₂-eq. yr⁻¹ at carbon prices between 20 and 100 US\$ tCO₂-eq. yr⁻¹), but given the enormity of challenges, all options need to be considered. Supply-side measures should be implemented immediately, focusing on those that allow the production of more agricultural product per unit of input. For demand-side measures, given the difficulties in their implementation and lag in their effectiveness, policy should be introduced quickly, and should aim to co-deliver to other policy agenda, such as improving environmental quality or improving dietary health.

Influence of water resource management, irrigation and water use efficiency

While abundant water availability provides opportunities for biomass production in some regions, water scarcity in other regions is seriously restricting land use and demand for bioenergy may add to the growing pressure on water resources. Rainfed feedstock production does not require water extraction from groundwater, lakes and rivers, but it can still reduce downstream water availability by redirecting precipitation from runoff and groundwater recharge to crop evapotranspiration. Water scarcity has been identified a possibly major obstacle for bioenergy expansion, but it has also been recognized that bioenergy demand opens up new opportunities to adapt to water related challenges and to improve the productivity of water use (Berndes 2002, 2008; Service 2009). The net effect on the state of water depends on the character of land use and water management associated with the bioenergy systems put in place, compared to the previous management. The review of studies that quantify bioenergy supply potentials showed that it remains to make comprehensive analyses of how water resource availability and management - especially irrigation - influence future bioenergy supply potentials. Own studies were therefore made in collaboration together with Potsdam Institute for Climate Impact Research (PIK).

Figure 3 shows preliminary results of global modelling done with the global biogeochemical soil-vegetation model LPJmL (Jans et al., forthcoming) to inform how investments in water management, including irrigation, may influence conditions for bioenergy mobilization and agriculture production in general. The scenario illustrate how water availability and irrigation strategies can determine the biomass mobilization potential on lands presently not used for agriculture production (excluding forests, wetlands, protected lands and lands with severely degraded soils). As can be seen, the influence of irrigation patterns is large and crop choice further amplifies the variation between scenarios. While lignocellulosic short rotation woody plants show a higher response to irrigation input, the higher land and water productivity of herbaceous plants allow a much larger total biomass production. It should be noted that the numbers presented here do not reflect economic costs of expanding irrigation infrastructures and cultivating areas where infrastructure currently is limited. Yet, the results clearly show the large influence of water availability and management, aspects that have not received sufficient attention in previous studies of the prospects for bioenergy mobilization.

In a parallel assessment of the case of Brazil it was found that available water resources could support an expansion of irrigated systems boosting Brazilian production tremendously, since the area that is suitable for irrigation from physical and logistical points of view is more than four times the presently irrigated area (6 Mha). The low use of irrigation is price driven and price changes for agricultural products can result in increased use of irrigation in multiple cropping systems.

Complementary to global modelling as presented in Figure 3, investigations on local and smaller regional level show that biomass can be cultivated in plantings that offer benefits from the perspective of water (see, e.g., Berndes et al., 2015 and Dimitriou et al., 2011). For example, some plants can be cultivated as vegetation filters for treatment of nutrient bearing water (e.g., pre-treated wastewater from households and runoff from farmlands). Soil-covering plants and vegetation strips can also be located to limit water erosion, reduce evaporating surface runoff, trap sediment, enhance infiltration, and reduce the risks of shallow landslides. Furthermore, some plants that are suitable as feedstock for the biobased industry are also drought tolerant

and relatively water efficient. These crops can be grown in areas not suitable for conventional food and feed crops. Plants that are cultivated in multi-year rotations can also make better use of rain falling outside the growing season of the conventional crops. Thus, there exist opportunities for improving water productivity in agriculture and alleviate competition for water as well as pressure on other land use systems.

However, these opportunities need to be carefully assessed from a water balance perspective. For instance, the use of marginal areas with sparse vegetation for establishment of high-yielding bioenergy plantations may lead to substantial reductions in downstream water availability. This may become an unwelcome effect requiring management of trade-off between upstream benefits and downstream costs. Availability and competing uses of water resources can therefore critically influence the feasibility of cultivating grasslands and pastures and strategies for expanding bioenergy feedstock cultivation on such lands need to be integrated into wider basin level planning that account for also other water needs, including environmental flow requirements.

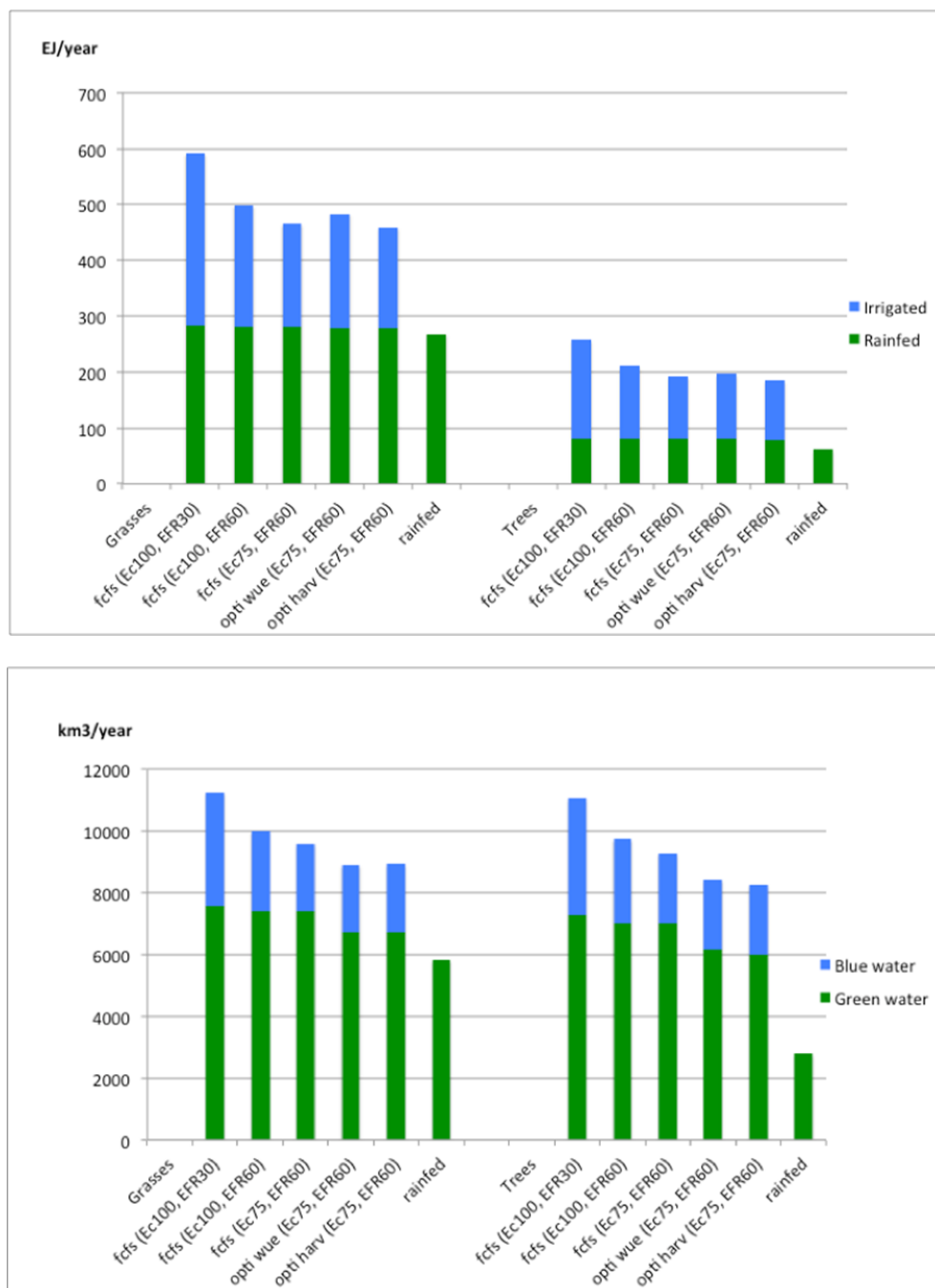


Figure 3. Primary energy potentials (top) and associated water consumption (bottom) when grasses and trees are cultivated under scenarios including varying efficiency with which water is conveyed from source of supply to the field (conveyance efficiency, EC: 75-100%), environmental flow requirements (EFR: 40-70% of available water used for irrigation), and irrigation schemes: "first-come, first-served" (fcfs) or basin-optimized irrigation for either highest yield per unit water (opti wue) or per unit area (opti harv). Blue water refers to water in rivers, lakes, wetlands and aquifers that can be withdrawn for irrigation and other human uses and green water represents soil moisture held in the unsaturated zone, which comes from precipitation and is available to plants.

Influence of climate policies that include LUC emissions

As stated above the overall objective of this project was to assess how sustainability requirements influence the prospects for bioenergy, especially how the possibilities in different regions to produce biomass and solid/liquid biofuels for the EU are influenced by sustainability requirements. Policies and regulations can also influence prospects for bioenergy indirectly and this project especially addressed the question how the pricing of carbon emission can have an influence when LUC emissions are included in a carbon pricing regime. Palm oil biodiesel production in Brazil was selected as a case study and both opportunities and risks were investigated for different energy, policy, and infrastructure scenarios.

Brazil is currently a minor producer of palm oil, but large areas are suitable for oil palm cultivation and Brazil has launched several initiatives that seek to promote and regulate expansion of oil palm, involving, e.g., technical assistance to farmers, agricultural and industrial incentives and credits, sustainability monitoring and evaluation, land titling, traditional people's protection, and social inclusion (Villela et al 2014). Although mainly used for other purposes, and historically mainly established at the expense of tropical forests, oil palm can be the most land efficient feedstock for biodiesel. Thus, if planted elsewhere than in forested areas, oil palm biodiesel can offer high GHG emissions reductions per unit area used - which naturally is attractive in a land-constrained world.

The result from the study is summarized below (see also Englund et al., 2015 and Englund et al., 2014). Large parts of Brazil have a high suitability for oil palm cultivation, and a series of policy initiatives have recently been launched to promote oil palm production. Spatially explicit calculations of the net present value of establishing new oil palm plantations for biodiesel production in Brazil were made for different energy, policy, and infrastructure scenarios. Corresponding biodiesel production volumes were calculated and land use change effects were analyzed, see Figure 4 and 5.

It was found that palm oil production for biodiesel could be profitable on very large areas, but the plantation establishment would displace native ecosystems and cause large land use change emissions in many places. However, 40-60 Mha of land could support profitable biodiesel production, corresponding to approximately 10% of the global diesel demand, without causing direct land use change emissions and without impinging on protected areas. Pricing of greenhouse gas emissions from land use change might make oil palm production unprofitable on the lands where conversion would bring the largest impacts on native ecosystems and ecosystem carbon stocks - provided that the carbon price becomes substantially higher than the present level on voluntary carbon markets.

Most of the land where oil palm could be planted without impinging on protected areas, and/or decreasing carbon stocks, is already under agriculture. The net GHG savings that can be obtained by planting on agricultural areas depend on whether such planting indirectly leads to LUC with high GHG emissions elsewhere. Establishing an effective LUC carbon pricing scheme with sufficiently high carbon prices, or other mechanisms for forest protection such as REDD+ is challenging. In the case of a LUC carbon pricing scheme, it would have to be applied for all agricultural activities, not just oil palm production, to avoid indirect LUC effects within Brazil. To avoid international leakage the carbon pricing scheme would have to be global.

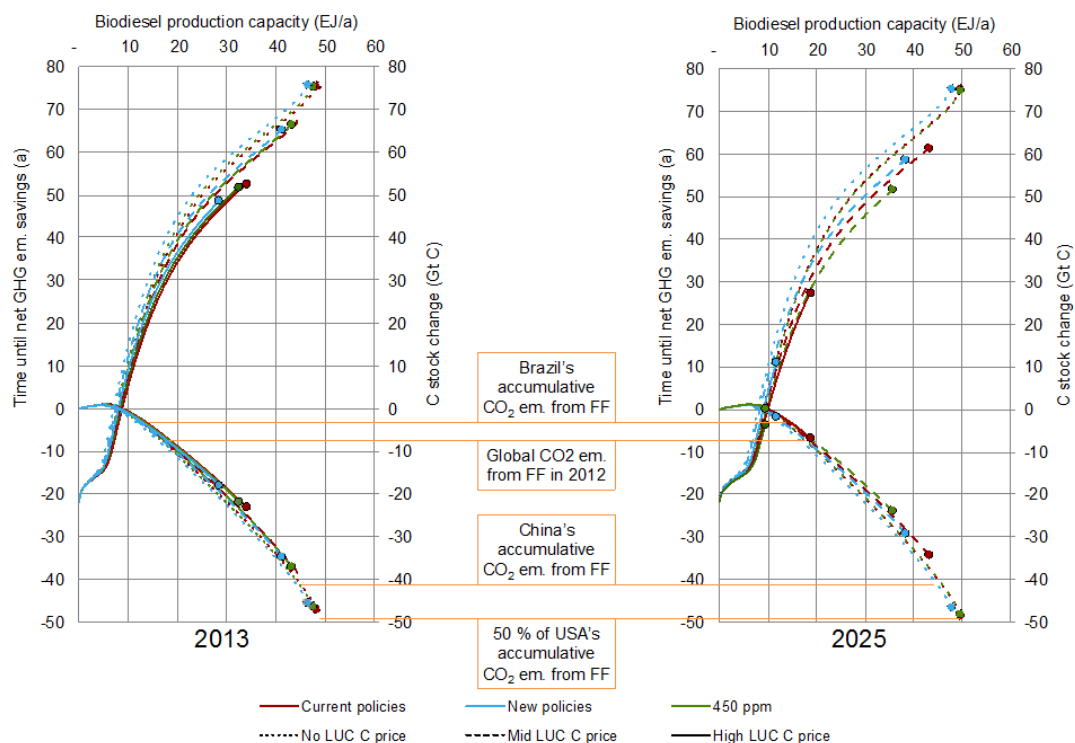


Figure 4. Biodiesel production capacity supported by oil palm (horizontal axis), corresponding effects of oil palm establishment on ecosystem C stocks (downward lines; right axis) and time it would take to achieve net GHG emissions savings from displacing petrodiesel (upward lines; left axis; calculated using 65% C savings), for the included scenarios. The lines end at the maximum biodiesel production capacity. The textboxes provide selected magnitude comparisons (FF = fossil fuels). Source: Englund et al. (2015).

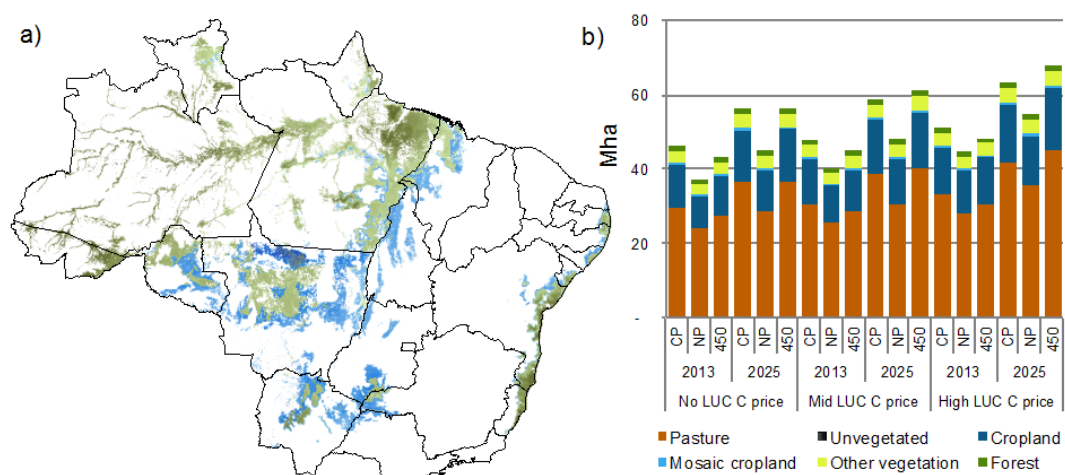


Figure 5. Areas where establishment of new oil palm plantations would (1) be profitable; (2) increase carbon stock; and (3) not impinge on land protected by law. a) shows the spatial distribution of this land in the scenario with the lowest potential (green) and highest (green+blue). Darker colours indicate higher yields; b) shows quantified results for all scenarios aggregated in six LULC classes. Source: Englund et al. (2015).

Impact of sustainability requirements

In the Renewable Energy Directive (RED, European Parliament, 2009) there are sustainability requirements regarding GHG emission saving related to the use of fossil fuels, biodiversity protection (specifically including highly biodiverse grasslands), land with high carbon stocks (specifically wetlands and forested areas), and peatland. In relation to sustainability criteria for solid biofuels requirements for sustainable forest management (SFM) are under discussion.

The influence of different sustainability requirements and implementation designs

Part of the collaboration with colleagues in the IEA Bioenergy network concerned a global stakeholder survey examining: (1) the multi-levelled governance to which they are subjected, (2) the impacts of that governance on bioenergy production and trade, and (3) the most urgent areas for improvement of certification schemes. There was significant support along the whole supply chain for new legislation which uses market based certification schemes to demonstrate compliance with sustainability requirements although some respondents did not see a need for new regulation. Most respondents had so far experienced positive or neutral changes to their bioenergy production or trade after the introduction of new sustainability governance. Legislative requirements and a green business profile were important motivations for getting certified, while lack of market advantages, administrative complexity and costs all were barriers of varying importance. Respondents noted the need to include, e.g., regular standard revision and dealing with conflicting criteria. Those associated with forestry schemes saw less need for revisions. Significant differences among schemes suggest that in order to maintain and increase the use of them it is crucial in the future to examine the tradeoffs between certification costs, schemes' inclusiveness, the quality of their substantive and procedural rules, and the subsequent effectiveness to consider different sustainability aspects on the ground.

The main conclusions from Pelkmans et al. (2014) addressing the role of sustainability requirements in international bioenergy markets include: (i) bioenergy markets would gain from harmonization and cross-compliance, (ii) a common language, including the same terminology and global/common definitions of the sustainability concept is needed as biomass sustainability involves different policy arenas and legal settings, (iii) policy pathways should be clear and predictable, and future revisions of sustainability requirements should be open and transparent, (iv) sustainability assurance systems (both binding regulations and voluntary certification) should take into account how markets work and not discriminate different end-uses and users and consider how investment decisions are taken, administrative requirement, and developing countries.

Selected results of the analyses related to the impact of sustainability requirements on the prerequisites for bioenergy are presented below (see also Englund and Berndes, 2015a; Englund and Berndes, 2015b; Englund and Berndes, 2014, Stupak et al., 2015, Hansson and Berndes, 2015). The presentation covers the following:

- consideration of biodiversity in different sustainability related standards,
- "quality of governance" in a broad selection of countries and implications for the roles of public and private governance in promoting sustainable bioenergy

- integration of ecosystem service concept into LCA
- impact of approaches to consider highly biodiverse grasslands in the EU-RED.

The influence of GHG emission reduction demands and the impact of related implementation issues related to GHG emissions demands is assessed in Hansson et al., 2015a and presented in the next section (since that study also relate to the project target on the impact on the Swedish bioenergy market).

How do Sustainability Standards Consider Biodiversity

While there is wide support for conserving biodiversity, operationalizing this support in the form of guiding principles, criteria/indicators, and legislation is complicated. This study investigates how and to what extent 26 sustainability standards (eleven for forest management, nine for agriculture and six biofuel-related) consider biodiversity, by assessing how they seek to prevent actions that can threaten biodiversity as well as how they support actions aimed at biodiversity conservation. For this purpose, a benchmark standard was developed, meant to represent a case with very high ambitions concerning biodiversity conservation.

Of the assessed standards, the biofuel-related standards demonstrated the highest level of compliance with the benchmark. On average, they complied with 72% of the benchmark's component criteria, compared to 61% for the agricultural standards and 60% for the forestry standards (see Table 1). Fairtrade, Sustainable Agriculture Network/Rainforest Alliance (SAN/RA), Roundtable on Sustainable Palm Oil (RSPO), and Roundtable on Responsible Soy (RTRS) were particularly stringent, while Green Gold Label S5 (GGLS5), PEOLG, Global Partnership for Good Agricultural Practices (GLOBALGAP), European Union Organic (EU Organic), National Organic Program (NOP), Green Gold Label S2 (GGLS2), and International Sustainability & Carbon Certification (ISCC) were particularly unstringent. All eleven forestry standards, six of the nine agricultural standards, and all six biofuel-related standards addressed ecosystem conversion, ranging from requiring that high conservation value areas be identified and preserved to requiring full protection. Finally, key barriers to, and challenges for, certification schemes are also discussed in the paper and recommendations are made for further development of sustainability standards.

Table 1. Compliance with Benchmark Principles for forestry standards (Table 6), agricultural standards (Table 8) and biofuel related standards (Table 10). Source: Englund and Berndes (2015a).**TABLE 6** | Forestry Standards: Compliance with Benchmark Principles

Principles	FSC	SFI	FFCS	MTCS	CSA-SFM	GGLS5	Naturland	ITTO	ATO/ITTO	ITTO/IUCN	PEOLG
1. Endangered species	+/-	+	+	+	+/-	+/-	+	+	+/-	+	+/-
2. Habitat destruction and fragmentation	+	+/-	+	+	+	+/-	+	+	+	+	+/-
3. Habitat degradation and modification	+/-	+	+/-	+/-	-	-	+	+/-	+/-	+/-	-
4. Overexploitation	+	+/-	+	+	+	+	+	+	+	+	+/-
5. Invasive species and GMOs	+	+/-	+/-	+/-	+	-	+	-	+/-	+/-	-
6. Energy use and GHG	+/-	+/-	-	+/-	+/-	+/-	+	+/-	+/-	-	+/-
7. Research, awareness, and education	+/-	+	+/-	+/-	+/-	-	-	-	+/-	+	+

ATO/ITTO, African Timber Organization and International Tropical Timber Organization; CSA-SFM, Canadian Standards Association and Sustainable Forest Management; FSC, Forest Stewardship Council; FFCS, Finnish Forest Certification System; GGLS5, Green Gold Label; GHG, xxx; GMO, xxx; ITTO, International Tropical Timber Organization; MTCS, Malaysian Timber Certification System; PEOLG, xxx; SFI, Sustainable Forestry Initiative. Green color (+) indicates considered; yellow color (+/-) indicates partly considered; orange color (-) indicates disregarded.

TABLE 8 | Agricultural Standards: Compliance with Benchmark Principles

Principles	GLOBALGAP	KRAV	EU Organic	NOP	GGLS2	Fairtrade	Naturland	IFOAM	SAN/RA
1. Endangered species	-	+	-	-	-	+	+/-	-	+/-
2. Habitat destruction and fragmentation	+/-	+/-	+/-	+/-	-	+	+	+	+
3. Habitat degradation and modification	+/-	+	+/-	+	+	+	+	+	+
4. Overexploitation	+	+	+	+	+/-	+	+	+	+
5. Invasive species and GMOs	-	+/-	+/-	-	-	+/-	+/-	+/-	+/-
6. Energy use and GHG	+/-	+	-	-	-	+/-	+/-	+/-	+
7. Research, awareness, and education	+/-	-	-	-	+/-	+	+/-	-	+

EU Organic, European Union Organic; GLOBALGAP, Global Partnership for Good Agricultural Practices; GGLS2, Green Gold Label S2; GHG, xxx; GMO, xxx; IFOAM, International Federation of Organic Agriculture Movements; KRAV, xxx; NOP, National Organic Program; SAN/RA, Sustainable Agriculture Network/Rainforest Alliance. Green color (+) indicates considered; yellow color (+/-) indicates partly considered; orange color (-) indicates disregarded.

TABLE 10 | Biofuel-Related Standards: Compliance with Benchmark Principles

Principles	RSPO	RTRS	Bonsucro	RSB	ISCC	Greenenergy
1. Endangered species	+	+	+	+/-	-	+
2. Habitat destruction and fragmentation	+	+	+	+	+/-	+/-
3. Habitat degradation and modification	+	+	+	+	+	+
4. Overexploitation	+	+	+/-	+	+/-	+
5. Invasive species and GMOs	+/-	+/-	+/-	+/-	-	+/-
6. Energy use and GHG	+	+	+/-	+/-	+/-	+/-
7. Research, awareness, and education	+/-	+/-	+/-	-	+/-	+/-

GHG, xxx; GMO, xxx; ISCC, International Sustainability & Carbon Certification; RSPO, Roundtable on Sustainable Palm Oil; RTRS, Roundtable on Responsible Soy; RSB, Roundtable on Sustainable Biofuels. Green color (+) indicates considered; yellow color (+/-) indicates partly considered; orange color (-) indicates disregarded.

Quality of governance and the roles of public and private governance in promoting sustainable bioenergy

Public sustainability governance of biomass and bioenergy (referred to as public governance), is framed by national legislation. Since the comprehensiveness of national legislation varies, production of biomass and bioenergy is governed differently in different countries. In order for public governance to be effective in promoting sustainable production of biomass and bioenergy, the legislation needs to be sufficiently comprehensive, but also sufficiently enforced. In many countries, insufficient enforcement capacity makes legislation ineffective, regardless of its comprehensiveness.

Public sustainability governance may be effective in promoting sustainable biomass production in large parts of Western Europe, Canada, USA, Australia, New Zealand, Chile, Japan, and South Korea (see Figure 6). However, in many countries, public sustainability governance does not suffice due to challenges with both legislation and enforcement. Most countries, primarily in Africa and Asia, face a “double” legal challenge, in developing more comprehensive legislation as well as a sufficient enforcement capacity, while a few countries face challenges with only one of the two. It appears that domestic private sustainability governance¹ can rarely fill a role in countries with legal challenges, due to low domestic consumer demand for products meeting certain sustainability requirements. However, results indicate that international private sustainability governance² can have a role in most countries in the world, and can therefore contribute to the development of sustainable bioenergy supply chains.

This especially when considering concerns about GHG emissions, air quality, and conversion of wetlands and grasslands, which often have a low legal coverage in national legislation. However, public governance cannot be fully substituted by private governance. Countries need to address both legal and institutional challenges associated with the public governance, which will always be essential in the promotion of sustainable bioenergy. Finally, there is a need for coordination both within and between different governance forms. If well-coordinated, actors engaged in bioenergy and sustainable development may constitute an effective governance of bioenergy supply chains.

¹ Domestic private sustainability governance, i.e., where non-governmental institutions govern activities within a nation's economy on the basis of sustainability principles, emerges when domestic consumers demand other types of sustainably produced products than those promoted by public governance, or that products meet different sustainability requirements than those associated with the public governance system. Producers will then provide the products that are not made available through the public governance system by, for instance, adopting codes of conduct and corporate social responsibility schemes meeting the consumer demands. In the case of biomass, producers mainly rely on voluntary sustainability certification as a means for verifying and communicating to consumers that products are produced in accordance with certain sustainability principles. These principles are defined in a certification standard using criteria and indicators formulated by governmental or non-governmental organizations, and/or private companies, and monitored and verified through third party independent auditing. In order for domestic private governance to be effective in promoting sustainable production of biomass and bioenergy, the domestic demand for sustainable products must be sufficiently high; without a sizeable market for certified products there is little chance that actors will show an interest in adapting their practices to reach compliance.

² International private sustainability governance, i.e., where non-governmental institutions govern activities that transcends across nations, emerges when there is an international demand for sustainable products. This demand can be either consumer-driven, or policy driven. Consumer driven international private governance emerges, as for domestic private governance, when consumers demand other types of sustainably produced products than those promoted by public governance in the producing country, or that products meet different sustainability requirements than those associated with the public governance system. Producers will then respond by providing, e.g., certified products for an international market. Policy-driven international private sustainability governance can play a role in countries where there are producers that target export markets, which are created by policies and associated with sustainability requirements.

Regarding the coverage of national legislation, the results indicate that there may be an overlap between EU RED requirements and national legislation considering *clearing of forests*, *impacts on threatened species*, and *impacts on protected areas*. On the other hand, *conversion of wetlands* and, most notably, *drainage of peatlands* and *conversion of grasslands*, appears seldom restricted by law and complementary forms of governance may be required to regulate these activities. On a more general level, there may be overlaps between national legislation and alternative forms of governance considering requirements related to *social sustainability* and *land use*, and, to a lesser extent, *water*, *soil* and *biodiversity*. Requirements related to *ecosystem services*, *carbon stock*, *air*, and, most notably, *GHG emissions*, are however less likely to exist in national legislation, and complementary forms of governance may thus be required if these concerns are to be taken into account.

The low coverage of *drainage of peatlands*, *carbon stock*, and *GHG emissions* may be explained by that developing countries until now rarely have considered GHG emissions in their legislation. Conversely, high priority for safeguarding of subsistence and basic human needs in national legislation may explain that *Social sustainability*, *land use*, and *water* were all well covered. The fact that protected areas and forests are relatively well considered in legislation may be explained by forests' cultural value or a long history of national/international concerns about deforestation. It is difficult to explain why air quality is not more considered in legislation, since it is a serious problem in many countries.

Sustainability concerns can differ among countries. For example, there may be contrasting views on whether conversion of grasslands is an attractive route for agriculture expansion that avoids deforestation or an issue of concern in itself. Such diverging views may pose a barrier for implementation of international private governance since there may even exist counteracting national incentives.

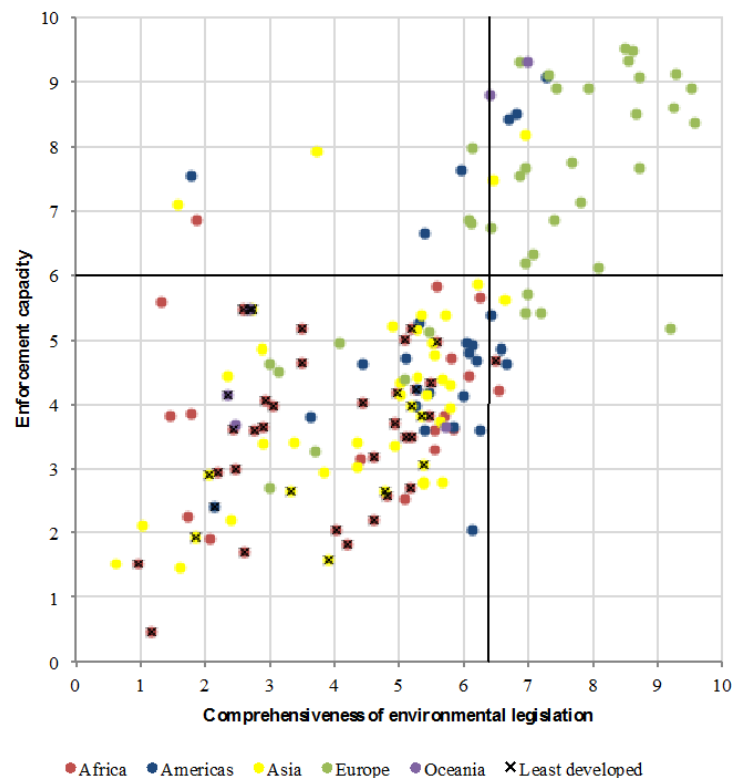


Figure 6. Estimated (i) enforcement capacity, and (ii) comprehensiveness of environmental legislation, for the countries included in the assessment. Source: Englund and Berndes (2015b).

Integration of ecosystem service concept into LCA

Ecosystem services can be classified into four categories: i) provisioning services (e.g. food and fuel supply), ii) regulating services (e.g. climate and freshwater regulation, and carbon sequestration), iii) supporting services (primary production, and habitat provision), and iv) cultural services (e.g. recreation, and health) (MEA, 2005). An analysis of the possibilities to integrate the ecosystem service concept and LCA methodology found that a large number of ecosystem services such as climate regulation, nutrient cycling, biodiversity and recreation, only partly covered by existing sustainability criteria, can be influenced by pellet or other biofuel production (see Nordin, 2014). But it is not possible to currently fully analyse these impacts with LCA. The possibilities to analyse ecosystem services within LCA vary due to the variation in definitions of and available information about the services. More research is needed to develop the approaches for analysing impacts on ecosystem services related to for example biomass and biofuels through LCA.

Approaches to consider highly biodiverse grasslands in the EU-RED

As summarized above, Englund et al. (2015) found that new oil palm plantations could be profitable on large pasture/grassland areas in Brazil while increasing carbon stock, and not impinging on land protected by law (see Figure 5). Linked to this, an initial assessment was made of how definition and handling of "highly biodiverse grasslands" might influence the potential contribution of bioenergy from global grasslands. It was investigated how highly

biodiverse areas and grasslands have been taken into account in estimates of the global biomass supply potential for energy. The consideration of grasslands from a biodiversity protection perspective in selected countries was also assessed.

Most of the reviewed biomass supply estimates use approaches where currently protected areas are excluded and it is common to also exclude additional land based on the assumption that additional areas will become protected in the future. However, hardly any studies allow for a quantification and comparison of how consideration to highly biodiverse grasslands influences the biomass supply potential. One notable exception, Böttcher et al (2013) report that 8.1% of global grasslands and 5.2% of natural vegetation are considered highly biodiverse. Thus, studies of biomass supply potentials commonly exclude biodiverse grasslands as no-go areas based on different nature protection priority schemes.

Studies that discuss biodiversity protection strategies in general commonly use more refined approaches than those only addressing the objective to guarantee that biofuels on the EU market do not come from lands previously supporting high biodiversity values. However, there is no globally established approach to assess and quantify grassland availability for bioenergy from a biodiversity protection perspective. Few national approaches for handling highly biodiverse grasslands have been identified so far. Thus, the supply potential associated to biodiverse grasslands whose preservation requires specific management with biomass extraction is little investigated. To conclude, the lack of definitions and guidance in relation to the RED leads to arbitrariness and uncertainty about prospects for biofuels from grasslands. Further analysis is needed in this area.

Potential influence of sustainability criteria on the Swedish bioenergy market

Our review of recent research addressing how the bioenergy market can be influenced by sustainability requirements (see Hansson et al., 2015b) revealed very high agreement that the introduction of sustainability requirements will affect the global bioenergy market. There might be an increased competition for biofuels due to the reduced supply potential and potentially increased demand for imports from e.g., the EU MS. National or industrial sustainability requirements might change the demand for certain pellet chains, potentially improving the prerequisites for the pellet chains fulfilling the requirements. If sustainability requirements prevent the use of conventional crops the demand for forest based biofuels will likely increase, even if also woody crops are affected. How the bioenergy market will be affected by sustainability criteria seem to depend on the actual criteria and their implementation.

According to Schueler et al., (2013) sustainability criteria for solid biomass in conformity with the RED criteria may influence the feedstocks and volumes available to pellet producers both in the EU or those aiming to export to the EU. It is indicated that the RED sustainability criteria affect roughly 90% of an estimated theoretical global biomass potential (agricultural and forestry residues and aquatic biomass are not included) (Schueler et al., 2013). The corresponding value for the studied world regions are above 80% with the exception of China at about 75% and Middle East about 0%. On a global level it is also indicated that the GHG emission saving restrictions in the RED concerns the largest share of the estimated theoretical biomass supply potential (about 70%), followed by the biodiversity considerations (about 60%), the forest restriction (about 50%) and the wetland and peat land considerations (about 10%). On a regional level it is further indicated that the GHG emission saving restrictions concerns the

largest share of the biomass supply potential in all regions except Latin America and Transition economies where biodiversity concerns the largest share (in Latin America closely followed by the GHG consideration). According to Schueler et al. (2013), roughly 100 EJ of biomass occurs in areas free of sustainability concerns, which is in line with the findings in our analysis presented in Creutzig et al., 2015. Schueler et al., (2013) does not specifically restrict or analyse the use of natural highly biodiverse grasslands.

Regarding GHG emissions Schueler et al., (2013) focus on the impact that emission saving thresholds can have on the theoretical biomass potential but do not consider the full production pathway as specified in the RED. Our analysis focus on the GHG emissions related to the full production pathway and is thus complementary to the analysis by Schueler et al., (2013). As already mentioned the impact of implementation issues related to GHG emissions demands is described in the next section.

As another outlook, Matzenberg et al., (2015) compare the results for future global bioenergy trade between world regions for a few selected energy systems and forest models and find that in ambitious scenarios bioenergy trade increase considerable (corresponding to about 14–26% of global bioenergy demand). It is indicated by Matzenberg et al., (2015) that current global models seem to over-estimate the amounts of biomass that can be traded especially in the medium term (2030) due to the associated challenges for biomass production and logistic chains. The reviewed scenarios do not include any specific sustainability criteria.

In Lloyd et al. (2014) we evaluate estimates of the amount of biomass available for bioenergy production in British Columbia and quantify the effects of the mountain pine beetle infestation on wood pellet feedstock supply chains. The results, though subject to significant uncertainties, suggest that mountain pine beetle-killed wood is unlikely to be a substantial constituent of wood pellet feedstocks unless substantial subsidies are provided to offset higher harvesting costs. Even if such subsidies are implemented, it is likely that harvest residues will constitute an increasing proportion of wood pellet feedstocks as the volume of beetle-killed wood becomes depleted. Therefore, it is imperative that wood pellet producers improve the cost efficiency of harvest residue collection if they are to remain competitive in the European marketplace.

The results of the analyses focusing on the Swedish bioenergy market (Hansson et al., 2014, Hansson et al., 2015a and Hansson et al., 2015b) is summarised below.

The analysis contains an assessment of the GHG emissions for heat and electricity from selected wood pellet value chains for the Swedish market and the associated potential emissions reduction in relation to fossil fuels using a life cycle assessment (LCA) perspective, and in relation to the approach described in recent EU policy developments. Nine different wood pellet value chains for heat and/or power production in Sweden are assessed (including pellets from Sweden, Latvia, Russia, and Canada). A sensitivity analysis was performed concerning the following aspects: (i) the allocation method, (ii) the GHG emissions for the fossil fuel comparator, (iii) the GHG emissions for natural gas used for drying, (iv) assumptions regarding sea transport, (v) the conversion efficiency in the CHP plant, and (vi) origin for electricity used for pellets production. Thus, assessing the impact of several aspects related to the actual implementation and design of sustainability criteria.

The total factory-gate GHG emissions at the conversion facility for the studied wood pellet value chains range between 2 and 25 g CO₂-eq/MJ pellets, with Swedish pellets at the lower end and Russian pellets using natural gas for drying the raw material at the higher end. Imported pellets

from Latvia, Russia, and Canada that use biomass for drying may also reach relatively low levels of GHG emissions. The potential GHG reduction as compared to a certain fossil fuel default energy comparator is 64–98% for the electricity produced in the pellet value chains studied and 77–99% for the heat produced (see Figure 7). The analysis concludes that many wood pellet value chains on the Swedish market will most likely be able to meet strict demands for sustainability from a GHG perspective. The sensitivity analysis indicate that (i) the choice of fossil fuel comparator (ii) the size and performance data for combined heat and power plans and (iii) assumptions related to electricity production mix may have a significant impact on GHG emissions and potential emissions reduction in relation to fossil fuels. Also the allocation method may have some influence on the result.

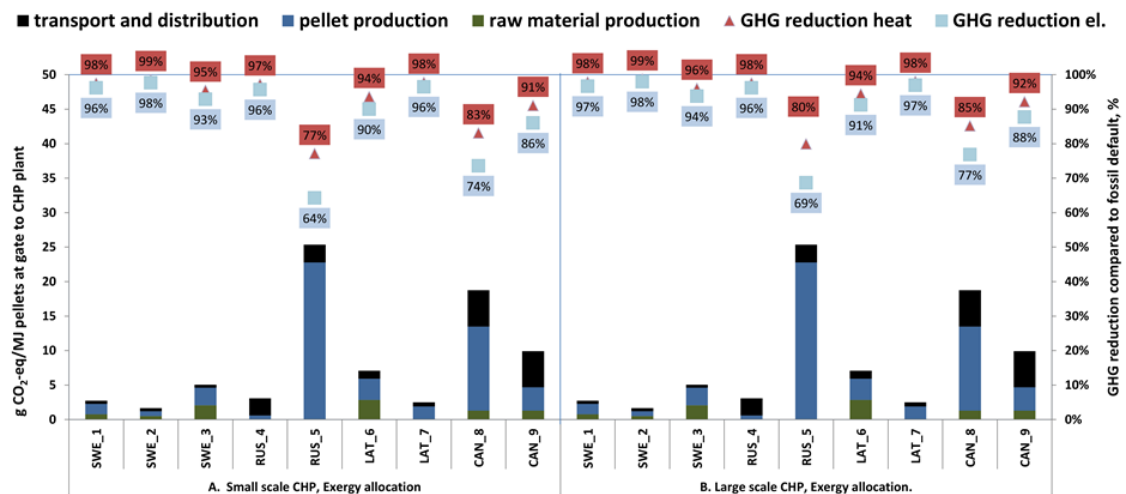


Figure 7. Estimated total GHG emissions (g CO₂-equivalent per MJ of pellets, left axis) for the pellet value chains studied producing heat and electricity in a small and large-scale CHP plant (denoted A and B relatively) as well as the estimated associated GHG emission reduction as compared to a default fossil energy source in percentages (for electricity and heat respectively, right axis). The red triangles indicate the GHG emission reduction for the heat produced and the blue rectangles indicate the GHG emission reduction for the electricity produced when compared to average EU fossil electricity. Source: Hansson et al (2015a).

A follow-up study was made to assess how the future Swedish pellets market could be influenced by the introduction of sustainability criteria for solid biofuels. The focus is on requirements for GHG emissions reduction and sustainable forest management (implemented jointly or by nations/industries). The study identifies the current and future expected main countries for producing and using pellets from forest biomass and assesses the GHG emissions for heat and electricity generation from selected wood pellet value chains potentially available on the Swedish market, specifically assessing the impact of torrefaction. The identified producer countries are also characterized in terms of current sustainable forest management and capacity to enforce legislation. The study represents an impact assessment of the recent policy development in the EU regarding sustainability criteria for solid biomass/biofuels that is complementary to for example Giuntoli et al. (2014), primarily by adding an assessment of the impact of torrefaction but also by including the perspective of sustainable forest management.

Eight different wood pellet value chains for heat and/or power production in Sweden are assessed. Swedish wood pellet value chains based on logging residues and alternative feedstock (willow wood chips) are included and torrefaction is assumed in the case of logging residues. Logging residues in western Canada are assumed to be converted into regular and torrefied wood pellets respectively. In order to further assess the importance of transport distance, two supply chains from western Australia - regular and torrefied wood pellets based on eucalyptus roundwood - are included.

The total factory-gate GHG emissions at the conversion facility for the wood pellet value chains studied are about 5- 10 g CO₂-eq/MJ for Swedish pellets (willow chips at the higher end), about 13 g CO₂-eq/MJ for Canadian pellets and about 27 g CO₂-eq/MJ for Australian pellets (see Figure VV). The potential GHG reductions as compared to a specific default fossil energy comparator for the electricity produced are 66-94% for the pellet value chains studied and 79-96% for the produced heat (see Figure 8).

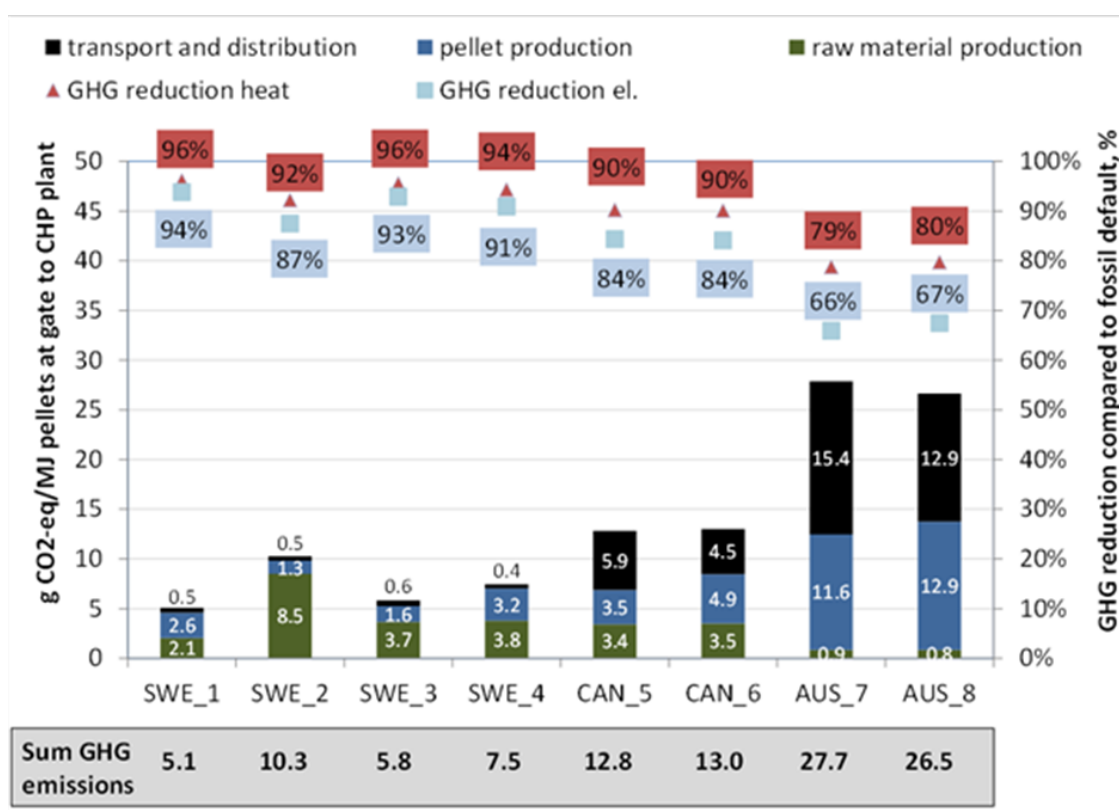


Figure 8. Estimated total GHG emission (g CO₂-eq/MJ pellets, left axis) and GHG emissions from the different productions steps of the studied pellet value chains. The estimated associated GHG emissions reduction compared to a reference fossil fuel energy comparator for the produced heat and electricity are given as well (right axis). Large-scale CHP is assumed as final use. The sum of GHG emissions of the pellet value chains is shown below the cases in g CO₂-eq/MJ pellets.

It is indicated that Swedish pellets produced from alternative feedstock (willow) has considerable higher GHG emissions than traditional Swedish pellets. This is largely caused by soil emissions of nitrous oxide (N₂O) due to fertiliser application and organic matter decomposition in willow cultivation. It should be noted that results may be very different

depending on methodology (including parameter assumptions) for quantifying carbon emissions associated with land use and land use change (see, e.g., Berndes et al. 2013 and Cintas et al., 2015). This pellet value chains has the potential to have lower GHG emissions than pellets import chains with long-distance transport (Canada). Regarding the impact of torrefaction it is indicated in the cases including pellets from Canada that the higher GHG emissions in the raw material collection and pellet production process in the torrefaction case are compensated by the lower transport emissions.

The result shows that all the studied pellet value chains meet a demand for 60% GHG saving for both heat and electricity production when compared to a specific default fossil energy comparator. All the studied pellet value chains except the Australian based cases meet a corresponding demand at 70%. Giuntoli et al., 2014 report GHG savings for solid biomass pathways generally above 60% for both the produced power and heat and some pathways that achieve savings above 70%. The higher potential GHG saving (and lower overall GHG emissions) in our assessment depend on the use of more actual cases and the focus on CHP compared to stand alone heat and electricity production.

Requirements for sustainable forest management (SFM) in EU sustainability criteria for solid biofuels are under discussion. For example, in European Commission (2013) it is stated that forest based biomass should come from sustainably managed forests in line with international principles and criteria. The characterization of potential producer countries in terms of current sustainable forest management and capacity to enforce legislation is shown in Table 2. Of the potential future wood pellet producers it is indicated that Ukraine, Russia, Mocambique and to some extent also Brazil might have problems to enforce legislation related to sustainability requirements on a national level.

Table 2. Classification of selected potential significant future pellets producing countries according to Global Forest Registry (2015). Legality includes legality and enforcement of laws related to forestry, illegal harvesting, and level of corruption related to forestry. Traditional and civil (T&C) rights includes social aspects such as child labor, right at work, use rights, cultural interests and status of timber exports. High conservation value forest (HCVF) includes effective protected areas and enforcement of legislation for HCVF. Conversion refers to conversion of natural forests and other naturally wooded ecosystems to plantations or non-forest use. GMO concerns the use of GMO trees and related restrictions. A plus sign indicate low risk and conformation to FSC standard and minus sign indicate "unspecified" risk and non-conformation.

Country	Sustainable forest management aspects					Forest area (Mha)	Share of certified forest area	Rule of law index (0-1)	Enforcement index (0-10)
	Legality	T&C rights	HCVF	Conversion	GMO				
Australia	+	+	-	-	+	149	7%	0.8	8.5
Baltic states	+	+	+	+	+	7	57%	0.76 (Estonia)	6.9 (Lithuania)
Brazil	-	-	-	-	+	520	2%	0.54	6.4
Canada	+	+	-	+	+	310	60%	0.78	8.2
Mozambique	-	-	-	+	+	27	1%	-	4.6
Russia	-	-	-	+	+	809	5%	0.45	4.5
Sweden	+	+	-	+	+	23	53%	0.85	9.3
Ukraine	-	-	-	-	+	9	14%	0.47	4.9
USA	-	+	-	-	+	304	16%	0.71	8.0

Swedish pellet producers are well-suited to meet demands for pellets with low associated GHG emissions that also meet expectations concerning social and environmental effects. It has been indicated that Swedish pellets chains meet the demand for GHG savings in the national systems for sustainability criteria in the UK, Belgium and the Netherlands. Thus, these current national systems will not likely come in the way of Swedish pellet exports to these countries

In general it seems like the level of GHG emission reduction as compared to a fossil energy comparator will have to be higher than the proposed 60-70% to affect the market as the pellet production chains studied here typically would meet this demand with the exception of pellets imported from Australia (very long-distance). Thus, many wood pellet value chains potentially occurring on the Swedish market will most likely be able to meet stringent sustainability requirements from a GHG perspective and the impact of near term GHG emission reduction demands on the Swedish pellets market seem limited. However, the real impacts will depend on levels of ambition as well as the methodologies and systems boundaries applied in the system implemented. And it is indicated that there are pellet value chains (Australian based) that might not be eligible for the EU market.

A potential restriction of the use of primary forest i.e., roundwood for pellets production could also influence the global as well as the Swedish pellet market since it affects potential export from e.g., the USA and Canada. To what extent depends on the definition of primary forest. According to Lamers et al (2014) such a restriction could reduce the pellets import to EU substantially. If roundwood use in general is defined as non-eligible feedstock in some countries, also some pellet exports from Sweden might be affected.

It is in general important how the calculation rules for different aspects related to GHG emission for the bioenergy chains are formulated in sustainability systems. A second example is the use of electricity: should national or regional emission factors be used and which system boundaries should be used? The GHG emissions per kWh could represent nationally produced electricity (electricity production mix) or consider the import of electricity from other countries with lower or higher average GHG emissions values (electricity consumption mix).

As for the GHG reduction demand for liquid biofuels (European Parliament, 2009) a future GHG emission reduction demand for solid biofuels might be stricter. However, the analysis indicates that all the studied pellet value chains except for the Australian cases have the potential to meet also considerable stricter demand for GHG emission reduction for solid biofuels.

Due to the level of certified forest areas, it seems unlikely that demand for SFM related to solid biofuels will have a significant or long lasting effect on the market for Swedish pellets. For most of the Swedish forest owners, the practical differences between their current management and management according to FSC or PEFC are considered to be small. However, an important factor is how well the legislation related to sustainability criteria is likely to be enforced in different countries. Enforcement of legislation seems to be a challenge in many of the potential pellet producing countries outside Europe and North America. This indicates that it might be difficult to implement and to prove the fulfilment of sustainability requirements and sustainable forest management demands in some countries. As argued in Englund and Berndes (2014) absence of good governance can represent a considerable business risk to actors operating in the bioenergy sector in import countries. For Sweden this could imply that the supply to the EU

market is somewhat limited which might increase the competition and the demand for Swedish biofuels.

In summary, sustainability requirements will probably not influence the Swedish pellet market in the sense that Swedish pellet exports will go down due to non-compliance with sustainability requirements. However, if some other large export countries face challenges meeting sustainability requirements in important import countries (e.g., UK, Belgium and the Netherlands), Swedish exports to such countries may grow to compensate for lower supply from other export countries. This could increase pellet prices in Sweden. Conversely, progressing build-up of pellet production capacity in some large export countries may in the future support an increased pellet export to Sweden since other planned export markets cannot be targeted due to certain sustainability requirements. This could press down pellet prices in Sweden.

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- World Bioenergy 2014, Jönköping Sweden 3-5 June,
- 23rd European Biomass Conference and Exhibition, 1-4 June, 2015, Wien, Austria.

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UNIVERSITY OF TECHNOLOGY



IVL Svenska Miljöinstitutet AB, Box 210 60,100 31 Stockholm
Tel: 08-598 563 00 Fax: 08-598 563 90
www.ivl.se