Ea Energy Analyses

Analysis of biomass prices

FUTURE DANISH PRICES FOR STRAW, WOOD CHIPS AND WOOD PELLETS “FINAL REPORT”

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1 Resume på dansk

Denne rapport er udarbejdet af Ea Energianalyse for Energistyrelsen som baggrundsmateriale for udarbejdelse af langsigtede fremskrivninger af brændselspriser til brug for samfundsøkonomiske analyser.

Der er udarbejdet prisfremskrivninger for fast biomasse (træpiller, træflis og halm) for perioden 2013 – 2050 med særligt fokus på perioden frem til 2035. Priserne angivet i denne rapport skal fortolkes som CIF-priser ved en dansk havn opgjort som faste priser (i 2012 EUR/GJ).

Der er ikke tale om egentlige prisprognoser, men prisfremskrivninger. Hermed menes mulige prisforløb forudsat en række antagelser og forudsætninger.

Forudsætninger og metodisk tilgang

Prisfremskrivningerne er for det første baseret på en antagelse af en regional og global efterspørgsel på biomasse til energiformål som den er beskrevet I 'New Policy' scenariet I IEA's World Energy Outlook 2012 publikation. Denne efterspørgselsstruktur for 2020 og 2035 er fremskrevet til at fortsætte frem mod 2050.

For det andet forudsættes Danmark at være 'pristager' på det globale marked for fast biomasse. Med pristager menes, at ændringer i den danske efterspørgsel ikke påvirker de globale priser. Denne antagelse er begrundet i Danmarks relativt lave efterspørgselsvolumen set i global skala.

For det tredje forudsættes det, at der dannes et effektivt marked for global handel med fast biomasse i fremtiden.

De konkrete prisfremskrivninger hindeholder følgende hovedelementer:

1) Der simuleres en række langsigtede scenarier ved anvendelse af 'Global Change Assessment Model' (GCAM). Modellen beregner en balancepris i beregningsårene, ved i princippet at optimere det globale langsigtede udbud og efterspørgsel på biomasse. Modellen indeholder en global database over arealanvendelse, og fremskriver udviklingen i det globale landbrug, skovbrug, marginaljorde, konverteringsteknologier samt efterspørgsel efter skovprodukter, energi, fødevarer foder etc.
2) Der udvælges herefter det scenarie, som på efterspørgselssiden bedst muligt kan sammenlignes med New Energy Policy scenariet i World

Energy Outlook 2012. Scenarieoutput er i form af én samlet prisudvikling på et simuleret globalt marked for en rå ubehandlede biomasseressource. Denne pris skal tolkes som ab skov.

3) Herefter efterberegnes output for at emulere en CIF Danmark pris, under antagelse om at Danmark er importland. Efterbehandling er i form af tillæg for bearbejdning, samt lokal og international transport. Dette er bl.a. under antagelse om hvilke områder der i fremtiden vil fungere som eksportlande til Danmark.

Ovennævnte modellering er under antagelse om, at den langsigtede ligevægtspris er omkostningsbestemt, hvilket ventes at gælde for træflis og træpiller. For halm anvendes derimod den antagelse, at halm til energiformål er et mere besværligt brændsel end flis, og på den baggrund kan prissættes med udgangspunkt i flisprisen. Baseret på historiske priser er det antaget, at halm til energiformål i Danmark altid prissættes ca. 10 % under træflis, målt efter energiindhold.

Baggrunden for valget af GCAM er, at denne model regnes som en af de førende integrerede analysemodeller (’Integrated Assessment Models’ - IAM’s) brugt til økonomiske, teknologiske og samfundsmæssige analyser af den globale arealanvendelse. GCAM blev lanceret i 1975 under navnet MiniCam (Mini Climate Assessment Model) og er siden blevet brugt i bl.a. IPPC’s arbejde.

Usikkerheder

I en langsigtet prisfremskrivning er der naturligvis betydelige usikkerheder i valg af forudsætninger og antagelser. Nogle af de vigtigste usikkerheder forbundet med dette studie er fremhævet nedenfor.

Varighed af den fremskrevne periode

Varigheden af den fremskrevne periode, knap 40 år, appellerer til forsigtighed. Her kan særlig nævnes forudsætninger om global arealanvendelse, konkurrerende efterspørgsel på biomasse (fødevarer, foder etc.) samt mulighederne for øget udbytte.

Antagelser i rammerne for GCAM modellering

Som et hvert andet rammeværk for modellering simplificerer GCAM virkeligheden, og antagelserne bag modelleringen kan have betydelig indflydelse på resultaterne. For det første opererer GCAM i dens ligevægtsberegninger med antagelsen om det ’perfekte marked’, som ikke eksisterer i virkeligheden. Ligeledes er der ikke modelleret subsidier (Dog er effekten af subsidie-bestemt efterspørgsel indirekte er repræsenteret gennem modeltilpasning med

WEO 2012 efterspørgselsfremskrivninger). Der er ligeledes gjort antagelse om et enkelt globalt biomassemarked (og et homogent biomasseprodukt.

Endelig modellerer den nuværende implementerede version af GCAM (GCAM-DTU) ikke specifikt omkostninger forbundet med ændringer i arealanvendelsen. Dette betyder, at barrierer for ændret arealanvendelse sandsynligvis undervurderes. (Konsekvensen heraf vurderes dog ikke at have signifikant betydning for det centrale scenario der anvendes i dette studie, Regional Policy scenariet).

Estimering af danske CIF priser

Der er i det ovenfor nævnte trin 3 under den metodiske tilgang gjort en række antagelser. Særlig opmærksomhed bør rettes mod antagelser omkring udvikling i transportafstand og håndteringsomkostninger, herunder ved fremstilling af træpiller, da disse parametre påvirker CIF priserne markant.

Bærdygtighed

Der er enighed om, at den biomasse der kan anvendes til energiformål skal være bæredygtig biomasse. Der er dog ikke bred enighed om hvordan dette præcist defineres og hvad det vil betyder for det globale udbud. Emner med særlig betydning i denne forbindelse er biodiversitet samt CO_2 påvirkning fra direkte og indirekte ændringer i arealanvendelsen. Det er det vigtigt at pointere, at *en egentlig undersøgelse af bæredygtigheden af fast biomasse ikke er fokus for denne analyse*.

Formålet med denne rapport er at fremlægge langsigtede biomasse prisscenarier, under hensyn til bæredygtighedsspørgsmålet. I denne sammenhæng er det oplagt, at restriktioner på udbudssiden f.eks. som følge af bæredygtighedskriterier, vil påvirke prisen opad. Da der er usikkerhed om definitionen af bæredygtig biomasse, er det særdeles vanskeligt at kvantificere effekten.

Det er dog vores vurdering, at fremtidige bæredygtighedskriterier skal være særdeles restriktive og i betydeligt omfang ændre rammerne for skovdrift og landbrug, hvis de skal påvirke prisfremskrivningen markant.

Samfundsøkonomiske prisfremskrivninger for biomassebrændsler 2013 – 2050 (CIF dansk havn)

Nedenstående tabel viser de danske CIF priser for halm, træflis og træpiller for tre forskellige scenarier. Bemærk venligst, at priserne for lokalt anvendte halm- og træflisressourcer kan ligge under CIF niveau. Halm antages at være et lokalt brændsel gennem hele perioden med priser bestemt af priserne på lokal træflis (se diskussionen efter tabellen).

Euro/GJ	Halm			Træflis			Træpiller		
Year	Lav	**Med**	Høj	Lav	**Med**	Høj	Lav	**Med**	Høj
2012	5,0	**5,5**	5,9	5,6	**6,1**	6,6	7,6	**8,3**	8,8
2013	5,0	**5,5**	6,0	5,6	**6,1**	6,6	7,6	**8,3**	8,8
2014	5,0	**5,5**	6,0	5,6	**6,1**	6,7	7,6	**8,3**	8,9
2015	5,0	**5,6**	6,1	5,6	**6,2**	6,8	7,6	**8,4**	8,9
2016	5,1	**5,6**	6,2	5,6	**6,2**	6,9	7,6	**8,4**	8,9
2017	5,1	**5,7**	6,2	5,7	**6,3**	6,9	7,6	**8,4**	9,0
2018	5,1	**5,7**	6,3	5,7	**6,4**	7,0	7,6	**8,5**	9,0
2019	5,1	**5,8**	6,3	5,7	**6,4**	7,0	7,6	**8,5**	9,0
2020	5,2	**5,8**	6,4	5,7	**6,5**	7,1	7,7	**8,5**	9,0
2021	5,2	**5,9**	6,4	5,8	**6,6**	7,2	7,7	**8,6**	9,1
2022	5,2	**6,0**	6,5	5,8	**6,6**	7,2	7,7	**8,6**	9,1
2023	5,2	**6,0**	6,6	5,8	**6,7**	7,3	7,7	**8,6**	9,2
2024	5,2	**6,1**	6,7	5,8	**6,7**	7,4	7,7	**8,7**	9,2
2025	5,3	**6,1**	6,8	5,9	**6,8**	7,5	7,7	**8,7**	9,2
2026	5,3	**6,2**	6,9	5,9	**6,9**	7,6	7,7	**8,7**	9,3
2027	5,3	**6,2**	7,0	5,9	**6,9**	7,7	7,7	**8,8**	9,4
2028	5,3	**6,3**	7,1	5,9	**7,0**	7,8	7,7	**8,8**	9,4
2029	5,3	**6,4**	7,1	5,9	**7,1**	7,9	7,7	**8,9**	9,5
2030	5,3	**6,4**	7,2	5,9	**7,1**	8,0	7,7	**8,9**	9,5
2031	5,3	**6,5**	7,3	5,9	**7,2**	8,1	7,7	**8,9**	9,6
2032	5,3	**6,5**	7,4	5,9	**7,2**	8,2	7,7	**9,0**	9,7
2033	5,3	**6,6**	7,5	5,9	**7,3**	8,3	7,7	**9,0**	9,7
2034	5,3	**6,6**	7,6	5,9	**7,3**	8,4	7,7	**9,0**	9,8
2035	5,3	**6,7**	7,7	5,9	**7,4**	8,5	7,7	**9,1**	9,9
2040	5,3	**6,9**	8,2	5,9	**7,6**	9,1	7,7	**9,2**	10,2
2045	5,3	**7,1**	8,6	5,9	**7,9**	9,6	7,7	**9,4**	10,6
2050	5,3	**7,4**	9,1	5,9	**8,2**	10,2	7,7	**9,6**	11,0

Tabel 1: Fremskrevne biomassepriser CIF Danmark i tre givne scenarier (€/GJ).

Til trods for at nogle aktører har indikeret, at handel med træflis vil vedblive at være et regionalt marked og ikke handles internationalt, er dette dog ikke tilfældet i dag, eftersom træflis er blevet handlet internationalt gennem mange år – primært til brug i papirindustrien. Over de seneste år er træflis til energiformål imidlertid også set importeret til Europa fra Afrika (også til Danmark), og europæiske energiproducenter er begyndt at undersøge mulighederne for at importere store mængder af træflis fra Nordamerika.

Brug af lokale ressourcer

På den anden side er det ikke realistisk at de danske CIF priser for træflis og halm præcist kan reflektere leveringsomkostningerne for træflis eller halm til et decentralt værk i Danmark, som har adgang til lokale ressourcer. I denne sammenhæng fungerer de ovenfor listede priser som et prisloft, men det er sandsynligt at de sammenlagte omkostninger til køb af lokal ressource + transport til værk vil være lavere end 'CIF + transport' prisen. Det anbefales derfor, at der anvendes en særskilt prissætningsmetode til at beregne priserne for lokalt halm og træflis.

Opsummering af prisfremskrivninger på fast biomasse

I sammenhæng med dette studies egen analyse af prisfremskrivninger, er der også blevet foretaget et review af andre prisfremskrivninger. Tabel 2 og Tabel 3 herunder opsummerer nøgletallene for prisestimater for træpiller og træflis fra central studier konverteret til en fælles enhed (EUR/GJ) for at lette sammenligningen. Bemærk venligst, at der er betydelige forskelligheder i form af fokus og formål for de forskellige studier, hvorfor en sammenligning af de opsummerede priser bør foretages med forsigtighed og med hensyn til de antagelser og specifikke forhold, der ligger til grund for de enkelte studier.

Prisvurdering kilde	2010	2015	2020	2030	2050	Kommentarer
Træpillepriser, EUR/GJ						
Sveaskog	6,98 to 8,05		5,5 to 6,71			Importerede piller
Pöyry		7,79				Højt pille- efterspørgsels scenario
Biomass Futures - PRIMES			15,30	19,46	20,13	Lille-skala træbiomasse: primært piller. Reference scenario
DEA 2011		9,66	9,93	10,74		Industrielle træpiller
IEA Task 40		8,19				ENDEX piller
E4tech			12,89			UK varme sektor, bulk-piller, lokal oprindelse
E4tech			13,96			UK varmesektor, bulk-piller, importerede
AEA	13,96		15,17	15,17		Bulk-piller
Nærværende studie DEA 2013		**8,4**	**8,5**	**8,9**	**9,6**	**CIF priser ved dansk havn**

Tabel 2: Opsummering af resultater fra centrale træpille prisfremskrivningsstudier, EUR/GJ

Prisvurdering kilde	2010	2015	2020	2030	2050	Kommentarer
Wood chip price, EUR/GJ						
Sveaskog	3,89 to 6,17		2,82 to 4,97			Træflis fra lokale energiafgrøder
Sveaskog	6,44 to 7,52		6,17 to 7,52			Træflis fra skandinaviske skovbrug (resttræ)
DEA 2011		6,58	6,98	7,79		
E4tech			8,19			UK varmesektor, UK energiafgrøder
E4tech			11,68			UK varmesektor, importeret biomasse
AEA	6,98		6,98	6,98		Industriel træflis, centralt scenario
Nærværende studie DEA 2013		**6,2**	**6,5**	**7,1**	**8,2**	**CIF priser ved dansk havn**

Tabel 3: Opsummering af resultater fra centrale træflis prisfremskrivningsstudier, EUR/GJ

2 Executive Summary

This study, carried out by Ea Energy Analyses, has been commissioned by the Danish Energy Agency (Ea Energy Analyses / DEA) and is a part of DEA's periodic publishing of long term projections of fuel prices for socio economic analyses.

The key deliverables of this study are price projections for solid biomass fuels (wood pellets, wood chips and straw) for the period of 2013 – 2050, with particular focus on the period until 2035. The prices hereby listed should be interpreted as CIF prices at a Danish port denoted in real terms (in 2012 EUR/GJ). The socio-economic fuel price projections set forth by the DEA are to be used, among other things, in planning and economic evaluations of prospective projects in the Danish energy industry.

The solid biomass fuel price projections hereby set forth should not be regarded as forecasts; rather, as a possible development path of the respective prices provided fulfilment of a certain set of assumptions and pre-conditions.

Assumptions and approach

The basis of the projection is, firstly, an assumption of a regional and global demand for biomass for energy as described in the New Policy scenario in the IEA publication World Energy Outlook 2012. This demand structure for 2020 and 2035 is projected to continue towards 2050.

Secondly, Denmark is assumed to be a 'price-taker' in the global solid biomass fuel market, with 'price-taker' in this sense meaning that changes in Danish demand do not affect the global prices. This assumption is based on Denmark's relatively small demand volumes on a global scale.

Thirdly, it is expected that global trade in solid biomass fuels will intensify in the future, meaning, among other things, more liquidity in the market and more competitive price-setting.

For these reasons the price estimation approach deployed in this study is comprised of the following primary elements:

1) Global long-term biomass supply and demand dynamics are modelled using the Global Change Assessment Model (GCAM). The model derives a global energy biomass price for the modelled years, in principle by finding an equilibrium price between global long-term supply and demand for biomass. The model includes a global database of land

use, and projects developments in global agriculture, forestry, land use, conversion technologies, as well as demand for forest products, energy, food, feed, etc.

2) Thereafter the scenario yielding a global biomass energy demand that most closely resembles that from the World Energy Outlook 2012, New Energy Policies pathway is selected. The scenario output is in the form of a price path development for a simulated global market for an unrefined biomass resource, a price that should be interpreted as 'at forest'.
3) This price is then further adjusted and processed to emulate a CIF Denmark price under the assumption that Denmark is a biomass importing country. This adjustment incorporates costs associated with the treatment, processing and local and international transport of the biomass, and reflects assumptions related to those regions that are expected to export to Denmark in the future.

The above modelling is undertaken given the assumption that the long-term equilibrium price is cost-related, which is expected to be the case for wood chips and wood pellets. For straw, however, the assumption that straw for energy purposes is a more troublesome fuel than wood is applied. On that basis straw as starting point can be priced in accordance with wood chip prices, but always somewhat lower. Based on historical prices, it is assumed that straw for energy purposes in Denmark will be priced roughly 10% less than wood chips, as measured by energy content.

The rationale for using the GCAM model is that it is one of the premier integrated assessment models (IAMs) used for economic, technological, and policy analysis. GCAM began in 1975 under the name MiniCAM (Mini Climate Assessment Model), and has since been used in the Intergovernmental Panel on Climate Change's (IPCC) ongoing work.

Uncertainties

In undertaking such an analysis, there is always a great deal of uncertainty related to the assumptions taken, models chosen, scenarios utilised, etc. Some of the most relevant uncertainties relating to this study are highlighted below.

Duration of projection period

The projection period itself, almost 40 years, calls for caution, especially when taking uncertainties about global land use, competing demands for biomass and prospects of yield increases into account.

Assumptions in GCAM modelling framework

As any modelling framework, GCAM simplifies reality, and the assumptions made can have significant impact on the results. First of all, GCAM operates under the assumption of 'perfect markets' in its equilibrium calculations, which is not the case in reality. There are also no subsidies modelled (though subsidy-induced demand effects are indirectly represented through model alignment with WEO 2012 demand projections).

Lastly, the current version of GCAM deployed, GCAM-DTU, does not specifically model costs associated with land use change, making land use shifts more drastic than could be expected in reality. However, this does not appear to have significant impact on the central scenario employed in the study, the Regional Policy scenario.

Danish CIF price estimation

A number of assumptions have been made in the above mentioned step 3, and the accuracy of the price projections are subject to the materialisation of the said assumptions. Particular attention should be paid to the assumptions regarding transportation distance and processing costs as variations in these parameters significantly affect the final CIF prices.

Effect of sustainability on prices

There is general agreement that biomass to be used for energy purposes should be sustainable. However, there is not yet a general consensus on how this is precisely defined, and what it means for the global supply. Topics of particular importance in this context are biodiversity and the CO_2 impact from direct and indirect land use change. It is important to state that a *thorough investigation of solid biomass sustainability is not the focus of this analysis*.

The authors of this report have been tasked with developing a methodology for estimating future biomass price scenarios, taking sustainability issues into account. In this context, it is obvious that restrictions on the supply side, for example as a result of sustainability criteria, will result in a price increase. With the uncertainty regarding the definition of what constitutes sustainable biomass, it is extremely difficult to quantify this effect.

However, it is our evaluation that any restrictions on the production or sale of international biomass brought about by the implementation of sustainability criteria would have to be quite excessive in order to influence biomass prices in a significant fashion.

Socio-economic price projections for biomass fuels 2013 – 2050 (CIF Danish port)

The following table displays the CIF Denmark prices for straw, wood chips and wood pellets under 3 different scenarios. Please note that in the case of locally used straw and wood chip resources the prices can be below CIF prices. Straw is assumed to be a local fuel throughout the period, with prices set by the price of local wood chips (see discussion below).

Euro/GJ		Straw			Wood Chips			Wood Pellets	
Year	Low	**Med**	High	Low	**Med**	High	Low	**Med**	High
2012	5.0	**5.5**	5.9	5.6	**6.1**	6.6	7.6	**8.3**	8.8
2013	5.0	**5.5**	6.0	5.6	**6.1**	6.6	7.6	**8.3**	8.8
2014	5.0	**5.5**	6.0	5.6	**6.1**	6.7	7.6	**8.3**	8.9
2015	5.0	**5.6**	6.1	5.6	**6.2**	6.8	7.6	**8.4**	8.9
2016	5.1	**5.6**	6.2	5.6	**6.2**	6.9	7.6	**8.4**	8.9
2017	5.1	**5.7**	6.2	5.7	**6.3**	6.9	7.6	**8.4**	9.0
2018	5.1	**5.7**	6.3	5.7	**6.4**	7.0	7.6	**8.5**	9.0
2019	5.1	**5.8**	6.3	5.7	**6.4**	7.0	7.6	**8.5**	9.0
2020	5.2	**5.8**	6.4	5.7	**6.5**	7.1	7.7	**8.5**	9.0
2021	5.2	**5.9**	6.4	5.8	**6.6**	7.2	7.7	**8.6**	9.1
2022	5.2	**6.0**	6.5	5.8	**6.6**	7.2	7.7	**8.6**	9.1
2023	5.2	**6.0**	6.6	5.8	**6.7**	7.3	7.7	**8.6**	9.2
2024	5.2	**6.1**	6.7	5.8	**6.7**	7.4	7.7	**8.7**	9.2
2025	5.3	**6.1**	6.8	5.9	**6.8**	7.5	7.7	**8.7**	9.2
2026	5.3	**6.2**	6.9	5.9	**6.9**	7.6	7.7	**8.7**	9.3
2027	5.3	**6.2**	7.0	5.9	**6.9**	7.7	7.7	**8.8**	9.4
2028	5.3	**6.3**	7.1	5.9	**7.0**	7.8	7.7	**8.8**	9.4
2029	5.3	**6.4**	7.1	5.9	**7.1**	7.9	7.7	**8.9**	9.5
2030	5.3	**6.4**	7.2	5.9	**7.1**	8.0	7.7	**8.9**	9.5
2031	5.3	**6.5**	7.3	5.9	**7.2**	8.1	7.7	**8.9**	9.6
2032	5.3	**6.5**	7.4	5.9	**7.2**	8.2	7.7	**9.0**	9.7
2033	5.3	**6.6**	7.5	5.9	**7.3**	8.3	7.7	**9.0**	9.7
2034	5.3	**6.6**	7.6	5.9	**7.3**	8.4	7.7	**9.0**	9.8
2035	5.3	**6.7**	7.7	5.9	**7.4**	8.5	7.7	**9.1**	9.9
2040	5.3	**6.9**	8.2	5.9	**7.6**	9.1	7.7	**9.2**	10.2
2045	5.3	**7.1**	8.6	5.9	**7.9**	9.6	7.7	**9.4**	10.6
2050	5.3	**7.4**	9.1	5.9	**8.2**	10.2	7.7	**9.6**	11.0

Table 4: Projected biomass prices CIF Denmark in given three scenarios (€/GJ).

While some actors have indicated that wood chips will continue to be a regional market and not be traded internationally, this is however not the case today, as wood chips have been traded internationally for numerous years (albeit primarily for use in the pulp and paper industry). More recently, wood chips for energy purposes have also been imported to Europe from Africa (including to Denmark), and European utilities are starting to investigate the possibility of importing large amounts of wood chips from North America.

Use of local resources

On the other hand, the CIF Denmark price for wood chips and straw is not likely to adequately reflect the delivered cost of wood chips or straw at a decentralised inland power plant in Denmark that has access to local resources. In this regard, the above prices, plus a transport cost, would act as price cap, but it is likely that a total 'local resource + transport to plant' cost would be less than the 'CIF + transport' cost. It is therefore recommended that an alternative pricing approach be utilised to calculate a local straw and wood chip price.

Summary of solid biomass future price projections

In conjunction with the price projection analysis presented in this report, a review of other projections was undertaken. Table 5 and Table 6 below summarise key price estimates for wood pellets and wood chips from prior studies respectively, converted to a common unit (EUR/GJ) for ease of comparison. Please note that there are substantial differences in terms of the scope and purpose of each of the studies reviewed, hence comparison of the values summarised should be done with caution and with reference to the key assumptions and specifications of each respective study.

Price estimate source	2010	2015	2020	2030	2050	Comments
Wood pellet price, EUR/GJ						
Sveaskog	6.98 to 8.05		5.5 to 6.71			Imported pellets
Pöyry		7.79				High pellet demand scenario
Biomass Futures - PRIMES			15.30	19.46	20.13	Small-scale woody biomass: mainly pellets. Reference scenario
DEA 2011		9.66	9.93	10.74		Industrial wood pellets
IEA Task 40		8.19				ENDEX pellets
E4tech			12.89			UK heat sector, bulk pellets, local origin
E4tech			13.96			UK heat sector, bulk pellets, imported
AEA	13.96		15.17	15.17		Bulk wood pellets
CURRENT STUDY DEA 2013		**8.4**	**8.5**	**8.9**	**9.6**	**CIF prices at Danish port**

Table 5: Summary of key wood pellet price projections study results, EUR/GJ

Price estimate source	2010	2015	2020	2030	2050	Comments
Wood chip price, EUR/GJ						
Sveaskog	3.89 to 6.17		2.82 to 4.97			Wood chips from local energy crops
Sveaskog	6.44 to 7.52		6.17 to 7.52			Wood chips from Scandinavian forest residues
DEA 2011		6.58	6.98	7.79		
E4tech			8.19			UK heat sector, UK energy crops
E4tech			11.68			UK heat sector, imported biomass
AEA	6.98		6.98	6.98		Industrial wood chips, Central scenario
CURRENT STUDY DEA 2013		**6.2**	**6.5**	**7.1**	**8.2**	**CIF prices at Danish port**

Table 6: Summary of key wood chip price projection study results, EUR/GJ

3 Global biomass overview

This chapter presents an overview of global biomass production and main utilisation streams.

3.1 Global land use and biomass production

The total surface of the planet earth is approximately 500 million km^2, or 50 billion ha (Gha). With land area being 29% of the total surface, land sums to 14.5 Gha. When ice sheets are deducted the resulting land area represents 13 Gha (The Geological Society of America n.d.).

In Figure 1 the distribution of this land between the major global regions and the way it was being used in 2009 is shown. Overall, approximately 10% (1.5Gha) was dedicated to producing arable crops, over 25% (3.5Gha) was used for pasture (to produce meat, milk and wool), and 30% was forestry (4Gha). The remaining ~30% (4Gha) is a broad category that includes all other uses, including barren land and built-up areas. (Slade, et al. 2011)

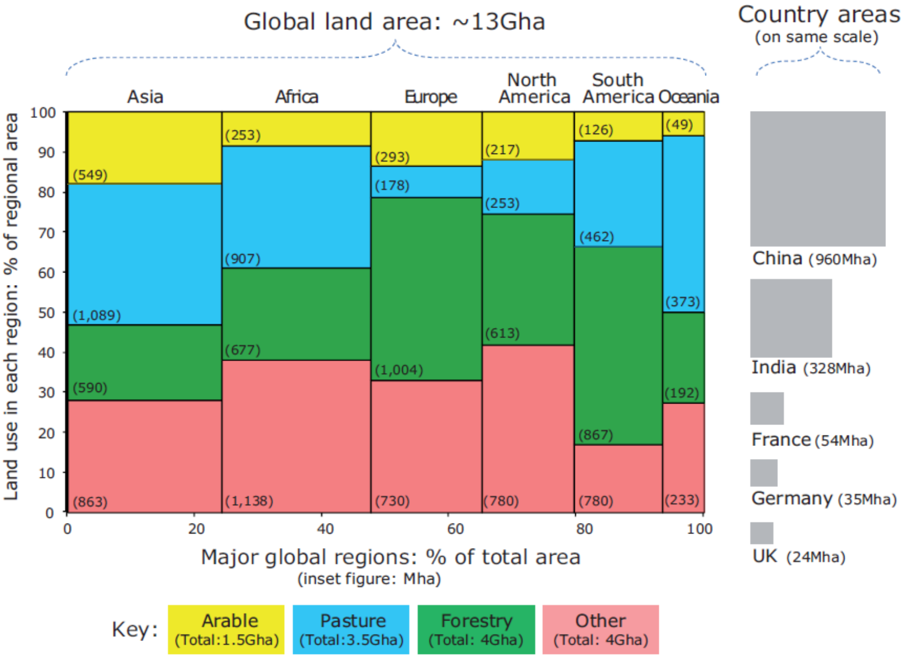

Figure 1: The global distribution of land by region and use. Source: (Slade, et al. 2011)

The figure draws a picture where human life has a substantial influence on global land use. Basically all arable land, and to some extent also pasture and forestry is affected by human activities.

The Net Primary Production (NPP) is a term expressing the production of plant material based on the photosynthesis process. Different sources estimate a global NPP from land biomass to be around 55 Gton Carbon/year (48 GT – 69 GT in the table below). With 45% carbon content in biomass and a lower heating value of 18 GJ/ton biomass the calorific value of the global terrestrial above ground NPP is 2,200 EJ/year.

Biomass	Global NPP (PG C yr-1)
Tropical forest	16.0–23.1
Temperate forest	4.6–9.1
Boreal forest	2.6–4.6
Tropical savannah and grasslands	14.9–19.2
Temperate grasslands and shrub lands	3.4–7.0
Deserts	0.5–3.5
Tundra	0.5–1.0
Croplands	4.1–8.0
TOTAL	**48.0–69.0**

Table 7: Estimates of Global NPP, Based on Christopher M. Gough, Virginia Commonwealth University) © 2012 Nature Education

Since the 1970s there have been concerns voiced about the human use of NPP. Based on data from FAOSTAT and other sources, the annual human harvest of global biomass can be approximated as shown below.

Biomass	EJ
Global cereals	40
Crop residues	60
Pasture	75
Roundwood + energy	25
Forest residues	20
TOTAL	**220**

Table 8: Estimate of global human harvest of biomass (Own evaluation based on FAOSTAT and other sources).

The table shows that the total human inflicted harvest of biomass for all purposes is approximately 10% of terrestrial NPP. However, according to a general definition of the term Human Appropriated Net Primary Production (HANPP) the percentage is somewhat larger, 20% - 25%. By this definition HANPP measures the combined effect of all human land use induced changes in NPP. (Erb, et al. 2009)

3.2 Agriculture and forestry

World average per capita food available for direct consumption (after allowing for waste, animal-feed and non-food uses, was 2,770 Kcal/day (11.5 MJ/per/day) (Alexandratos og Bruinsma 2012). With 7 billion people on the planet, the direct food consumption seems to equal “only” 29.6 EJ/year.

		2005/07	2050
Population	Mio.	6,584	9,306
Cereals, food	Kg/capita	158	160
Cereals, all uses	Kg/capita	314	330
Meat, food	Kg/capita	38.7	49.4
Oilcrops, food	Kg/capita	12.1	16.2
Oilcrops all uses	Kg/capita	21.9	30.5
Cereals production	Mio. tonnes	2,068	3,009
Meat production	Mio. tonnes	258	455
Cereals yield	Tonnes/ha	3.32	4.3
Arable land	Mio. ha	1,592	1,661

Table 9: Development of key variables towards 2050 (Alexandratos og Bruinsma 2012).

Table 9 shows that the average human diet consists of 18% meat on a weight basis. The annual global production of fish is roughly 145 million tonnes (not included in the table), with 85% used for direct food purposes. Based on these figures, the average human diet can be calculated to consist of approximately 23% meat and fish.

The table also shows that FAO projects average cereal yields to increase with more than 40% over the period, corresponding to 0.6% p.a. Total cereals production will grow by 45% and meat production by 76% over the period.

With the simple assumption that 1 energy unit of meat demands 10 energy units of biomass, the NPP value of the cereals, oilseeds and meat production is 65 EJ in 2005/07 and 106 EJ in 2050. When including residues left in the field and wastes, this figure could probably be doubled to 130 EJ in 2005/07 and above 200 EJ in 2050. These assumptions yield good compliance with the figures in Table 8.

In the publication Agricultural outlook 2012-2021, OECD-FAO has analysed, among other things, price drivers and price trends for agricultural products. The figure below shows that cereals are expected to experience a very moderate growth in prices in spite of growing demand. Note that growth is shown in nominal terms.

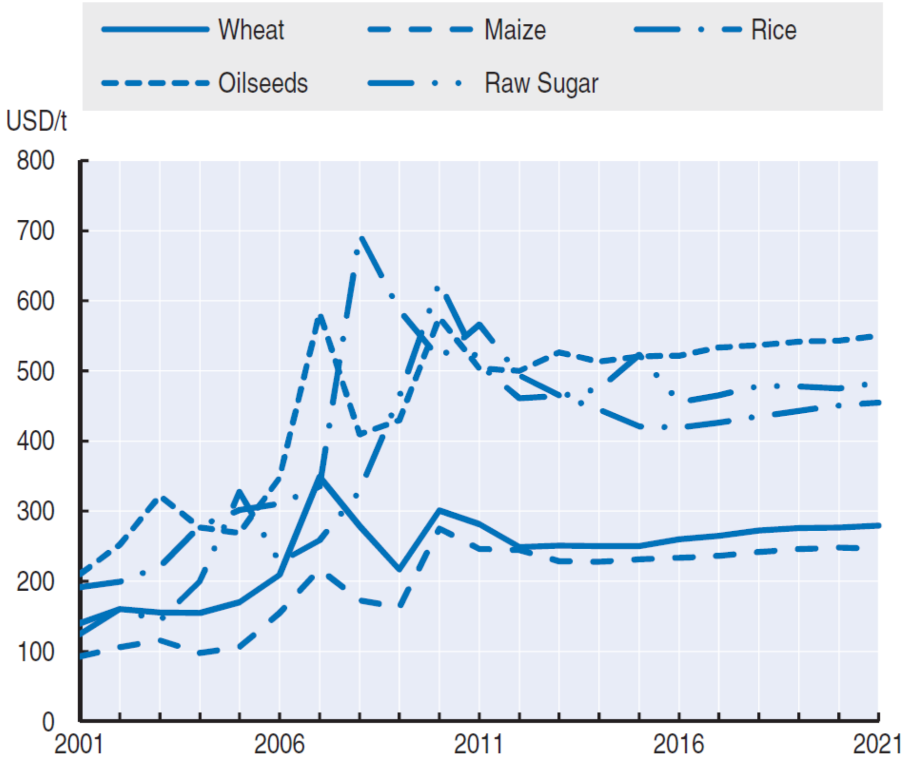

Figure 2: Price trends in nominal terms towards 2021. Source: OECD-FAO, Agricultural Outlook 2012-2021.

Forestry

According to FAO and other sources, forests cover 4 billion hectares of land, more than 30% of total global land areas (excluding permanent ice covered land). Primary forests – forests of native species in which there are no clearly visible signs of past or present human activity – are estimated to occupy 36 per cent of the total forest area. Other naturally regenerated forests make up some 57 per cent, while planted forests account for an estimated 7 per cent, of the total forest area. (Global Forest Resourcse Assessment 2010).

The rate of deforestation shows signs of decreasing. Around 13 million hectares of forest were converted to other uses – largely agriculture – or lost through natural causes each year in the last decade. Both Brazil and Indonesia, which had the highest net loss of forest in the 1990s, have significantly reduced their rate of loss. Afforestation and natural expansion of forests in some countries have contributed to reduced net loss of forest area at the global level. The net change in forest area in the period 2000–2010 is estimated at 5.2 million hectares per year (0.13% of total forest area). (Global Forest Resourcse Assessment 2010)

Figure 3 shows the global production of forestry products in the five main regions in the world in 2011. The production is split into wood for energy and wood for industrial purposes (Faostat n.d.).

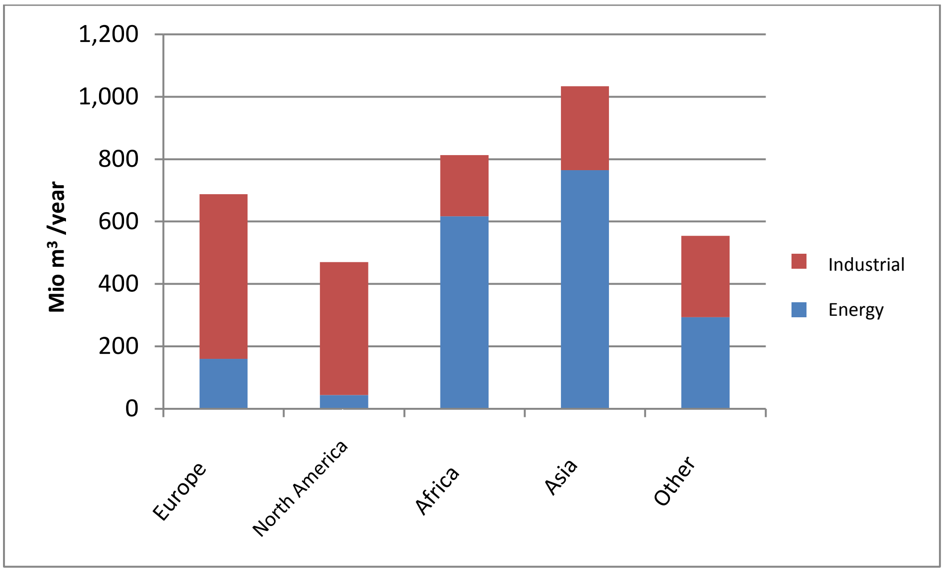

Figure 3: Production of forestry products 2011 (www.faostat.fao.org)

In the figure below the production from forestry is converted to energy units (EJ). The total production has been quite stable over the past 10 years with a decline in output for industrial purposes as a consequence of the financial crisis in 2008. The decline was mainly observed in America.

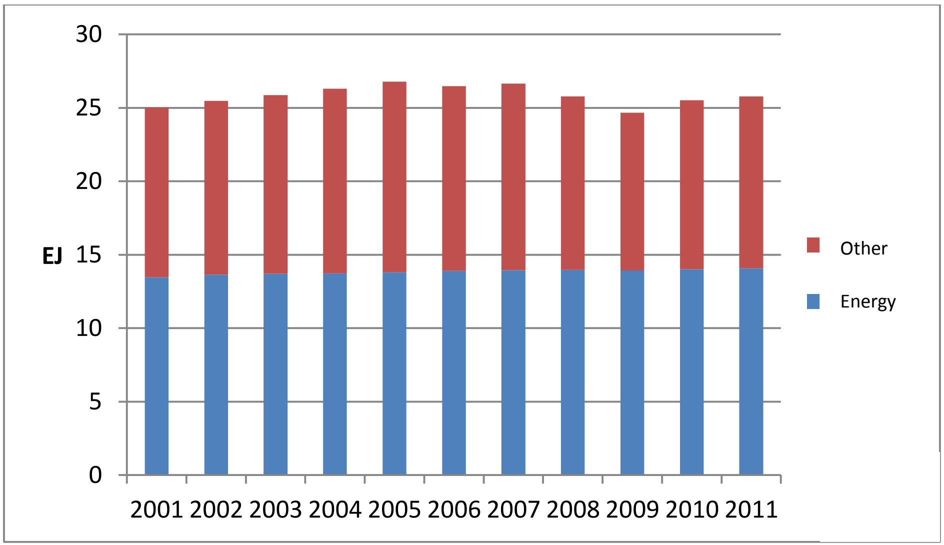

Figure 4: Global forestry output 2001-2011 (www.faostat.fao.org).

4 Biomass for energy

The following chapter will review biomass used for energy, presenting the different types of biomass fuels and their key characteristics. An overview of standardisation and sustainability issues will be given, as well as a review of solid biomass markets.

Global bioenergy usage

According to the 2012 World Energy Outlook, global bioenergy usage was roughly 53 EJ in 2010, with nearly 60% being classified as traditional biomass (IEA 2012). Bioenergy usage according to sector (%) is displayed in Figure 5.

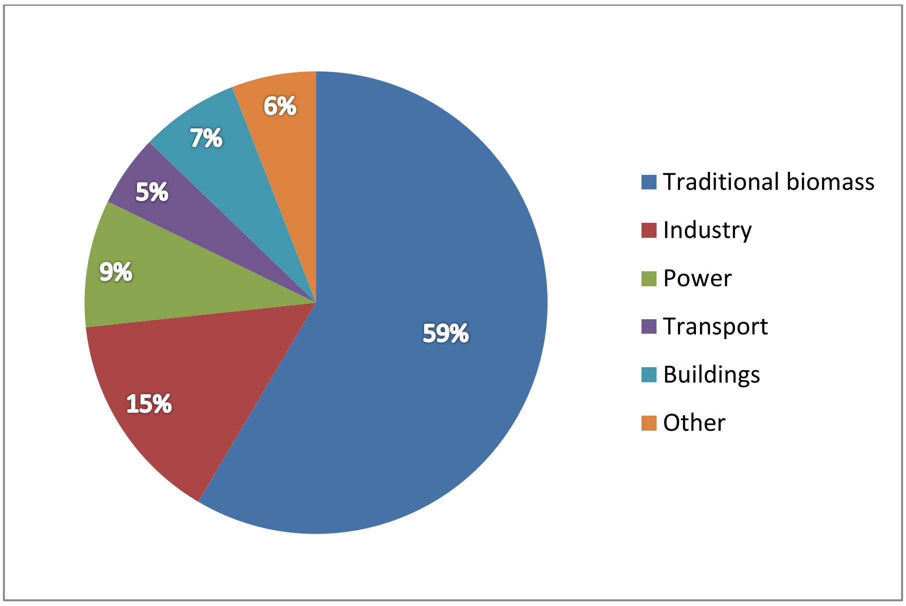

Figure 5: Global bioenergy usage by sector and for traditional usage (%) (IEA 2012)

Traditional biomass demand is primarily from developing countries, and involves rather inefficient usage forms, for example direct meal preparation and heating. Meanwhile, bioenergy usage in OECD countries is to a larger extent attributed to power plants, industry, and transport. Perhaps it is not surprising then that of the 53 EJ of global bioenergy, only 11 GJ were utilised in OECD countries, while the rest was utilised in non-OECD countries. This is reflected in Figure 6 where the global dispersion according to selected regions / countries (EJ) is displayed.

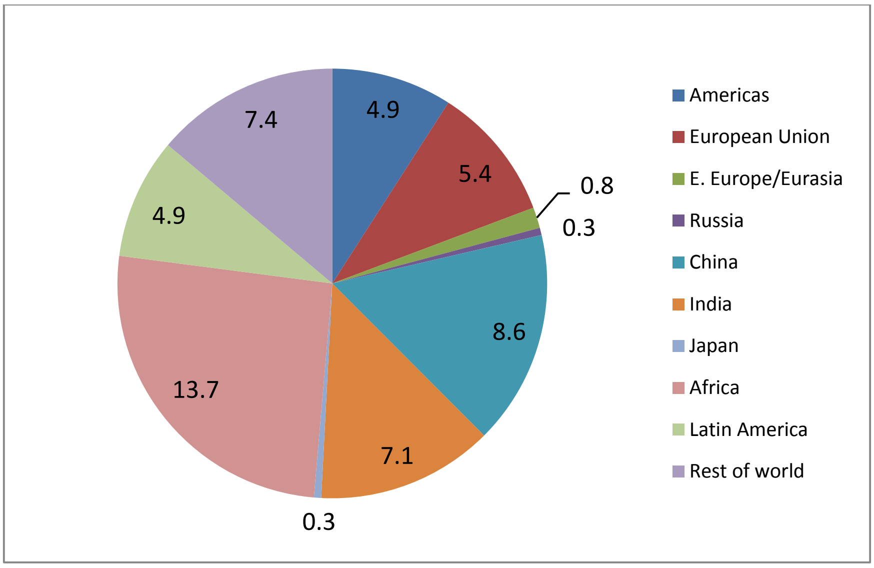

Figure 6: Global bioenergy usage for selected countries/regions (EJ) (IEA 2012)

Bioenergy types

Bioenergy can largely be broken down into:

- Solid biomass from forestry
- Sold biomass from agriculture
- Liquid biomass
- Traditional biomass
- Biomass portion of MSW

The task of this study is to provide future price projections for wood pellets, wood chips, and straw, and as such the primary focus is on woody biomass and straw. Woody biomass and straw can however not be seen in isolation, and therefore the model used will also factor the other forms of biomass into account.

Wood Pellets

The global demand for wood pellets is largely dominated by the EU, while production of wood pellets is concentrated in both North America and Europe. Figure 7 below displays the individual country production and consumption of wood pellets for 2010.

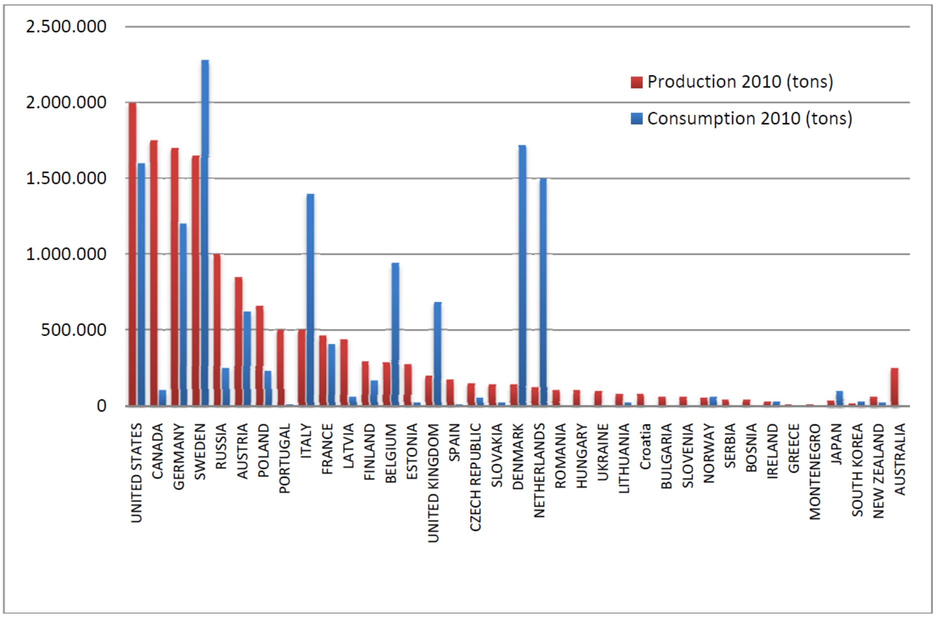

Figure 7: Individual country 2010 wood pellet production and consumption (Cocchi, et al. 2011)

Wood chips

The global demand for wood chips for energy purposes is currently primarily used in smaller decentralised heat and electricity plants, however large dedicated plants that utilise wood chips are becoming a viable alternative and several plants are in the planning or construction stage in the Nordic countries.

Straw

Denmark is one of the very few countries that utilises a substantial amount of straw for energy purposes. Annual usage varies, but in 2011 the figure was just under 20 PJ. With a heating value of 14.5 GJ/tonne, this corresponds to a little less than 1.4 million tonnes of straw.

4.1 Biomass trade

Relative to other commodities the volumes of long-distance biomass trade for non-food purposes have traditionally been quite limited, with the major importers being Japan (wood chips for use in pulp and paper), and the EU for use in pulp and paper, but also, to a growing extent, for energy purposes (primarily wood pellets, but also some wood chips).

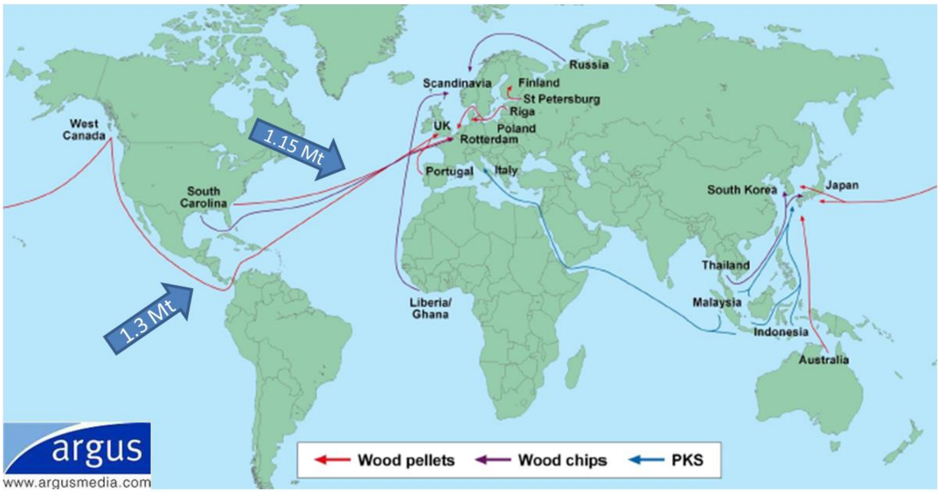

Figure 8: 2011 Biomass trade flows (Argus 2012). PKS = Palm kernel shells

The above figure displays some of the major global flows of biomass in 2011, many of which are expected to grow in the upcoming years.

Trade in Wood pellets

While still quite limited relative to other commodities, the international trade in wood pellets is increasing, and while Figure 8 gave a picture of the general global biomass flows, Figure 9 below gives more detailed figures for international wood pellet trade alone.

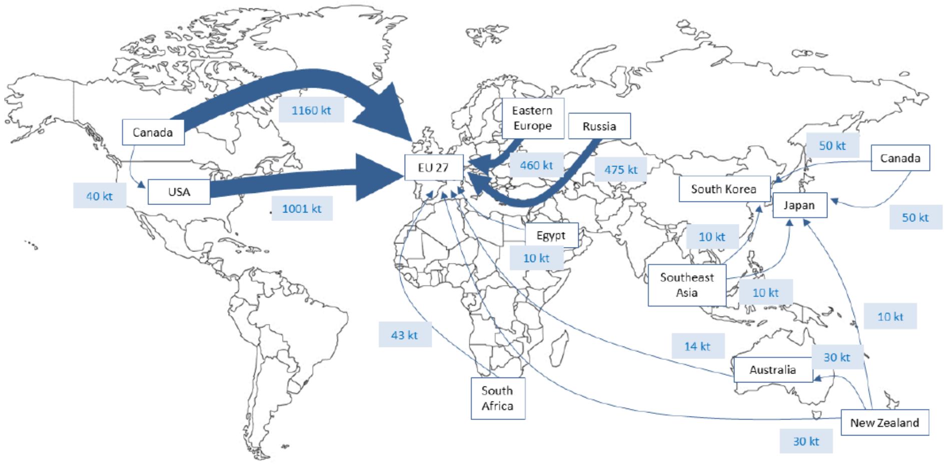

Figure 9: Global Wood pellet flows for 2011 in ktonnes (Pelkmans, et al. 2013)

As can be seen from the previous figure, the EU is the primary destination for the vast majority of international wood pellet trade. The major pellet demand destinations within the EU are Belgium, Denmark, Italy, the Netherlands, the UK, and Sweden.

Trade in wood chips

Global

While international trade of wood chips for use in the pulp and paper industry has been on-going for some time, trade in wood chips for energy purposes has until recently been quite limited as it was regarded as more of a local resource.

In June of 2012 IEA Bioenergy Task 40 released a publication on the global trade in wood chips, and the table below displays its figures for production, import and export (Lamers, et al. 2012). It is estimated that approx. 10% of the annual trade of wood chips is designated for energy purposes, while the remaining trade is primarily for paper and pulp production. The study indicates that trade with wood chips for energy purposes primarily involves European countries.

Country	Production	Import	Export
Canada	20,725	1,312	443
Australia	4,968	1	4,759
Sweden	4,263	1,345	293
South Africa	3,561	-	2,122
China	3,536	2,766	7
Chile	2,293	-	3,695
Russia	2,035	2	1,377
Brazil	1,921	-	1,025
USA	1,650	57	2,849
Finland	1,596	1,908	227
Japan	1,556	10,478	-
Austria	964	1,007	166
Germany	860	395	1,278
Latvia	783	7	1,449
Thailand	572	6	1,253
Uruguay	315	-	860
Turkey	234	1,542	-
Italy	116	691	9
South Korea	-	741	-
Norway	-	619	77
Other	7,429	3,429	3,307
World	**59,374**	**26,305**	**25,194**
Data inconsistency		1,111	

Table 10: 2009 Wood chip production, import, and export (1,000 tonnes) (Lamers, et al. 2012)

The largest wood chip -producing countries in 2009 were Canada (37%), Australia (8%), Sweden (7%), Russia (6%), China and Finland (each 5%). All of these countries are also producers of pulp and paper, as is Japan, which was by far the largest importer of wood chips in 2009. There is currently a clear trend in the paper industry to move production from the northern to southern hemisphere. As a result, in the future it is expected that wood chips for the paper industry will increasingly come from South America (e.g. Brazil) and Southeast Asia (e.g. Vietnam) (Lamers, et al. 2012).

EU

Within Europe it is possible to distinguish between two markets for wood chips. The first is comprised of the countries bordering the Baltic Sea, where Denmark and Sweden (and to a certain extent, Finland and Germany) have been the main importers of wood chips, primarily from the Baltic States and Russia. The second market is concentrated around Italy, which imports from neighbouring countries, particularly the Balkan countries (Lamers, et al. 2012).

In recent years there has been an increase in the European trade of wood chips. Instead of using locally produced wood chips, the Scandinavian countries have increasingly imported wood chips from the Baltic States and Russia. Another more recent manifestation has been the import of wood chips across the Atlantic from North America and South America, as well as from West Africa to Europe.

Trade in straw and other agricultural residues

Today straw is primarily a local or national resource, and has not traditionally been transported long distances for energy purposes. Meanwhile, some agricultural residues are already transported long distances today for use in the energy sector, for example palm kernel shells.

Relative to woody biomass it is more difficult for most power plants to utilise agricultural residues, and therefore the total raw material input cost + transport cost of straw or other input will have to be lower than the equivalent cost for woody biomass. If this is the case, then there is a substantial global potential that could eventually be traded.

4.2 Future potential biomass areas

Woody biomass

The Nordic, Baltic and remaining European countries are not expected to be able to export large amounts of woody biomass for energy production in the coming years as any increased production is likely to be utilised to satisfy increasing domestic/regional demand.   While some Nordic countries do have ample forest resources, the remoteness and slow growth of the resource make it difficult to compete price-wise with imports from other regions on the global market.

With its significant resources, but challenges related to logistics and investment risk, Russia remains a wildcard.

In speaking with various market actors, the eastern US and Brazil are touted as those areas that can supply Europe with the largest amount of secure sustainable woody biomass in the near future. It is estimated that these two regions could supply between 15-20 million tonnes of woody biomass per year. While more risky, estimates for West Africa are in the neighbourhood of 3-5 million tonnes.   These expectations are reflected in forecasts from for example RWE, which is predicting over 13 million tonnes of wood pellets alone to be imported by Europe by 2015 (see below).

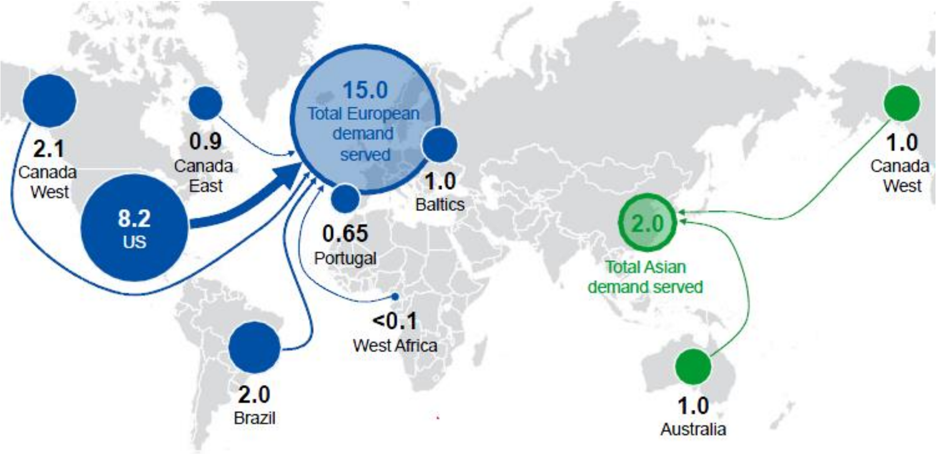

Figure 10: Expected world trade flow of wood pellets for 2015 in millions of tonnes (Argus 2012)[1]

Torrefaction

Torrefaction is a partial pyrolysis process which transforms the biomass properties into a more dense and water repelling substance suited for transport and open air storage. Torrefied and pelletised biomass is sometimes referred to *as black pellets*. A major benefit with black pellets is their ability to replace coal in existing coal fired power plants with only minor refurbishment costs. The benefits mentioned above might be outweighed by the energy loss and other costs and challenges in the production process. Black pellets have not yet made a significant inroad on the market but a good deal of discussion is

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[1] Strictly wood pellets to plants with 100 MW capacity or greater. Asia may have more demand for other types of biomass due to dedicated plants coming online

taking place regarding the future role of the torrefaction process. A more detailed description is provided in appendix 12.2.

If the challenges in the production processes are solved, black pellets might take its share on the global biomass market, especially where long distance transports are involved, or if more difficult feedstocks (than woody biomass) can be utilised in advanced power plants. In this case, torrefaction could lead to a lower price of biopellets in the long term than anticipated in this report.

4.3 Standardisation

There is a wide array of different types of solid biofuels, ranging from woody biomass (wood chips, pellets, briquettes, firewood) and herbaceous biomass (straw, grass, miscanthus etc.) to fruit biomass and 'blends and mixtures' (Kofman 2010). Moreover, there is great variability across a number of critical features within each of the solid biomass sub-types. Historically this problem has been solved on an ad-hoc basis, by buyers setting forth a list of specifications required for their particular application. However, with solid biomass fuels gaining importance and expectations of increasing international trade in certain types of solid biomass fuels, the standardisation issue has become increasingly relevant.

Wood chips and pellets

As far as wood fuels are concerned, the critical parameters that are commonly defined in the specifications list of a standard are as follows (Biomass Energy Centre 2012), (Kofman 2010):

1) Moisture content
2) Dimensions
3) Origin
4) Ash content and properties
5) Calorific value

Please see Appendix I for more information on the key standardisation parameters.

Straw

Currently there does not appear to be a common set of standards for straw, yet a straw supplier might need to meet certain requirements set by individual buyers (power plants). Some of the basic parameters would include (DONG Energy 2012):

1) Dimensions of the straw bales
2) Moisture content

Other features specific to straw that should be considered include ash content (cereal straw in particular has a very high ash content), ash melting temperature (some types of straw have a low ash melting point, giving rise to clinker formation and potentially damaging the boiler) as well as trace elements (relatively high content of potassium and chlorine which can be problematic).

Current standards

Several notable standardisation initiatives have been taking place, among which the standards set forth by the European Committee for Standardisation (CEN) should be noted. CEN has established Technical Committee 335 – Solid Biofuels, which covers a wide range of woody biomass. TC 335 first set forth technical standards (TS) defining terminology, specifications, fuel quality assurance and sampling methodology, which were later revised and implemented as Euro Norms (ENs) displacing all previous national standards across the EU. The new EN would also be used as a basis for the new ISO standards (Biomass Energy Centre 2012).

A relatively recent initiative in the US by the Pellet Fuels Institute and the American Lumber Standard Institute entails the possibility for pellet mills to certify their products via a third-party verification system (Geiver 2012). ENplus in Europe is a similar certification scheme, which is based on fulfilment of the EN 14961-2 provisions, yet requires even stricter quality criteria (ENplus 2013).

An example of a set of standards for industrial wood pellets as commodities is presented in Table 11 (a set of standards in line with Initiative Wood Pellet Buyers Group Industrial 2 specifications used by Argus Media for their wood pellet international bulk spot market analysis) and Table 12 for wood chips (Argus Media 2013). The presented set of standards is also consistent with the wood pellet standards used by the ENDEX wood pellets biomass exchange (Endex 2012).

Wood pellets specifications			
Parameters and rejection limits	**Units**	**I2 industrial**	
Physical parameters		**Limit**	**Tolerance**
Diameter	mm	6 to 10	within range
Length ≤50 mm	weight %	99.9%	within range
Length ≤40 mm	weight %	99.9%	within range
Water content	weight % ar	≤ 10 %	0.5% absolute
Bulk (apparent) density	kg/m³	≥ 600	2% of limit
Maximum bulk temperature	°C	≤ 60	1°C
Net calorific value at constant pressure	GJ/ton ar	≤ 16.5	0
Ash content	weight% DM	≤ 1.5%	10% of limit
Particle size distribution (square hole sieves)			
% < 3.15 mm	weight %	>98%	1% absolute
% < 2.0 mm	weight %	>90%	2% absolute
% < 1.0 mm	weight %	>50%	5% absolute

Table 11: Argus Biomass Wood pellets product specification. Source: Argus Biomass (2013)

Wood chip specifications	
Energy content	lower heating value/net calorific value in GJ
Ash content	3-4%
Chlorine	0.05%
Sulphur	0.05%
Size	97% of chips to be max size of 50x50x20mm

Table 12: Argus Biomass Wood chips product specification. Source: Argus Biomass (2013)

4.4 Effect of sustainability on prices

Major concerns regarding the sustainability of extensive use of biomass for energy have been raised over the years. Concerns have traditionally been focused on direct land management issues and adverse effects on: Biodiversity, land fertility, loss of original forest, human rights, and the rights of indigenous peoples.

In recent years more global issues have also gained focus, namely competition with food and the CO_2 effect from direct and indirect land use changes. The food competition issue gained special focus in connection with the price increase of maize, rice, etc. in 2007 and 2008 (often referred to as the tortilla crises).

The question of CO_2 impact from direct and indirect land use changes is extensively debated. However it is important to state that a *thorough investigation* *of solid biomass sustainability is not the focus of this analysis*. The authors of this report have been tasked with developing a methodology for estimating future biomass price scenarios, taking sustainability issues into account.

Anytime restrictions are placed on supply this will of course result in a price increase. However, it is our evaluation that any restrictions on the production or sale of international biomass brought about by the implementation of sustainability criteria would have to be quite excessive in order to influence biomass prices in a significant fashion. This evaluation is primarily based on the different price scenarios developed by using the GCAM model (see following chapters), and provided that global demand follows the path described in the World Energy Outlook New Policies scenario.

5 Solid biomass prices

Danish prices

Biomass for energy purposes is primarily traded via bilateral contracts and as such prices vary from contract to contract. However, by combining a number of purchases it is possible to get a general price for each commodity over a particular time period. A good source for Danish biomass prices is the Danish District Heating Association, which collects the prices that its members has paid for various fuels, compiles them, and generates a weighted average for each fuel on a quarterly basis (see Figure 11 below). Prices are in DKK/MWh for the fuel at the plant gate, exclusive VAT, but including energy and CO_2 taxes for fossil fuels (biomass is exempt from energy and CO_2 taxes up until 2014). Reading from the graph and converting to DKK/GJ, the average prices in second quarter 2012 were approximately: Wood pellets: 70 DKK/GJ; Wood chips: 49 DKK/GJ; Straw: 42 DKK/GJ.

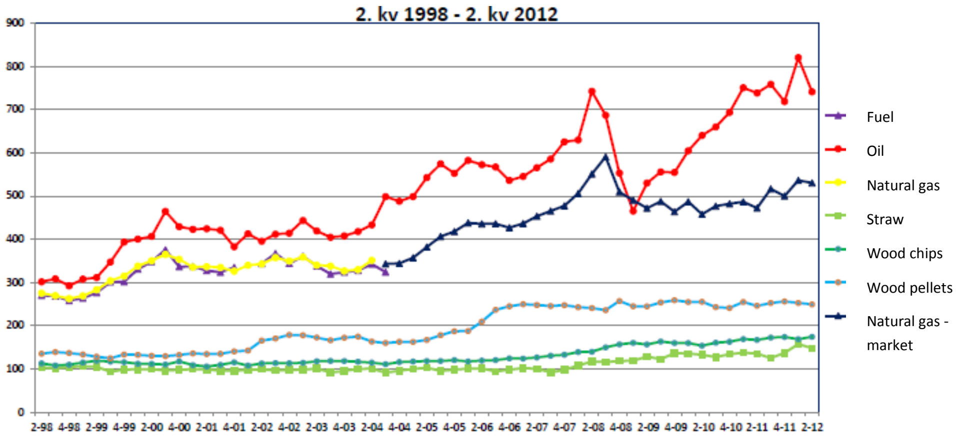

Figure 11: Nominal fuel prices delivered to Danish district heating plants from the 2nd quarter of 1998 till the 2nd quarter of 2012 in kr./MWh. Prices are exclusive VAT, but inclusive other taxes. Red = oil, navy blue/yellow = natural gas, turquoise with brown dots = wood pellets, darker green = wood chips, light green =straw. (Danish District Heating Association 2012)

From the figure it is apparent that over the past 10 - 15 years the prices for various biomasses in Denmark have been quite steady, particularly when compared to those for fossil fuels. It is also apparent that the prices of straw and wood chips follow each other closely, with straw prices historically being 5%-15% lower. The costs displayed are nominal values, and as such in real terms the cost of straw (light green), and wood chips (dark green) have stayed quite constant over this period, with wood pellets (turquoise with brown dots) showing a more gradual increase. Costs for all three biomass forms have grown and fluctuated significantly less than costs associated with natural gas (dark blue), and oil (red).

As was indicated above, the prices in Figure 11 are a weighted average delivered at plant gate. In later years the import of solid biomass for energy purposes has grown steadily, and in 2011 28 PJ of wood pellets and 6 PJ of wood chips were imported to Denmark. (Danish Energy Agency 2012). Imports accounted for 92% of pellet consumption and 34% of wood chip consumption in that year.

Further analysis of the price statistics reveals that there is a good deal of price variance within the above displayed average prices for all three fuels, particularly so for the most local fuel, straw. There are generally two main ways of acquiring straw in Denmark, through local contracts or via tenders.

- Smaller amounts of straw are mostly traded via local contracts between the farmer and the energy producer, where the straw comes from local farmers within a radius of 30-50 km. Under this model, the local decentralised district heating companies enter into contracts with one or more of the local farmers regarding the delivery of an amount of straw for a certain price. These types of contracts typically run for 3-5 years (Holst 2010).
- Dong Energy and Vattenfall are the largest consumers of straw for energy purposes, purchasing roughly 950,000 tonnes per year.[2] The vast portion of this is purchased via tender, and the transport distance for this type of procurement can be farther, typically within a radius of 75 km (Boldt 2009) (Holst 2010). Under this procedure the energy producer puts out a tender containing information about which plants demand a certain type of straw for the following period. The tender does not reveal the amounts of straw needed, and the farmers then submit their bids on how much straw they can deliver to the specific plant at what price.

Under both procurement systems regional and local variations in straw prices can occur due to local surpluses or shortfalls in the straw yield from year to year.

North American and European prices of woody biomass

Relative to other commodities there are very few financial transactions that take place involving wood pellets and wood chips. As a result, the market liquidity or "trading churn rate" for both commodities is extremely low (see text box).

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[2] With average national straw for energy figures of ca. 1,400,000 tonnes, these two energy producers purchase roughly 68% of the total average (Holst 2010).

Trading churn rate - is simply the amount of times an underlying good is involved in a financial transaction for each time it physically changes hands (i.e. total traded volume/physically traded volume), and for wood pellets and wood chips this ratio is close to one. This is due to the lack of physical clearing houses for wood pellets and chips, and as such it has only been possible to act through trading companies or by direct contact between supplier and customer. Oil on the other hand has a trading churn rate of 150, which implies that for every time a barrel of oil is physically traded, it has been involved in 150 financial transactions. Other examples (and their churn rates) include sea grains (3), wheat (10), corn (15-20), and soya (50). The international trading company Nidera suggests that the liquidity threshold for a commodities market is between at least 10 and 15, and thus the churn rate of just 1 for wood pellets and wood chips suggest that these markets are still quite far from reaching this threshold. (Nidera 2010)

In an attempt to add more liquidity and transparency to the wood chip and pellet markets indexes such as APX-ENDEX and Argus Biomass have been established.

APX-ENDEX

In 2008 APX-ENDEX introduced an industrial wood pellet index where a pricing panel consisting of a number of market participants contributed to generating reference prices for 3 month forward contracts, 3 quarter forward contracts, and 1 year forward contracts. In 2009 the number of panel members and contracts in the price index were increased. In November of 2011 APX-ENDEX launched the world’s first biomass exchange which consisted of forward contracts for industrial wood pellets covering 3 months, 3 quarters, and 3 years. According to APX-ENDEX:

> “The development of the biomass exchange follows a two-phased approach. In phase one, the exchange started with non-cleared products, meaning the physical settlement is arranged bilaterally between the counterparties after the trade has been concluded. Phase two will include the development and implementation of clearing services for wood pellets contracts, thereby providing further financial security to market participants.” (APX-ENDEX 2013)

The figure below displays the APX-ENDEX wood pellet future prices for March of 2012 till February of 2013 for monthly, quarterly and yearly forward contracts. Prices are in euro per metric tonne CIF Rotterdam.

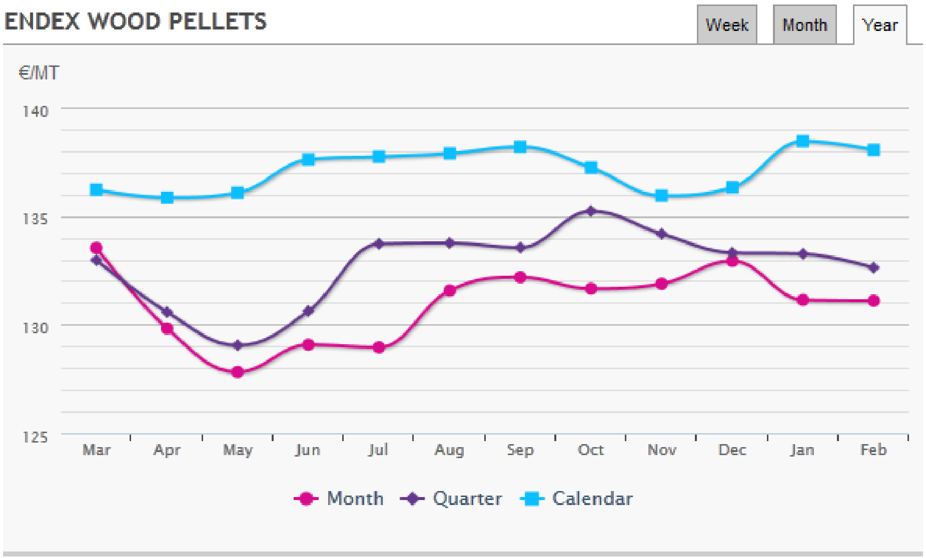

Figure 12: APX-ENDEX wood pellet future prices for March of 2012 till February of 2013 for monthly, quarterly and yearly forward contracts. Prices are in euro per metric tonne CIF Rotterdam. (APX-ENDEX 2013). Please note that the vertical axis starts at 125 euros.

Argus Biomass

Like APX-ENDEX, Argus Biomass has a price index for wood pellets, and it also has price indexes for wood chips. These prices are published weekly via its Argus Biomass Markets publication, and this publication is constantly adding new CIF and FOB prices. The table on the following page gives an overview of the current indexes tracked and published by Argus as of February 2013.

Markets covered	Location	Contracts assessed
Wood pellets CIF	ARA	Spot, 3 quarters ahead, 3 years ahead
Wood pellets FOB Baltic	Riga	Spot, 3 quarters ahead, 3 years ahead
Wood pellets FOB Portugal	Aveiro	Spot, 3 quarters ahead, 3 years ahead
Wood pellets FOB North America	Northeast US	Spot
	Southeast US	Spot
	Northwest US	Spot
	Southwest Canada	Spot
Wood pellets US Domestic	Portland, Maine	Spot
	Camden, NJ	Spot
	Wilmington, NC	Spot
	Port Everglades, FL	Spot
	Mobile, AL	Spot
	Chicago, IL	Spot
	Seattle, WA	Spot
North American wood chips spot - FOB export and CIF delivery	Portland, OR	Spot
	Tacoma, WA	Spot
	Vancouver, BC	Spot
	Mobile, AL	Spot
	Moorhead City, NC	Spot
	Sheet Harbour, NS	Spot
Wood chips CIF	Northwest Europe	Spot, 3 quarters ahead, 3 years ahead

Table 13: Overview of Argus Biomass indexes as of February, 2013. (Argus Biomass 2013)

According to its methodology and specifications guide, the indexes are:

> "Weekly and based on two elements — a survey of market participants' views on where prices stand, and a volume-weighted average of any trades which fit the index specifications and which Argus has been able to verify with more than one counterparty to the deal. Argus may apply editorial judgment to the survey where necessary and may discard prices which, in the editorial team's judgement, are not repeatable and not representative of the market price." (Argus Biomass 2013)

In addition to the above indexes, the weekly publication also includes forward prices and shipping costs for various ship sizes on the main trading routes.

Argus CIF ARA wood pellet spot prices from early 2013 were for example 56 DKK/GJ, meanwhile CIF ARA wood chip prices were 44 DKK/GJ. [3]

As previously mentioned, these prices are based on a survey of market participants, as well as a volume-weighted average of verified contracts considered 'repeatable' (Argus Biomass 2013). Thus, while these figures may be a good indicator of current prices, actual contracts may vary from these values depending on the amount, duration, etc.

Price overview

Table 14 summarises the various cost figures outlined above.

Source	Straw	Wood chips	Wood pellets
DDHA, 2nd quarter 2012[4]	39.9	49.4	71.3[5]
Argus CIF ARA - early 2013	N/A	44.3	55.9
ENDEX CIF Rotterdam – early 2013	N/A	N/A	56.1

Table 14: Various price indicators for straw, wood chips and wood pellets (2012 DKK/GJ).

Due to the main transport routes of pellets and wood chips it can be assumed that CIF Denmark would be slightly above CIF ARA for pellets and slightly below CIF ARA for wood chips. There is (thus far) no international price indicator for straw. The rather large difference between the DDHA wood pellet price and the international price indicators is not analysed but could to some extent be caused by the following factors:

- The pellet consuming DH plants are relatively small, and local handling and transport is a factor
- Some of the price contracts could be fixed prices including storage facilities

5.1 Key biomass price determinants: literature review

Biomass prices are inherently complex phenomena depending on a variety of factors, and there does not appear to be a consensus as to the specifics of this mechanism. Previous studies carried out on behalf of the Danish Energy Agency have identified 13 different factors that might have an effect on biomass prices (Boldt 2009). However, the four factors described below were noted as dominating:

- General development in food prices and other biomass products (land rent).

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[3] In 2012 DKK.

[4] Weighted average, delivered at plant gate

[5] Without transport, figure is 68.2 DKK/GJ

- Local supply/demand balance, especially in import situations with dominating transport costs (straw).
- General price development on energy products – in the sense that these costs influence the supply curve. Assumed that particularly oil prices and CO_2 prices will influence prices.
- Projections regarding increased efficiency (cost reduction) on supply side.

Cost of production

A substantial body of research seems to suggest that cost of production (as opposed to willingness to pay) is the key determinant of biomass prices, explained in part by the nature of some solid biomass types used for energy purposes (e.g. agricultural and forestry residue), as well as the fact that (for wood fuels in particular) the production process has been very labour-intensive (Olsson, et al. 2010). A manifestation of this has been observed in e.g. Sweden when during the 1990's, in spite of increasing demand for wood fuels, the price of the wood fuels stayed relatively constant due to a stable supply of residues from the forestry sector (Hillring 1999).

Fossil fuel prices

The link between fossil fuel prices and biomass prices is not straight-forward. First of all, one should distinguish between short-term and long-term price effects, though there appears to be little correlation between the two in the short term. For example, in late 2008 and early 2009 when decreases in the price of oil, coal and natural gas were observable, the price of wood fuels was in contrast increasing (Junginger, et al. 2012). This has been explained by less access to the 'easy' solid biomass fuel feedstock (e.g. sawdust and other residue material) due to a decrease of activity in the construction industry and hence less timber being processed. This would in turn give additional support to the claim of production costs being the key price determinant of solid biomass fuels.

In the short-term, higher fossil fuel prices would affect biomass fuel production costs, but the fraction of the production costs made up by fossil fuel costs are deemed to be relatively minor. Another short-term impact would be long-distance transport in case of international trade of biomass (Olsson, et al. 2010). Some references suggest that short-term correlation between biomass and fossil fuel prices will increase should co-firing of e.g. coal and wood pellets in large-scale industrial sector become wide-spread, as this would make the two fuel types mutually substitutable (Junginger, et al. 2012).

There is more evidence of fossil fuel prices and solid biomass fuel prices correlation in the long term. As fossil fuel prices rise, market participants gain an incentive to seek alternatives (Olsson, et al. 2010). In most cases this would, however, require investments in new technologies and equipment, as well as other long-term decisions. Hence, it would be reasonable to expect that increased fossil fuel prices in one period would affect solid biomass fuel prices further down the line. There are some studies that would seem to suggest that a lag of 1 to 2 years should be expected for this price effect to take place (Boldt 2009, Junginger, et al. 2012).

Yet another factor that makes the determination of biomass and fossil fuel price correlation difficult (or indeed, the link between solid biomass fuel prices and any other key price driver) is the fact that large solid biomass fuel consumers often choose to organise procurement via long-term fixed (or regulated) price contracts (E4tech 2010). This delays or even neutralises many of the short- to medium-term effects that variability of a certain price driver would have otherwise brought about. Having said that, one should, however, note that some studies have attempted estimating short-term correlation between solid biomass fuel and fossil fuel prices. A study carried out by Hedenus et. al (2010)[6] concludes that there is no statistically significant relation between residential wood pellet prices and the oil price. The same result could be derived from Figure 11 above regarding industrial pellets. Fuel price analysis done by Strauss (2012) suggests correlation between heating oil prices and residential wood pellet prices, yet wood pellets following at a slower rate. As an example, diesel and heating oil price increase of 4% p.a. is said to result in wood pellet price increase of 2.8% p.a.

Biomass demand

A graphical illustration of wood flows in Europe is presented in Figure 13, which gives a good idea of the complex structure of the competing industries requiring (in this case woody) biomass.

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[6] As per citation in Olsson et. al (2010)

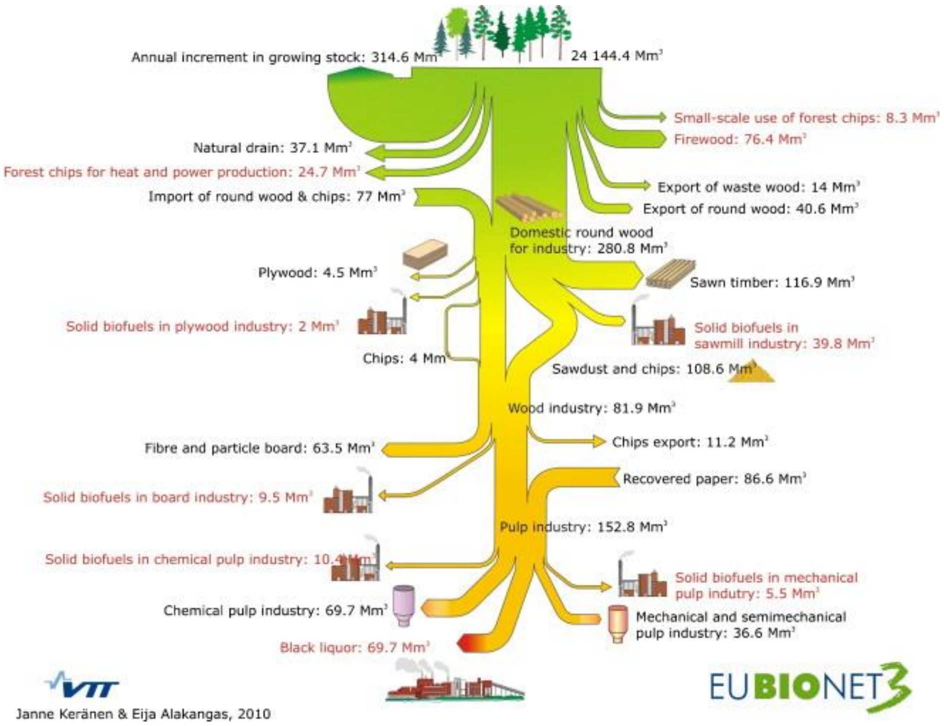

Figure 13: Wood flows in Europe 2008. Illustration from Junginger et. al (2012)

As far as the selected solid biomass fuels in question are concerned, a study carried out by the AEA (2010) with a goal to estimate the potential biomass supply in the UK between 2010 and 2030 has set forth a methodology which, among other things, provides an overview of the most relevant competing demand industries (from the standpoint of bioenergy demand) for selected types of solid biomass feedstock. A summary is presented in Table 15.

Type of feedstock	Competing demand industries
Sawmill residues	Pulp mills, panel board manufacture, animal bedding
Forest residues and small round wood	none
Short rotation forestry	none
Straw	Animal bedding, animal feed

Table 15: Major competing biomass demand industries. Source: AEA (2010)

What Table 15 in fact demonstrates is that not all solid biomass fuel feedstock types have alternative uses, yet again giving support to the claim that production costs might be the main driving force behind the prices of certain biomass fuel types. When it comes to pulp mills, several studies indicate that pulp and paper industries are facing a weak market with demand declining over time, especially for newsprint products (Olsson, et al. 2010), the only exception being China (Strauss 2012). Nonetheless it is also being pointed out that currently it is still more profitable to use pulpwood for paper rather than for energy production (ForestBioEnergy 2007).

From a demand perspective it is also worth noting that the energy industry has been found to exhibit lesser price sensitivity with regard to biomass prices as compared to fossil fuel prices. The forestry industry has also been found to be more price sensitive with regard to biomass as compared to the energy industry (Lundmark 2009).

Type of feedstock

Price mechanisms can also vary depending on the biomass feedstock - a study by Hedman (1992)[7] analysing the Swedish wood chip market reveals that the main price determinant for wood chips produced out of cutting residues (e.g. branches, wood from thinning, low quality stemwood) is the cost of production, whereas sawmill residue price was more dependent on the willingness to pay on the part of competing demand industries, e.g. particle board industry. As to wood pellets and briquettes, cost of production was said to be the main price driver, though the price level of heating oil was denoted as a natural 'price ceiling'.

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[7] As per citation in Olsson et. al (2010)

6 Scenarios for supply and demand

6.1 Future demand of biomass for energy

This section will review literature regarding anticipated future demand for biomass, including official government releases, NGO reports, climate agreements and consultancy reports, to provide an overview of what future biomass demand may look like. Depending on the source, there is a huge variation in future estimates, due either to the competing interest of those providing the estimates, or the assumptions utilised. As such the assumptions underlying the forecasts are often just as important, or perhaps even more so, than the actual figures. Many of these assumptions are further investigated throughout this report. The section will start with looking at estimates of future Danish demand for biomass, before looking at the EU, and finally the global picture.

Denmark

In terms of solid biomass for energy purposes, as of 2011 Denmark uses roughly 120 PJ of biomass annually. Of this approximately 21 PJ is from biodegradable waste, thus leaving 99 PJ from straw and woody biomass. The Danish solid biomass consumption from 1980 till 2011 is displayed in Figure 14 below.

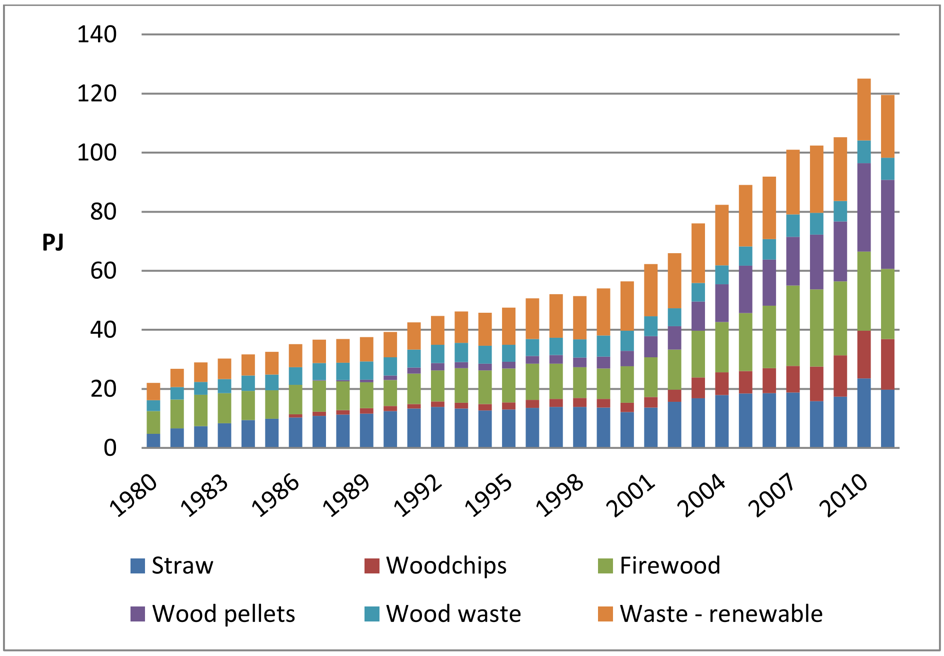

Figure 14: Danish solid biomass consumption from 1980 till 2011 (Danish Energy Agency 2012).

While straw usage has been relatively stable for the past 10 years, usage of woody biomass, particularly wood chips and wood pellets has grown substantially. This is in large part to due to large centralised power plants which have replaced a portion of their fossil fuel inputs with woody biomass. With the current Danish legislative incentives in place, this is a trend that it is anticipated to continue in the years to come.

Denmark has set a number of energy related targets and goals for future years, including major targets in:

- 2020 - 50% of traditional electricity consumption is to be covered by wind power, and more than 35% of final energy consumption from renewables (Ministry of Climate, Energy and Building 2012).
- 2030 - Phasing out coal and oil from electricity and heat supply (The Danish Ministry of Climate, Energy and Buildings 2011)
- 2035 - Phasing out natural gas from electricity and heat supply (The Danish Ministry of Climate, Energy and Buildings 2011)
- 2050 - Entire Danish energy supply, including transport is covered by renewable energy (The Danish Ministry of Climate, Energy and Buildings 2011).

In addition to the above goals, Denmark also has an EU renewable energy target of 30%. All of the above targets will affect Denmark's future biomass demand for energy purposes. Different strategies for how the above goals can be achieved have been put forward, including that of the Danish Commission on Climate Change Policy (Klimakommission), a panel of leading scientific experts, whom were tasked with presenting suggestions as to how Denmark can in the future phase out fossil fuels.

According to the prognosis of the Klimakommission (Klimakommissionen 2010), the fraction of biomass in the Danish primary energy consumption under various future scenarios concerning the overall economic and regulatory framework development would consistently be in the range of ca. 100 – 120 PJ per annum by 2050, the only exception being the 'unambitious future' scenario (characterised by high oil prices, low CO_2-quota prices, low biomass prices and no limitations on biomass use) which would result in extremely high biomass consumption (exceeding 400 PJ per annum). The probability of the latter scenario materialising is however questionable.

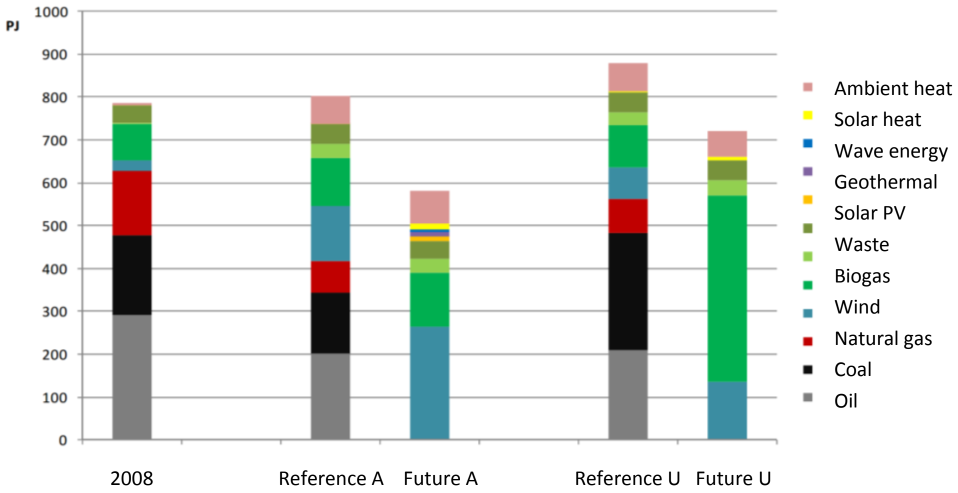

Figure 15: Denmark's primary energy consumption (in PJ) by 2050 under various future scenarios. 'Reference' assumes no further environmental regulatory decisions. 'A' stands for environmentally ambitious global economic framework; 'U' for unambitious. Source: Klimakommissionen (2010).

EU

National Renewable Energy Action Plans (NREAPs) provide detailed information on how each individual EU member state is envisioning meeting the legally binding renewable energy targets by 2020. Hence, the cumulative solid biomass share of future primary energy consumption in the EU (as prescribed by the NREAPs) would serve as a sound basis for EU's demand prognosis for solid biomass. An overview of solid biomass[8] demand projections in accordance with NREAPs has been created as a part of Biomass Futures project (Atanasiu 2010), and is expected to amount to 3,475 PJ by 2020.

Wood pellets

EU demand for wood pellets is forecasted to be in the range of 20 – 50 million tons by 2020 (please see an overview of prior studies in Figure 16), depending on the assumptions on the key regulatory and economic developments, such as (Cocchi, et al. 2011):

- Policies regarding co-firing in the UK, Netherlands, Belgium, Germany and Poland (as well as market dynamics on coal and CO_2 emission allowances)
- Price of fossil fuels for heating and support schemes for pellet stove and boiler purchases (determining the attractiveness of switching to wood pellets for residential heating)

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[8] Includes biodegradable fraction of solid industrial and municipal waste

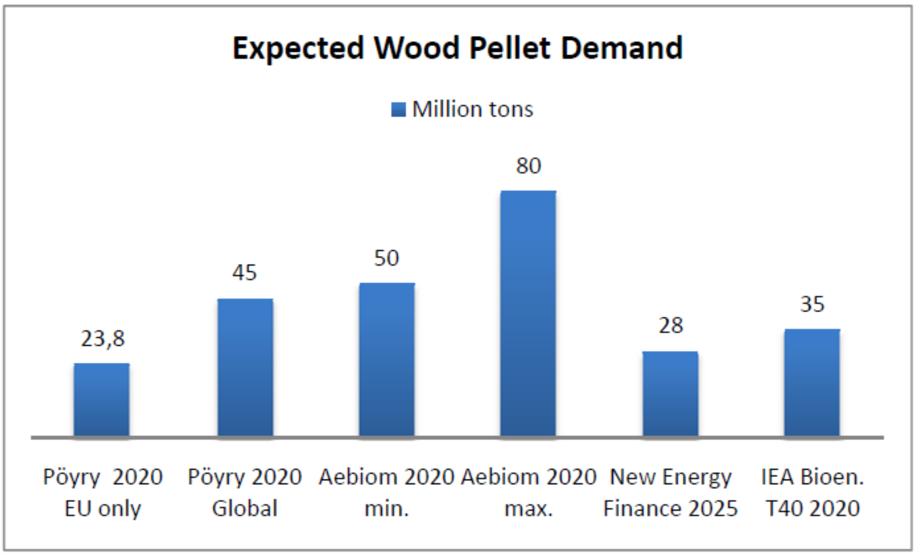


Figure 16: Expected 2020 wood pellet demand according to various sources (Cocchi, et al. 2011).

Extrapolation of current demand trends exponentially would lead to a consumption level of almost 35 million tons by 2020 in the EU (Cocchi, et al. 2011).

World

According to the projections of the International Energy Agency in the World Energy Outlook 2012 in their New Policies Scenario, the global primary energy demand for bioenergy (excluding traditional biomass) would more than double from 2010 to 2035 (from 22 EJ to over 50 EJ, respectively), growing at an annual rate of 3.3% (International Energy Agency 2012). The projections including traditional biomass as well as their respective uses by sector are presented in Figure 17.

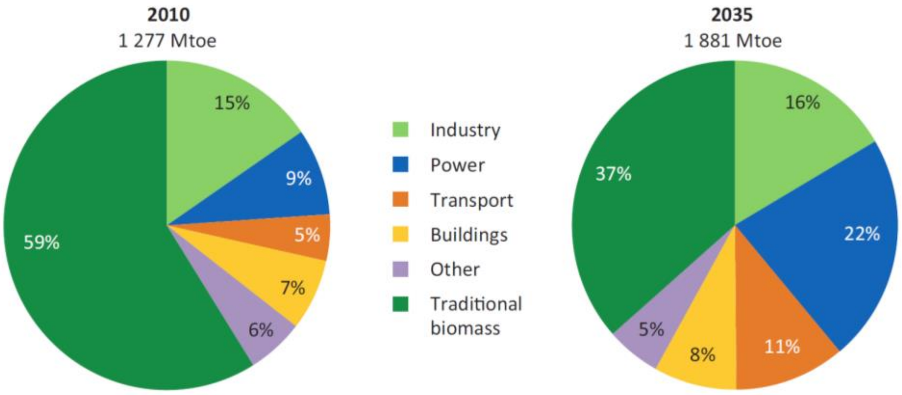


Figure 17: World bioenergy use by sector and use of traditional biomass in the New Policies Scenario, 2010 (53 EJ) and 2035 (78 EJ). Source: (International Energy Agency 2012).

Wood pellets

For wood pellets, the European Union is expected to remain the main demand driver on a global scale, yet developments in Japan, South Korea and China could be significant for the East Asian demand for solid biomass, which is expected to be in the range of 5 – 10 million tons in 2020 (Cocchi, et al. 2011). Global wood pellet consumption outlook per region by Pöyry is presented in Figure 18.

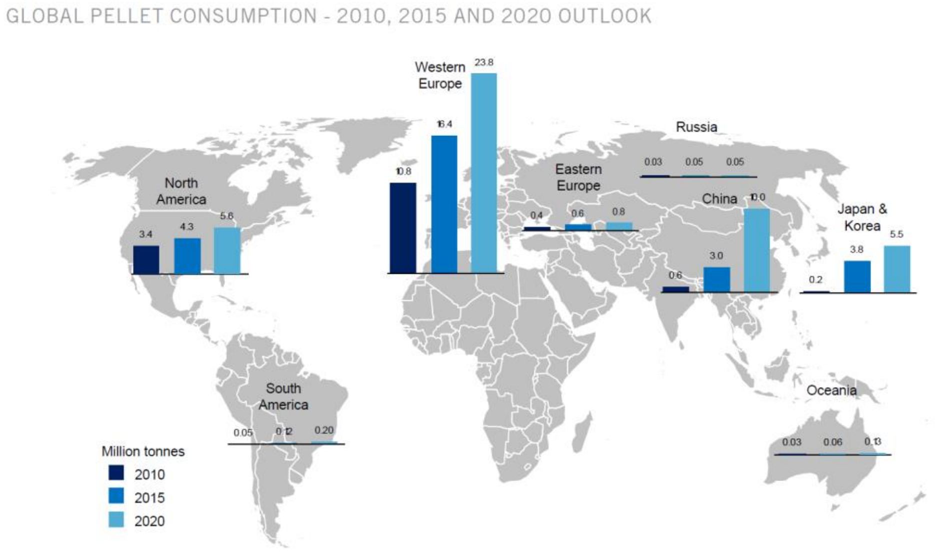


Figure 18: Pöyry's global wood pellet consumption forecast (Pöyry 2011).

Wood pellet use in the US is expected to remain limited to small-scale use in households. The demand in Canada would be determined by the progress of the implementation of the announced coal phase-out by the Ontario Power Generation (Cocchi, et al. 2011).

6.2 Future supply of biomass

According to IEA's analysis in the WEO 2012, the global bioenergy resources should be more than sufficient to satisfy the expected global biomass demand by 2035. In fact, the global available resources would be nearly double the expected demand of 78 EJ (International Energy Agency 2012).

There is, however, large variability in terms of biomass resource distribution in the world. The regions with the largest resource potentials are estimated to be Latin America (especially Brazil), the US and China. Large variance is also expected in terms of the degree to which the domestic bioenergy demand could be satisfied with domestic production. Figure 19 demonstrates the expected shares of imports across regions by 2035.

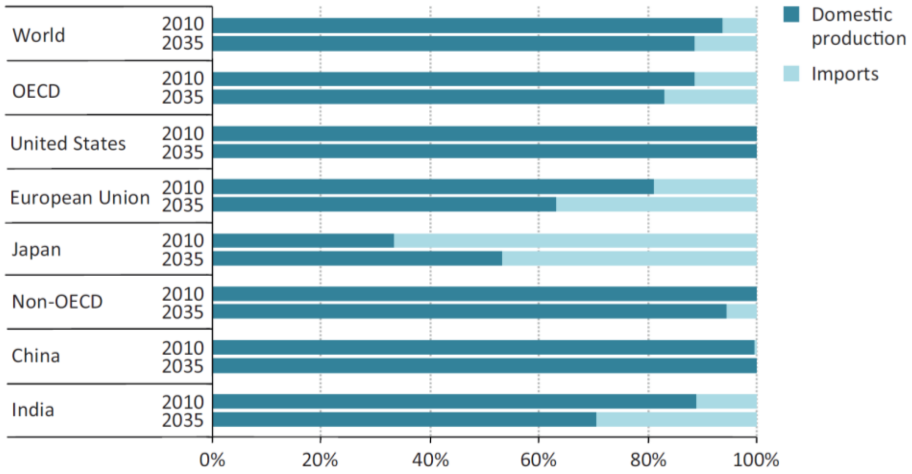


Figure 19: Share of bioenergy demand for biofuels and power generation from domestic production and imports, 2010 and 2035. Source: (International Energy Agency 2012).

As can be seen, Japan and the EU would be the largest importers, whereas the US and China are expected to be fully self-sufficient.

Wood pellets

In terms of wood pellets, significant production growth is expected in Western Europe, the Americas, as well as China (Pöyry 2011) – see Figure 20.

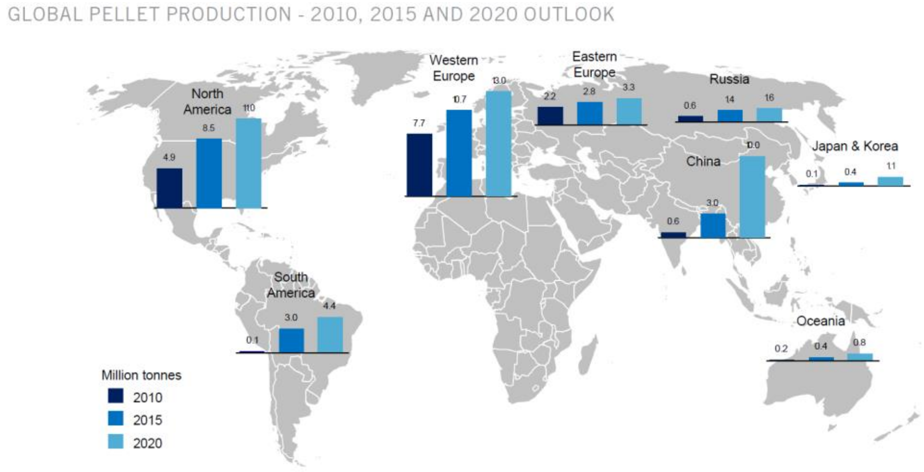


Figure 20: Pöyry's global wood pellet production forecast.

In terms of wood pellet trade, IEA's WEO 2012 in the New Policies Scenario projects the US, Canada and Russia to be major exporters (International Energy Agency 2012).

The estimates on quantity of wood pellets available for exports specifically to the EU vary significantly, and depend on the assumptions made about the key influencing factors. A 'business-as-usual' scenario (presented in Figure 21) assumes industry development in line with the historic dynamics (Cocchi, et al.

2011). In this scenario, there would be ca. 280 PJ of wood pellets available for exports to the EU by 2020, the major supply sources being South-East USA and Brazil.

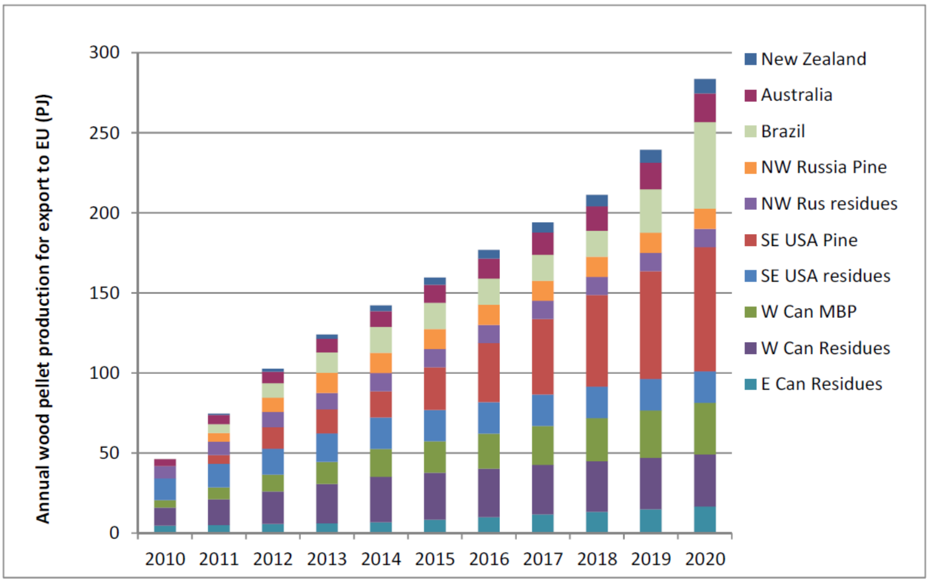


Figure 21: Wood pellet supply available for export under IEA Bioenergy's 'business as usual scenario' (Cocchi, et al. 2011).

A 'high import' scenario assumes large investments in additional pellet plants triggered by the rapid growth of biomass demand in the EU, as well as a strong development in short rotation crops and energy plantations in certain regions of the world (e.g. Brazil, Uruguay, West Africa, Mozambique and Russia). The total quantity of wood pellets (as well as sourcing composition thereof) is presented in Figure 22. Under the 'high import' scenario there is now almost 600 PJ of wood pellets available for export to the EU in 2020, and North-West Russia is a major exporting region. It should, however, be noted that the 'high import' scenario assumes ambitious development prospects highly diverging from the current situation in the global market.

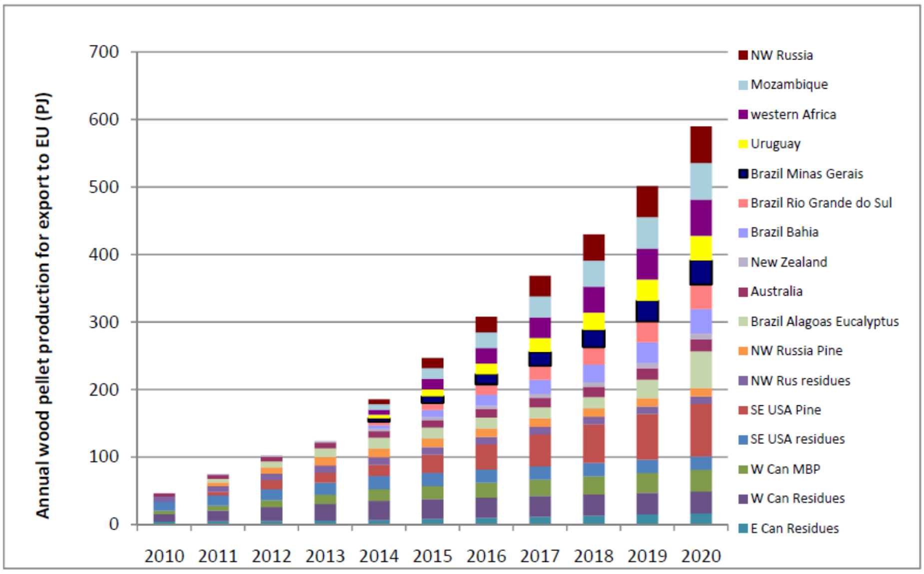


Figure 22: Wood pellet supply available for export under IEA Bioenergy's 'high import scenario' (Cocchi, et al. 2011).

7 Methods and models for analysing future biomass prices

7.1 Overview of recent studies of price development for biomass

Despite increasing interest in bioenergy, and solid biomass as one of the means of achieving this goal, attempts to project future prices of solid biomass fuels are still relatively few and far in between. Moreover, there is certain variability in terms of the approaches used (and more importantly yet, the results obtained). In the following section an overview is given of the most important recent biomass future price estimation studies from a methodological perspective, followed by an overview of their respective results.

Models used for analysing biomass prices

Key models, approaches and methodologies deployed in the most important recent biomass price estimation studies are described below.

Cost-of-supply approach

Cost-of-supply approach has its roots in the assumption that production costs are the main drivers for solid biomass fuel prices. In a study carried out for the UK's Department of Energy and Climate Change by E4tech, biomass prices to be paid by the UK heat and electricity sectors in 2010 and 2020 were estimated. Figure 23 provides a schematic of a supply cost curve estimation process for wood chips imported into the UK heat sector.

Figure 23: Supply cost curve estimation approach for imported wood chips. Source: E4tech (2010).

Cost-of-supply approach has also been used in a previous biomass price prognosis report by the Danish Energy Authority in the report Opdatering af samfundsekønomiske brændselspriser – Biomasse (EA Energianalyse and Wazee 2011).

Finally, an analysis jointly carried out by the European Climate Foundation, Sveaskog, Södra and Vattenfall (Sveaskog, et al. 2010) has also applied a modification of cost-of-supply approach in order to assess the cost competitiveness of biomass as a fuel for heat and power production. The approach deployed in this report is specific in terms of its focus on cost improvement potential across the whole value chain of biomass, from feedstock production to combustion processes, as illustrated in Figure 24.

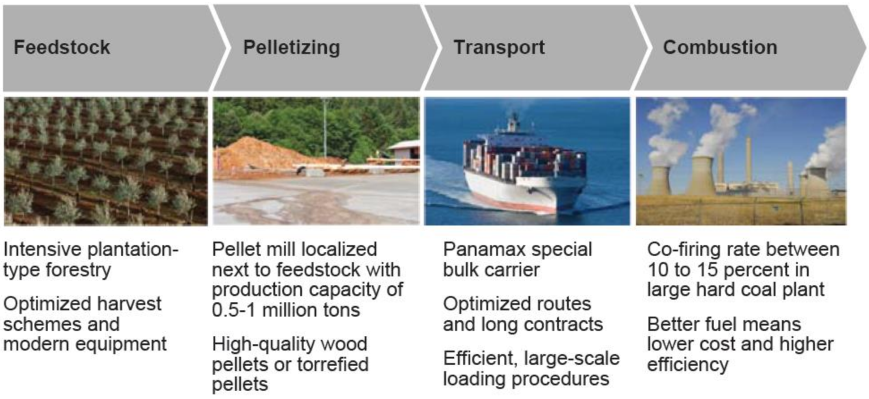


Figure 24: An example of optimised global supply chain. Cost-of-supply approach, cost improvement potential focus across the entire value chain of biomass. Source: Sveaskog et al. (2010).

Atlas of EU biomass potentials by Biomass Futures project

Being a part of the Biomass Futures project, the Atlas of biomass potentials study derives cost-supply curves at national and EU levels for 2020 and 2030 according to 2 different future scenarios. As a starting point, biomass potentials for 2020 and 2030 are quantified based on region-specific data on present technically feasible biomass potentials and various forecasting methodologies depending on the feedstock. E.g. a methodology developed by the Joint Research Centre has been used to estimate sustainable straw potential, whereas woody biomass potentials have been estimated using the EFISCEN model. Next, cost estimates for the different types of feedstock are estimated based on competing uses, costs of production, yielding and transport. The obtained biomass supply potentials and cost estimates are then synthesised into cost-supply curves (Elbersen, et al. 2012).

World Energy Model by IEA

World Energy Model (WEM) is the underlying tool for the International Energy Agency's World Energy Outlook analysis (IEA 2012). The outline of the model is presented in Figure 25.

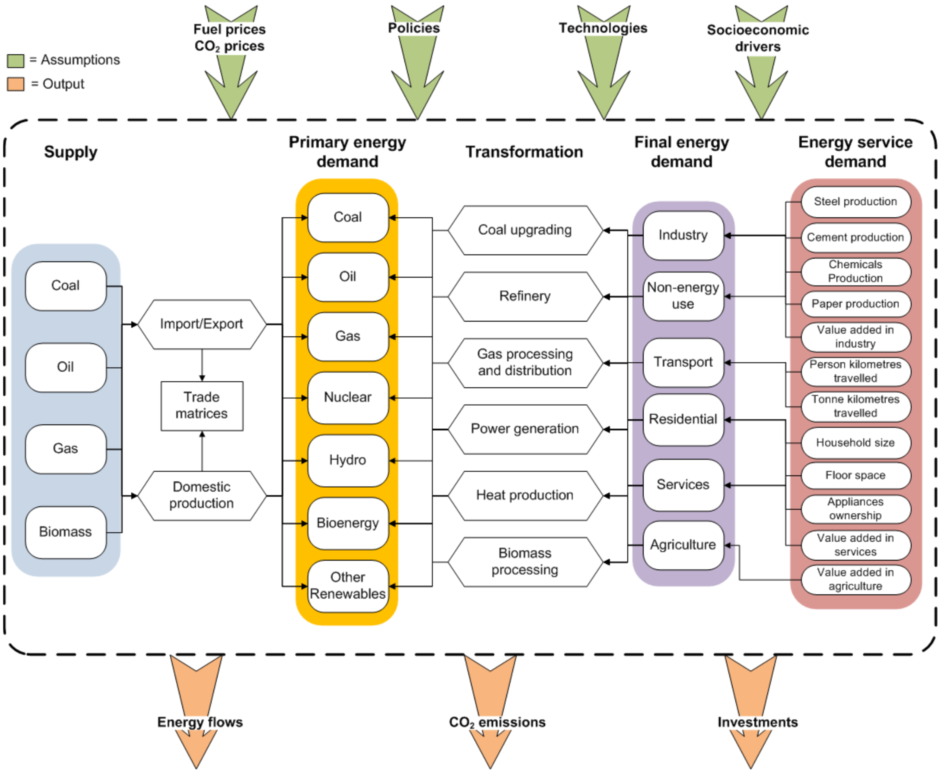


Figure 25: World Energy Model overview. Source: IEA (2012).

Based on a set of inputs and drivers, the WEM models the energy flows and final energy demand on a least-cost basis. As of 2012, a Bioenergy Supply and Trade module has been incorporated into the WEM. The module estimates the available biomass and biofuel resources per region and assesses the ability of the specific region to satisfy their internal bioenergy demand with local resources. Alternatively, the module simulates international trade of solid biomass (only biomass pellets are internationally tradable in WEM) and biofuels. A schematic of the module is presented in Figure 26.

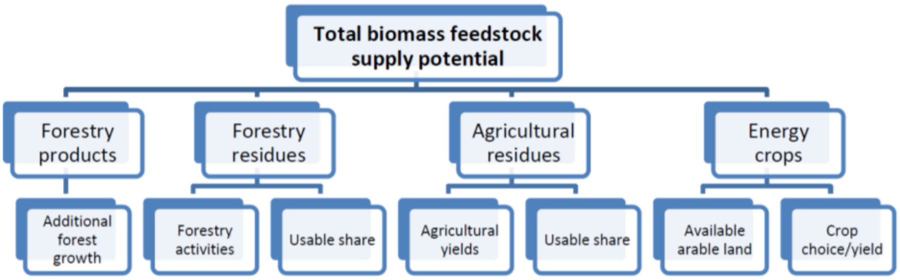


Figure 26: Schematic of WEM Bioenergy Supply and Trade Module, the Biomass supply potentials. Source: IEA (2012).

In essence, WEM's biomass module takes as a point of departure the absolute possible biomass feedstock potential based on a wide range of data related to agriculture, food demand, land availability etc. The respective feedstocks compete to meet the demand on a least-cost basis in terms of feedstock prices and conversion costs. International trade also takes place on a least-cost basis once transportation costs have been accounted for (IEA 2012). The intersection between the projected demand curve and biomass supply curve is then the estimated biomass price in WEM.

Oxford Economics model

In a study examining potential biomass supply in the UK between 2010 and 2030 for the UK's Department for Energy and Climate Change, Oxford Economics with assistance from AEA estimated the biomass resource potential in the UK, as well as predicted price levels for different types of biomass (AEA 2010).

The approach used is akin to WEM in the sense that its starting point is also the establishment of total available biomass resource (as exemplified by the schematic in Figure 27), as well as the fact that 'usable' share of the total resources are further estimated based on a set of constraints e.g. competing uses. One differing factor could be the fact it regards supply side issues only and does not address the constraint issues with regard to conversion and use of biomass.

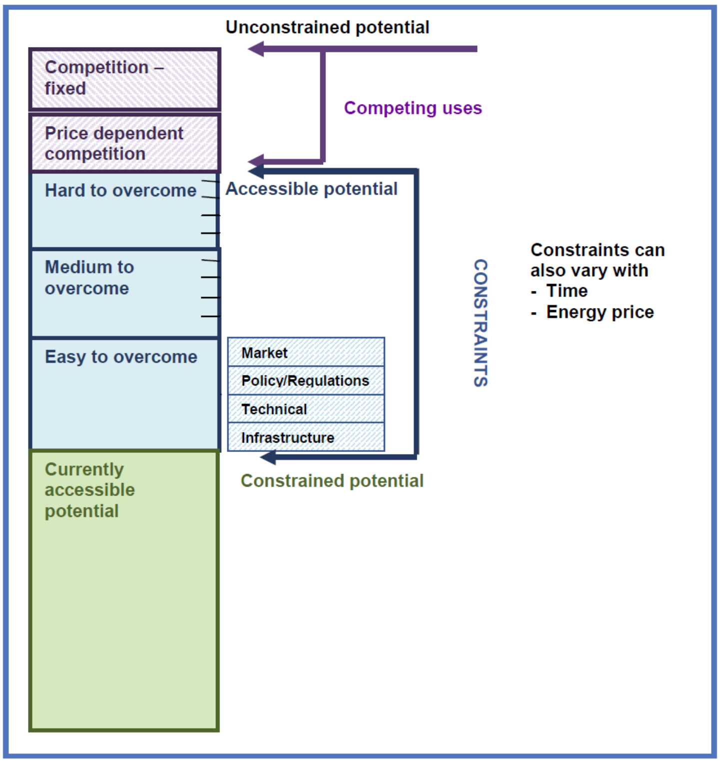


Figure 27: Diagrammatic representation of Biomass resource potential estimation approach. Source: AEA (2010).

The pricing model developed by Oxford Economics (outlined in Figure 28) assumes that the prices of the biomass fuels are primarily determined by the price of the underlying feedstock, which in turn is determined by the supply of the feedstock, by the respective demand (both energy and non-energy), as well as prices of other energy sources.

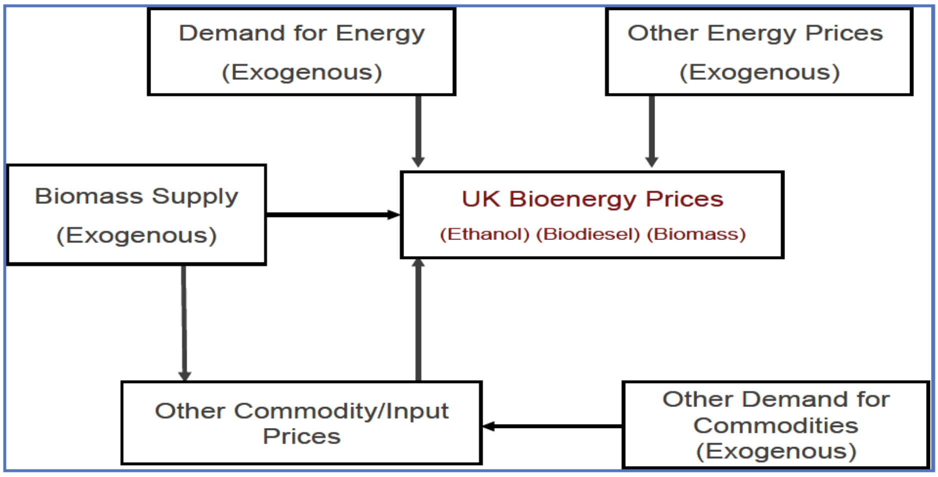


Figure 28: Schematic representation of the Oxford Economics Bioenergy pricing model. Source: AEA (2010).

One key difference of the model as compared to e.g. WEM is that it does not involve full supply-cost curves. Instead, it chooses certain price levels for biomass resources and estimates the biomass resource available at the given price levels.

PRIMES Biomass Model

PRIMES Biomass Model (PBM) is a model created by E3Mlab/ICCS of the National Technical University of Athens and has been used to evaluate the economics of supply of biomass and waste for energy purposes as a part of the Biomass Futures project (Apostolaki, et al. 2012). Like WEM, PBM tries to optimise the utilisation of available biomass resources to satisfy a certain demand. Future energy demand in PBM is obtained either from PRIMES base model, or derived from National Renewable Energy Action Plans. Also, like WEM, PBM models biomass production pathways using inputs on land availability, crop yields and conversion technologies. In contrast to WEM, though, PBM is mostly focusing on the EU region, and international trade is modelled only on main biomass trade routes, e.g. CIS and North America to Europe for woody biomass, Brazil to Europe for bio-ethanol, etc.

GCAM

In the study “Global and regional potential for bioenergy from agricultural and forestry residue biomass” maximum sustainable amount of energy potentially available from agricultural and forestry residues has been estimated.

The approach entails two parts. First, the maximum available sustainable supply of biomass residue is estimated based on crop and forestry production statistics and crop-specific parameters (input obtained from the Food and Agriculture Organization of the United Nations database) as well as accounting for the requirement of soil loss mitigation and soil nutrient preservation. Secondly, using an integrated assessment model, a market is simulated to estimate the fraction of the maximum sustainable supply of residue biomass that would be collected and utilised for 14 aggregated regions of the world all the way up to 2095.

The economics of harvesting residue biomass is simulated using data generated for the EIA NEMS (Energy Information Administration National Energy Modeling System), a model developed by the US Department of Energy to forecast US energy markets (supply, demand, prices, etc.) in order to inform energy policy decisions. For each region, the model estimates GDP based on assumptions about labour productivity and then estimates energy demand by end use. The model is designed to simulate, under various carbon markets, the integrated interactions between energy production (coal, petroleum, natural gas, nuclear, solar, geothermal, hydro, wind, biomass, and future exotic energy sources), energy transformation (e.g., refining, electricity production, hydrogen production), energy end use (buildings, industry, transportation), agricultural production (corn, wheat, rice, other grains, oil crops, sugar crops, fiber crops, fodder crops, miscellaneous, and biomass crops), forestry and forest production (both for managed and unmanaged forestland), rangeland and animal production, as well as land allocation dynamics (Gregg og Smith 2010). An overview of agriculture and land use model structure in GCAM is presented in Figure 29.

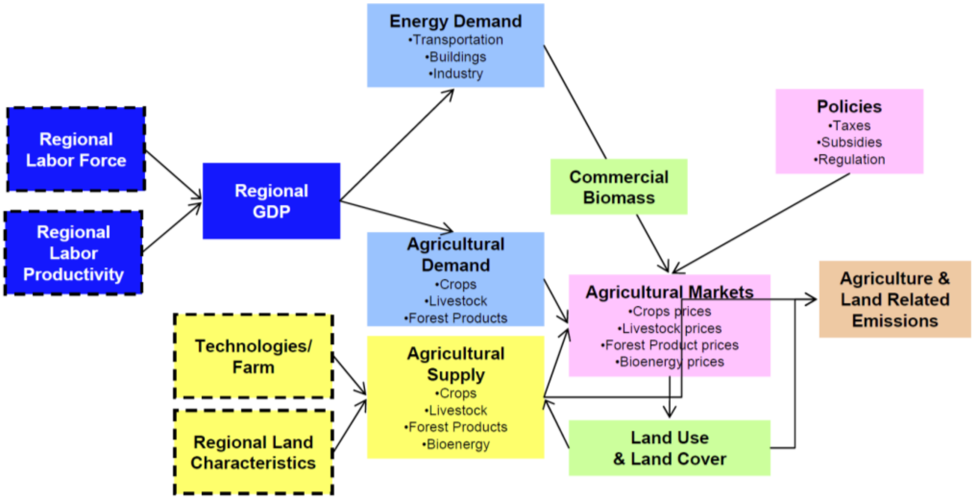
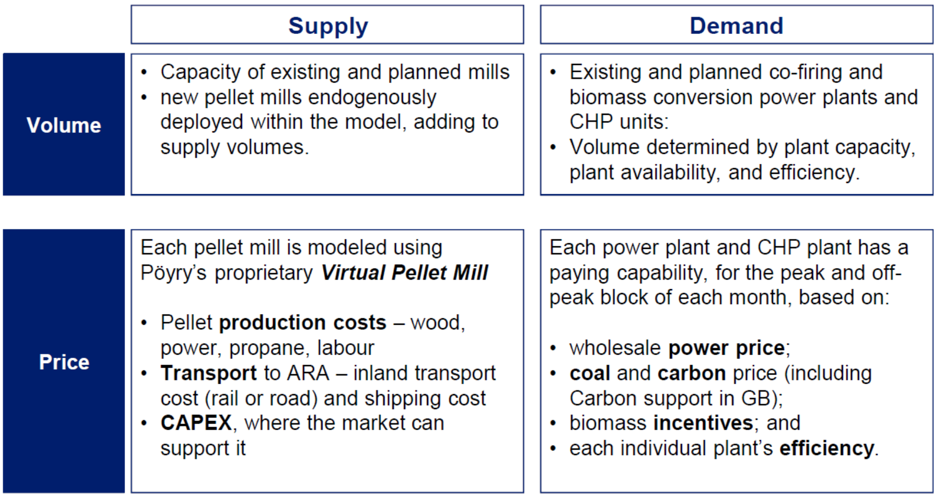


Figure 29: Agriculture and land use model structure of GCAM. Source: Kim (2010).

Pöyry's pellet pricing model

Pöyry Management Consulting have developed a model that forecasts future wood pellet price development by constructing forward supply and demand curves based on data on power plants, pellet mills and assumptions on future markets and regulatory environment (O'Carroll 2012). An overview of supply and demand factors deployed in the model is presented in Figure 30.



	Supply	**Demand**
Volume	• Capacity of existing and planned mills • new pellet mills endogenously deployed within the model, adding to supply volumes.	• Existing and planned co-firing and biomass conversion power plants and CHP units: • Volume determined by plant capacity, plant availability, and efficiency.
Price	Each pellet mill is modeled using Pöyry's proprietary ***Virtual Pellet Mill*** • Pellet **production costs** – wood, power, propane, labour • **Transport** to ARA – inland transport cost (rail or road) and shipping cost • **CAPEX**, where the market can support it	Each power plant and CHP plant has a paying capability, for the peak and off-peak block of each month, based on: • wholesale **power price**; • **coal** and **carbon** price (including Carbon support in GB); • biomass **incentives**; and • each individual plant's **efficiency**.

Figure 30: An overview of supply and demand factors underlying Pöyry Management Consulting's pellet pricing model. Source: O'Carroll (2012)

The key demand and supply factors are then quantified and incorporated into the model to construct demand (see Figure 31 for demand model structure) and supply curves (see Figure 32) respectively.

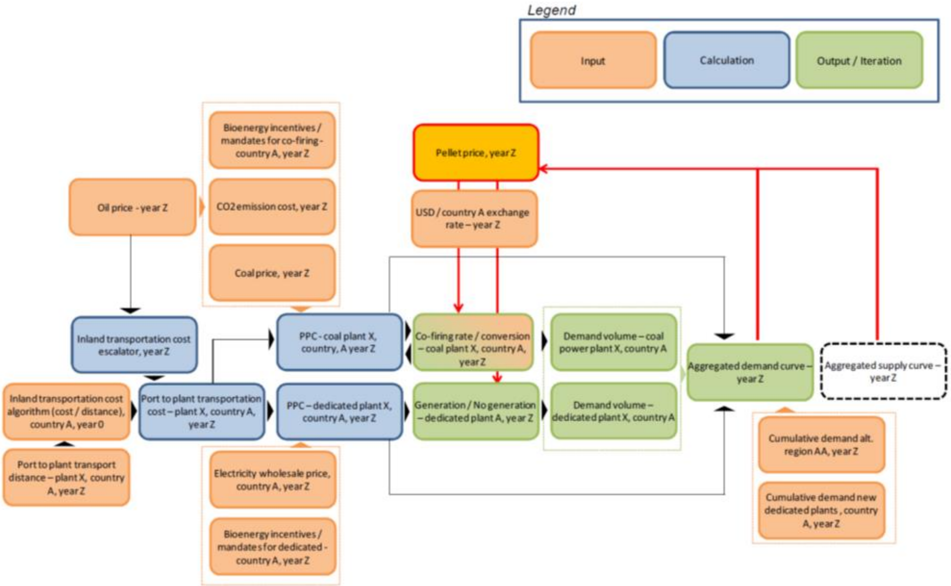


Figure 31: Model structure for Demand of the Pöyry Management Consulting's pellet pricing model. Source: O'Carroll (2012).

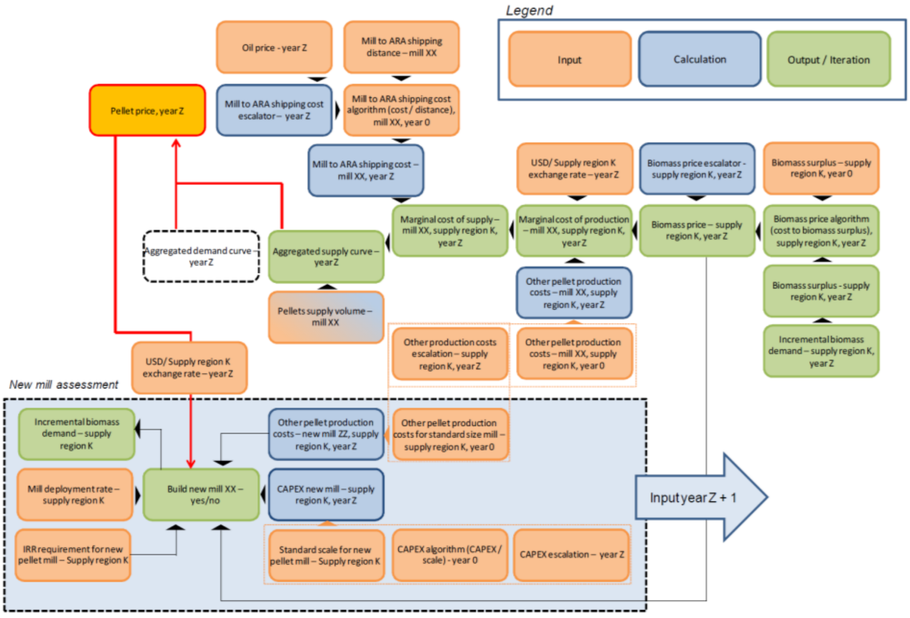


Figure 32: Model structure for Supply of the Pöyry Management Consulting's pellet pricing model. Source: O'Carroll (2012).

Arguably the key differentiating factor distinguishing Pöyry's approach from most other observed models is the fact that Pöyry's model does not consider supply factors at the top of the biomass supply chain e.g. the total volume of theoretically / technically feasible global / regional biomass resource. Instead, the supply focus has been shifted further up the value chain to points of processing of biomass (i.e. the pellet mills) and respectively matched by specific focus on points of demand (i.e. power plants).

Biomass price projections: overview of estimates in prior analyses

In the following section an overview is given of the key assumptions and results of the most important recent biomass future price estimation studies.

Sveaskog/Vattenfall – Biomass for heat and power

Key assumptions:

- Not a forecast. Instead, an aggressive European supply mobilisation scenario for 2020 estimating how much supply Europe could mobilise by 2020 if European countries set the ambition to utilise this resource to the furthest extent possible, given sustainability constraints.
- Focus on cost, not the price of biomass. Cost defined as the cost accrued by a fully backwards-integrated power or heat producer (Sveaskog, et al. 2010).

Results:

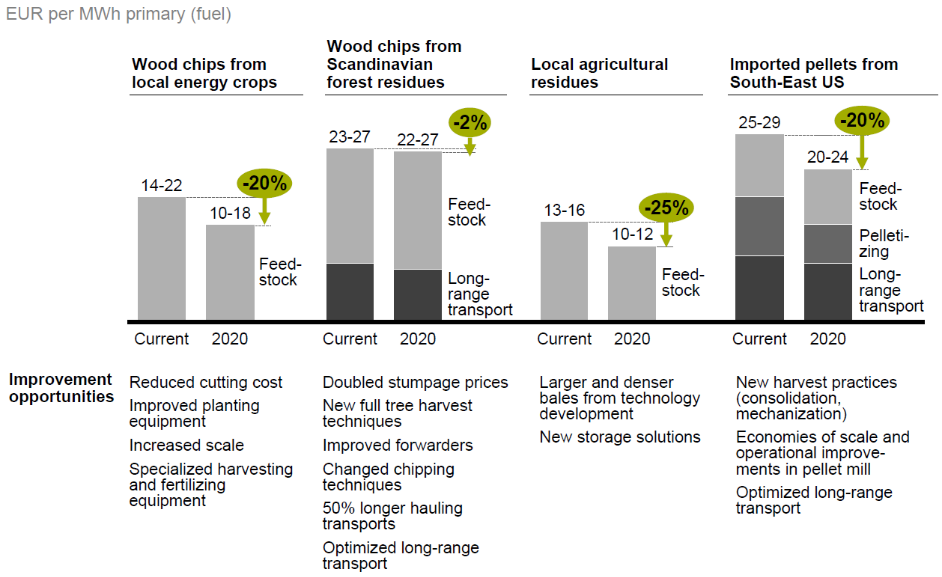


Figure 33: Cost reduction potential for biomass fuel delivered to power and heat plants in continental Europe. Source: Sveaskog et al (2010).

Pöyry – Biomass pellet prices

Key assumptions:

- 'High scenario' for 2015 being modelled, entailing high pellet demand and high paying capability (driven by high coal, power and carbon prices and high level of conversion and co-firing) as well as highest supply costs (driven by higher transportation costs, indexed to high oil price).
- Forward supply and demand curves are being modelled, each point on the curves representing an individual pellet mill or power plant, respectively (O'Carroll 2012).

Results:

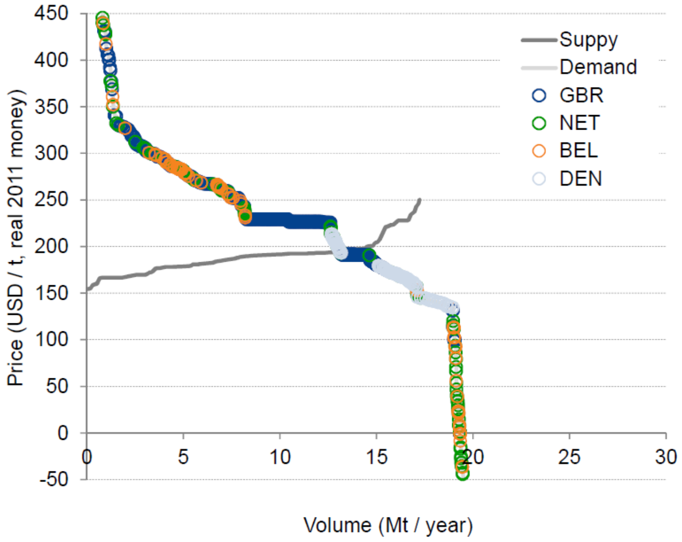


Figure 34: Pöyry future pellet price High Scenario for 2015. Source: O'Carroll (2012).

Biomass Futures – Atlas of EU Biomass potentials

Key assumptions:

- Cost estimates for biomass as it is received at the gate of the conversion / pre-treatment plant are made. The projections are made for 2020 and 2030 according to the Reference scenario and the Sustainability scenario for each year.
- In the Reference scenario GHG mitigation requirement (50% as compared to fossil fuels) as well as limitations on the use of biomass from biodiverse land or land with high carbon stock are only applied to biofuels and bioliquids consumed in the EU. In the Sustainability scenario all the limitations above (which are moreover applied in a stricter form, e.g. 70 % GHG mitigation requirement for biofuels as well as bioelectricty and heat in 2020 and 80% in 2030, respectively) apply to all bioenergy consumed in the EU, as well as GHG mitigation requirement includes compensation for indirect land use changes (Elbersen, et al. 2012).

Results:

MTOE	2020		2030	
	Reference	**Sustainability**	**Reference**	**Sustainability**
0-199 Euro/Toe	284	259	217	179
200-399 Euro/Toe	58	49	55	49
400-599 Euro/Toe	79	72	87	79
600-999 Euro/Toe	4	0	51	46
>=1000 Euro/Toe	5	0	1	0
Total	**429**	**379**	**411**	**353**

Table 16: Biomass Futures project, Atlas of EU biomass potentials results. Overview of biomass potential (MTOE) per price class for 2020 and 2030 in the Reference and Sustainability scenarios for EU-27. Source: Elbersen et al (2012).

Biomass Futures – PRIMES biomass model projections

Key assumptions:

- Consumer prices of the final biomass products used for energy purposes are modelled based on 4 different scenarios.
- Reference scenario assumes the implementation of the entire EU Climate and Energy package for 2020 and successful implementation of all policies adopted by the EU until March 2010. Reference NREAP scenario updates the demand side of the Reference scenario so that it would be in line with the set-up set forth in NREAPs. Decarbonisation scenario assumes compliance with the EU long-term target of 80% GHG emission reduction in the EU by 2050. Sustainability scenario models tightening of sustainability requirements in line with the EU's fuel quality directive (EC 2009). Maximum biomass scenario assumes all biomass potential as available and maximises bioenergy demand (Apostolaki, et al. 2012).

Results:

Scenario	2020	2030	2050
Small-scale solid biomass (mainly pellets), EUR / toe			
Reference	645	818	844
Reference NREAP	680	812	844
Decarbonisation	688	901	1022
Sustainability	742	957	1032
Maximum biomass	691	917	1052

Table 17: Commodity price estimates of small-scale solid woody biomass for 2020, 2030 and 2050 as per Biomass Futures - PRIMES biomass model projections, EUR/toe. Source: Apostolaki et al (2012).

Scenario	2020	2030	2050
Large-scale solid (woody biomass for use in power generation), EUR / toe			
Reference	625	636	558
Reference NREAP	662	708	594
Decarbonisation	651	649	585
Sustainability	648	707	605
Maximum biomass	657	684	631

Table 18: Commodity price estimates of large-scale solid woody biomass for 2020, 2030 and 2050 as per Biomass Futures - PRIMES biomass model projections, EUR/toe. Source: Apostolaki et al (2012).

Danish Energy Authority – Socio-economic biomass price prognosis

Key assumptions:

- Price-at-power plant among others has been estimated for a range of solid biomass types.
- It was set forth that biomass prices in Denmark will increasingly be dependent on international price developments as opposed to variations in Danish demand. The price projections were mainly based on future production costs estimates combined with expectations in terms of relevant transportation cost developments (Energistyrelsen 2012).

Results:

2011 DKK/GJ	Straw	Wood chips	Wood pellets (industrial)
2012	41.5	47.3	70.2
2013	41.8	47.8	70.8
2014	42.1	48.4	71.3
2015	42.3	48.9	71.8
2016	42.6	49.5	72.3
2017	42.9	50.1	72.9
2018	43.2	50.6	73.4
2019	43.5	51.2	73.9
2020	43.8	51.8	74.4
2021	44.1	52.4	75.0
2022	44.4	53.0	75.5
2023	44.7	53.7	76.0
2024	45.1	54.3	76.5
2025	45.4	54.9	77.0
2026	45.7	55.6	77.6
2027	46.0	56.3	78.1
2028	46.3	56.9	78.6
2029	46.7	57.6	79.1
2030	47.0	58.3	79.7
2031	47.3	59.0	80.2
2032	47.7	59.7	80.7
2033	48.0	60.4	81.2
2034	48.4	61.2	81.8
2035	48.7	61.9	82.3

Table 19: Socio-economic biomass price prognosis (price-at-power plant) by the Danish Energy Authority. Source: Energistyrelsen (2012).

IEA Bioenergy Task 40 – Global market for wood pellets and price development

Key assumptions:

- Expected price developments for wood pellets until 2015 based on ENDEX-Pellet index, Rotterdam.
- Market development and price factors assumed include the effect of torrefaction technology, increasing demand (based on NREAPs in the EU and national initiatives in e.g. Japan, South Korea, UK), as well as possible price increases due to indirect land use change relating to the expected high sustainability standards (IEA and DTI 2012).

Results:

	2011	2012	2013	2014	2015
	ENDEX wood pellet price, EUR / tonne				
Wood pellets	128	132.5	136.8	139.5	142.3

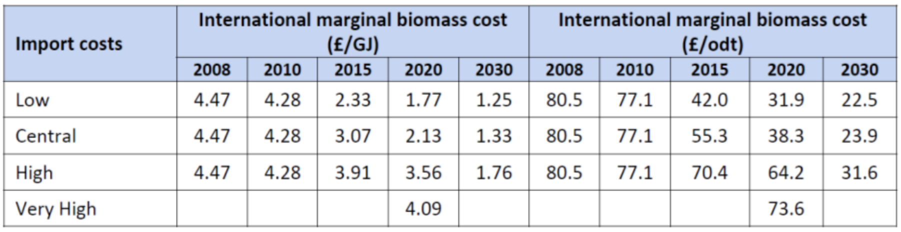
Table 20: Expected price development for wood pellets until 2015 (ENDEX-pellet index, Rotterdam). Source: IEA and DTI (2012).

E4tech – Biomass prices in the UK heat and electricity sectors in the UK for the Department of Energy and Climate Change

Key assumptions:

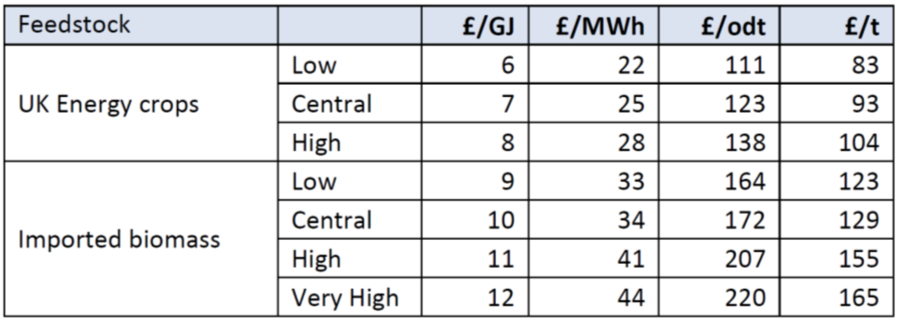
- ‘Willingness-to-supply’ price estimates for wood chips and wood pellets in the UK’s heat and electricity sectors in 2020 have been derived. I.e. the price estimates are based on a cost model without considering potentially higher prices due to competing uses of the feedstock. The price estimates provided correspond to delivered price of biomass as seen by the UK customers.
- Prices for 2020 were only quantified for the heat sector (heat-only and CHP plants between 3 MW and 10MW). The biomass price mechanisms in the electricity sector were deemed too uncertain to arrive at a single price estimate (E4tech 2010).
- Different cost level scenarios have been explored – Low, Central, High and Very High, respectively.

Results:



Import costs	International marginal biomass cost (£/GJ)					International marginal biomass cost (£/odt)				
	2008	2010	2015	2020	2030	2008	2010	2015	2020	2030
Low	4.47	4.28	2.33	1.77	1.25	80.5	77.1	42.0	31.9	22.5
Central	4.47	4.28	3.07	2.13	1.33	80.5	77.1	55.3	38.3	23.9
High	4.47	4.28	3.91	3.56	1.76	80.5	77.1	70.4	64.2	31.6
Very High				4.09					73.6	

Table 21: International marginal biomass costs GBP/GJ and GBP/odt based on an intersection of estimated global supply cost curve for energy crops, forestry and wood industry residues with estimated demand for woody residues, respectively. Source: E4tech (2010).



Feedstock		£/GJ	£/MWh	£/odt	£/t
UK Energy crops	Low	6	22	111	83
	Central	7	25	123	93
	High	8	28	138	104
Imported biomass	Low	9	33	164	123
	Central	10	34	172	129
	High	11	41	207	155
	Very High	12	44	220	165

Table 22: Projected wood chip prices in the UK heat sector in 2020. Source: E4tech (2010).

Feedstock			£/GJ	£/MWh	£/odt	£/t
UK Energy crops	Bagged	Low	12	43	213	196
		Central	13	46	229	211
		High	14	50	249	229
	Bulk	Low	10	36	182	168
		Central	11	40	199	183
		High	12	44	218	201
	Overall (50:50 split)	Low	11	40	198	182
		Central	12	43	214	197
		High	13	47	233	215
Imported biomass	Bagged	Low	13	48	242	222
		Central	14	51	253	233
		High	17	60	300	276
		Very High	18	63	317	292
	Bulk	Low	11	41	204	187
		Central	12	43	215	198
		High	14	52	259	239
		Very High	15	55	276	254
	Overall (50:50 split)	Low	12	45	223	205
		Central	13	47	234	215
		High	16	56	280	257
		Very High	16	59	296	273

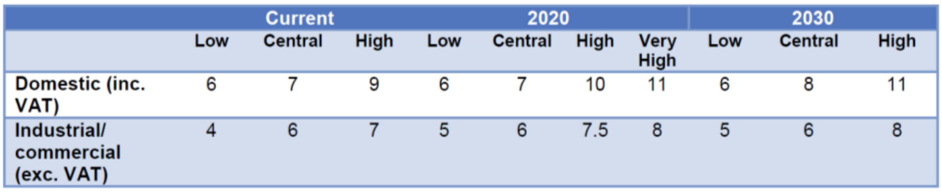
Table 23: Projected wood pellet prices in the UK heat sector in 2020. Source: E4tech (2010).

AEA and Oxford Economics – UK and Global Bioenergy resource

Key assumptions:

- Prices of internationally traded wood chips and wood pellets to 2030 have been estimated. Wood pellet prices are related to use in the heat sector. Wood chip price estimates are provided both for industrial/commercial heat and domestic heat users. Large scale electricity sector is not a part of this price estimation due to its reliance on large bilateral agreements.
- Price projections have been made for 3 different scenarios. Central – business-as-usual scenario for global biomass supply, Low – a scenario of weaker economic growth and lower energy prices, as well as less investment in biomass supply and hence lower level of biomass supply, High – a scenario of stronger global economic growth and higher energy prices, as well as more investment in biomass supply (AEA 2010).

Results:



	Current			2020				2030		
	Low	Central	High	Low	Central	High	Very High	Low	Central	High
Domestic (inc. VAT)	6	7	9	6	7	10	11	6	8	11
Industrial/ commercial (exc. VAT)	4	6	7	5	6	7.5	8	5	6	8

Table 24: Bioenergy price projections for wood chips (GBP/GJ) 2010 prices. Source: AEA (2010).

	Current			2020				2030			
	Low	Central	High	Low	Central	High	Very High	Low	Central	High	Very high
Bulk	11	12	13	12	13	15	17	11	13	15	18
Bagged	13	15	17	15	17	19	21	13	16	19	23
Overall	12	14	16	14	15	18	20	12	15	18	21

Table 25: Bioenergy price projections for wood pellets (GBP/GJ) 2010 prices. Source: AEA (2010).

GCAM – Global and regional potential for bioenergy from agricultural and forestry residue biomass

Key assumptions:

- The global price for residue biomass is estimated based on total energy demand and the prices for competing sources of energy (Gregg og Smith 2010).
- Two climate policy scenarios are modelled – Reference (with no carbon price) and Policy (where 450 mm atmospheric concentration of CO_2 by the end of century is reached). In addition, the impact of variation in crop yields on biomass price is modelled (Default – modest increases in crop yields in line with historic averages, Low – no increase in yield rates, High – double yield rates in the next century) as well as impact of variation in the average costs of collecting, processing and delivering biomass (Midprice Default – base value, Midprice Low – 50% of the base value, Midprice High – 200% of the base value).

Results:

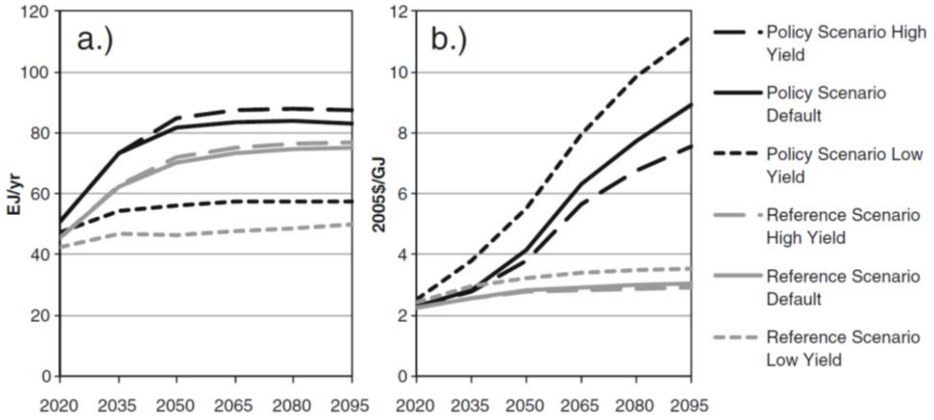


Figure 35: Projected biomass total resource and price for different agricultural productivity scenarios across Reference and Policy climate scenarios. Source: Gregg and Smith (2010).

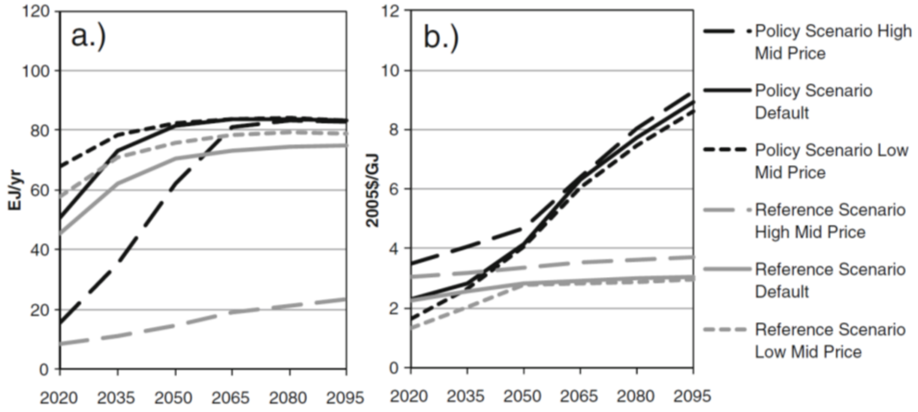


Figure 36: Projected biomass total resource and price for different Mid Price level (i.e. the average cost of collecting, processing and delivering a resource) scenarios across Reference and Policy climate scenarios. Source: Gregg and Smith (2010).

Summary of solid biomass future price projections

The tables below summarise key price estimates for wood pellets and wood chips from prior studies respectively, converted to a common unit (EUR/GJ) for ease of comparison. Please note that there are substantial differences in terms of the scope and purpose of each of the studies reviewed, hence comparison of the values summarized should be done with caution and with reference to the key assumptions and specifications of each respective study.

Price estimate source	2010	2015	2020	2030	2050	Comments
			Wood pellet price, EUR/GJ			
Sveaskog	6.98 to 8.05		5.5 to 6.71			Imported pellets
Pöyry		7.79				High pellet demand scenario
Biomass Futures - PRIMES			15.30	19.46	20.13	Small-scale woody biomass: mainly pellets. Reference scenario
DEA 2011		9.66	9.93	10.74		Industrial wood pellets
IEA Task 40		8.19				ENDEX pellets
E4tech			12.89			UK heat sector, bulk pellets, local origin
E4tech			13.96			UK heat sector, bulk pellets, imported
AEA	13.96		15.17	15.17		Bulk wood pellets

Table 26: Summary of key wood pellet price projection study results, EUR/GJ.

Price estimate source	2010	2015	2020	2030	2050	Comments
			Wood chip price, EUR/GJ			
Sveaskog	3.89 to 6.17		2.82 to 4.97			Wood chips from local energy crops
Sveaskog	6.44 to 7.52		6.17 to 7.52			Wood chips from Scandinavian forest residues
DEA 2011		6.58	6.98	7.79		
E4tech			8.19			UK heat sector, UK energy crops
E4tech			11.68			UK heat sector, imported biomass
AEA	6.98		6.98	6.98		Industrial wood chips, Central scenario

Table 27: Summary of key wood chip price projection study results, EUR/GJ.

8 Description of model used in this study: GCAM

8.1 Description of GCAM

The Global Change Assessment Model (GCAM) is one of the premier integrated assessment models (IAMs) used for economic, technological, and policy analysis. GCAM began in 1975 under the name MiniCAM (Mini Climate Assessment Model), and has since been used in every Intergovernmental Panel on Climate Change (IPCC) assessment report, and is one of four IAMs chosen to develop the new representative concentration pathways (RCPs) for future anthropogenic CO_2 emissions in the fifth assessment report. GCAM has also been one of the IAMs used in the Climate Change Science Program (CCSP) and the Climate Change Technology Program (CCTP), assessments of the Climate Change Research Initiatives by the US Government. GCAM has also been a part of every Energy Modeling Forum (EMF), a forum for IAM modeling teams, climate study.

GCAM is designed as a model to understand the socioeconomic dimension of global change. It combines an economic energy module, an integrated land use agroforestry model, and a climate model to assess how these human drivers impact the global environment. GCAM is a partial equilibrium model and as such it focuses on aggregate human drivers: population demographics, labour productivity, gross domestic product, and the corresponding food, timber, and energy demands from the industrial, transportation, and buildings sector for 14 geopolitical regions of the world. The energy system contains resource data for all of the major energy sources (petroleum, coal, natural gas, nuclear, solar, wind, bioenergy, geothermal, hydro, exotic sources) and contains a detailed technology demand representation. The integrated land use model is a particular strength of GCAM in comparison to many other IAMs (Table 28) and includes representation of 12 crop types, 6 animal product categories, forestry, pasture, and biomass crops. While not a detailed Global Climate Model (GCM), GCAM's integrated climate module analyses the climatic effect of energy and land use emissions for 16 different greenhouse gases and short lived species.

GCAM takes an economic equilibrium approach and solves for all energy and land markets simultaneously by finding a vector of prices that balance supply and demand. Markets can be set up as regional, multi-regional, or global, depending on user specifications. The model is dynamic recursive, meaning that GCAM solves each period in a stepwise fashion, and then takes the solution from a given period and applies the appropriate initial conditions to the next time step (Wise og Calvin 2011).

In GCAM, biomass is produced from agroforestry land as purpose grown energy crops (dedicated plantations), as crop residues (stalks and stover from agricultural products), forestry residue (slash from timber operations), mill residue (sawdust and pulping liquors), and municipal solid waste. Biomass crops compete with other land uses, based on equalising marginal profit rates against competing land uses. However, GCAM is not winner-take-all, and this allocation is subject to a share weight function that prescribes the ease at which land can be converted from one use to another. Furthermore, food demand is relatively inelastic and crop yields are fixed within each region for each crop for a given time step and by default is based on estimates produced by the Food and Agriculture Organisation (FAO) (Bruinsma 2009). All biomass crops are aggregated into one generic energy crop in the version of GCAM employed in this study, GCAM-DTU. Agroforestry residues are a by-product of other activities, namely food and forestry, and the amount of residue biomass harvested (the proportion of the sustainable technical potential) that enters the energy stream is a function of the equilibrium price for the biomass market. The sustainability constraint requires a portion of the residue to remain on the land to retain soil nutrient levels and to reduce soil loss through erosion. Production of municipal solid waste is estimated via a function of the per capita GDP for each region at each time step.

Biomass is on a global market in GCAM, and though interregional trade is not explicitly modelled, the supply of biomass is considered a global resource from which all regional demand is met. The equilibrium price represents the average cost of production for biomass, including collection and aggregation (per crop variable costs, which in essence set a price floor for production), and marginal land rent (with the exception of conversion of unmanaged land, which does not produce a product, and in such cases the average land value is used). Variation in profit is due to variation in cost of production: As the area devoted to one land use expands, cost increases. In the case of a climate policy where there is a price on carbon emissions, then emissions associated with land use change and conversion are also included in the biomass price, based on the difference of the estimated carbon stocks within the different land classes (Wise og Calvin 2011).

It should, however, be noted that the version of GCAM employed in this study, GCAM-DTU, does not include cost of land use change. I.e. should a switch in land use from e.g. forest to agricultural land be modelled for a given area, there would be no cost associated with this switch per se. As such, it represents a departure from reality (as in practice there would be possibly significant costs associated with turning a forest into agricultural land, e.g. deforestation, soil preparation etc.) and allows for too extensive land use changes than one would expect in reality.

GCAM assumes a perfect market in its equilibrium calculations: that is, a free market, perfect knowledge, and no tariffs, subsides, quotas, mandates or other market distortions. Trade in GCAM is not modelled explicitly, and while some goods have transportation costs added, this is done in a simplistic fashion where a flat rate is added; i.e., there is no geographical representation of transportation distances with trade. For the purposes of this study, we consider only the global biomass price where the GCAM transportation costs are neglected. Finally, hereafter we refer to the model as GCAM-DTU (GCAM Denmark Technical University), which is built on the GCAM 2.0 architecture, but has slightly more optimistic assumptions on future modernisation of the African industrial sector.

8.2 Other economic models of agriculture and land use

In this section a brief overview of other prominent economic models of agriculture and land use will be given, as well as their comparison alongside GCAM-DTU across critical model characteristics. Table 28 summarises the key models and provides an overview of their respective critical attributes.

Model	Regional Scope	Number of Land Regions	Economic Sector Scope	Land Type Coverage	Crop Production Modelling	Economic Solution Approach	Time Horizon
FASOM	US (curves non-US)	60	Ag. & Forest	Crop, Pasture, Comm. Forest	Discrete Crop Technologies	Constrained Optimisation	100 years
Polysys	US	300	Ag.	Crop, Pasture	Discrete Crop Technologies	Constrained Optimisation	20 years
GLOBIOM	Global	27	Ag. & Forest	Crop, Pasture, Comm. Forest	Discrete Crop Technologies	Constrained Optimisation	30+ years
GTAP	Global	117+	Everything	Crop, Pasture, Comm. Forest	Economic Production Functions	General Equilibrium	Static
FAPRI	Global	dozens	Ag.	Non-spatial	Economic Equations	Market Equilibrium	10+ years
GCAM 3.0	Global	151+	Ag., Forest, Energy	All	Discrete Crop Technologies	Market Equilibrium	100+ years

Table 28: Comparison of most prominent economic models of agriculture and land use across key attributes. Source: Wise and Calvin (2011)

Overall, given the specifics of the research question underlying the current report, one can argue that GCAM-DTU is one of the best fits based on several of the critical attributes. First of all, regional scope should be global given the fact that the main area of investigation is Denmark and prospective global biomass import flows should also be considered. Secondly, given the energy industry focus, it is imperative that the model deployed would have the capability of reflecting energy industry and economic interrelations therein. Finally, the time horizon covered by the model should be sufficient to provide an estimate for 2050. High resolution of regional difference representation and broad land type coverage are additional factors that should enhance the relative accuracy of the GCAM-DTU results.

8.3 Scenarios

Eight scenarios were run for the analysis. The first, a reference scenario, is the default assumptions of GCAM-DTU: no climate policy, FAO future diet and yield projections. Two climate policy scenarios were run, the RCP 4.5, a global carbon policy that stabilises the climate at 4.5 W/m^2 radiative forcing, equivalent to an atmospheric concentration of about 525 ppm CO_2 and roughly 2.5° C warming by 2100. The price path is seen in Figure 37 below. A regional policy was also considered, with the same prices in RCP 4.5, but in contrast to the RCP 4.5, the market included only the developed regions (US, Canada, Western Europe, Eastern Europe, Former Soviet Union, Australia/New Zealand, Japan, and South Korea).

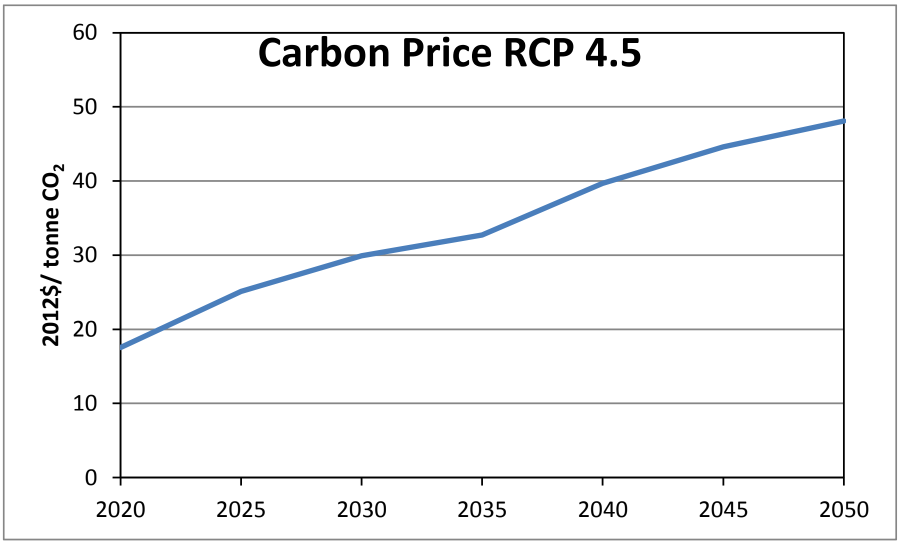


Figure 37: Carbon price for RCP 4.5. The price is defined by a global carbon cap and trade system designed to stabilise the greenhouse gas concentration by 2100 such that the radiative forcing is 4.5 W/m^2 above preindustrial times. The same price path is used in the regional policy, but only applied to develop regions of the world.

One of the major input assumptions is the FAO assumption for future yield from (Bruinsma 2009). This scenario has generally increasing crop yields (based on historic levels) to 2050, specific to each region and each crop. The High Yield scenario is even more optimistic about future agricultural technologies to improve global crop yields. The Low Yield scenario is a pessimistic case where there are no regional crop specific yield improvements beyond 2005. These are summarised for the world's three major grains (maize, wheat, and rice) weighted by global calorie output per unit of planted land in Figure 38. Note, that even in the reference scenario, global average crop yields will decline as the production moves to areas of the world and land types with lower yields. Furthermore, while yield improvements are assumed in biomass plantations, no yield improvements are assumed for roundwood production in the forestry sector in any scenario.

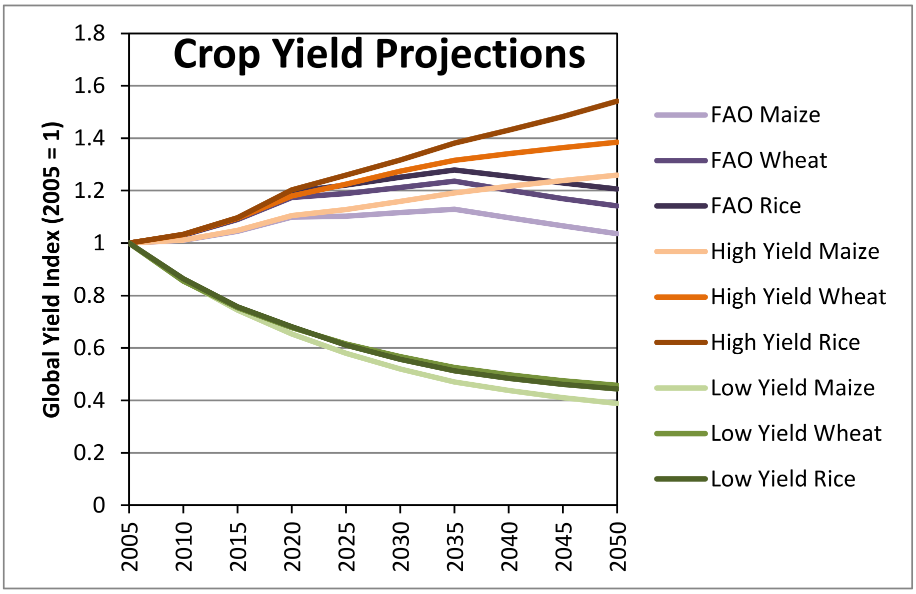


Figure 38: Global crop yield projections for three scenarios, weighted by calorific output per unit of land.

Finally, three additional diet scenarios were considered in addition to the reference scenario. First, a constant diet is run, where the current regional per capita caloric intake is projected into the future. Second, a western diet scenario is run, where the world evolves to diet similar to that of US, Canada, Western Europe and Australia/New Zealand by 2100. This diet is approximately 3700 kcal/cap/day, of which about 35% comes from animal products. Finally, a vegetarian diet is considered, where the world evolves to a diet patterned off of the current average diet of India by 2100: about 2500 kcal/cap/day, 10% of which are from animal products. In these scenarios, the regional proportional consumption of crops and animal products remains the same (i.e., the Middle East prefers sheep and goat to pork, etc.); only the relative proportion of animal products to vegetal products are scaled. This is done to keep the cultural aspects of the diets similar, but to evolve them in such a way that the regions can consume more or less animal products. Also, these diet scenarios are not considered likely scenarios, but rather demonstrate logical extremes in order to better understand the effect this parameter has on future biomass prices.

In summary, the scenarios are:

1. Reference: A scenario where the default GCAM-DTU assumptions on future yield and diet and no climate policy
2. RCP 4.5: A scenario with an ambitious global climate policy designed to stabilise the climate at 4.5 W/m2 radiative forcing
3. Regional Policy: a scenario with a partial participation climate policy, where only the developed regions of the world see a carbon price; emissions are free in developing regions
4. High Yield: a scenario with optimistic improvements in future crop yields
5. Low Yield: a pessimistic scenario where there are no future crop yield improvements
6. Current Diet: a scenario where the per capita calorific consumption for each food type in each region is held constant through time and population is the only driver for changing food demand
7. Western Diet: a scenario where the world evolves to the current western diet (in terms of animal product proportions and total calorific intake)
8. Vegetarian Diet: a scenario where the world evolves to the current Indian diet (in terms of animal product proportions and total calorific intake).

8.4 GCAM-DTU Results

The presence of a climate policy, particularly a global policy, encourages more biomass crops to be grown and a greater proportion of the crop residues to be collected. Compare Figure 39 and Figure 40, where the total bioenergy supplied to the market increases from around 90 EJ/yr. in 2050 to over 140 EJ/yr. in 2050. The regional policy falls in between these two extremes.

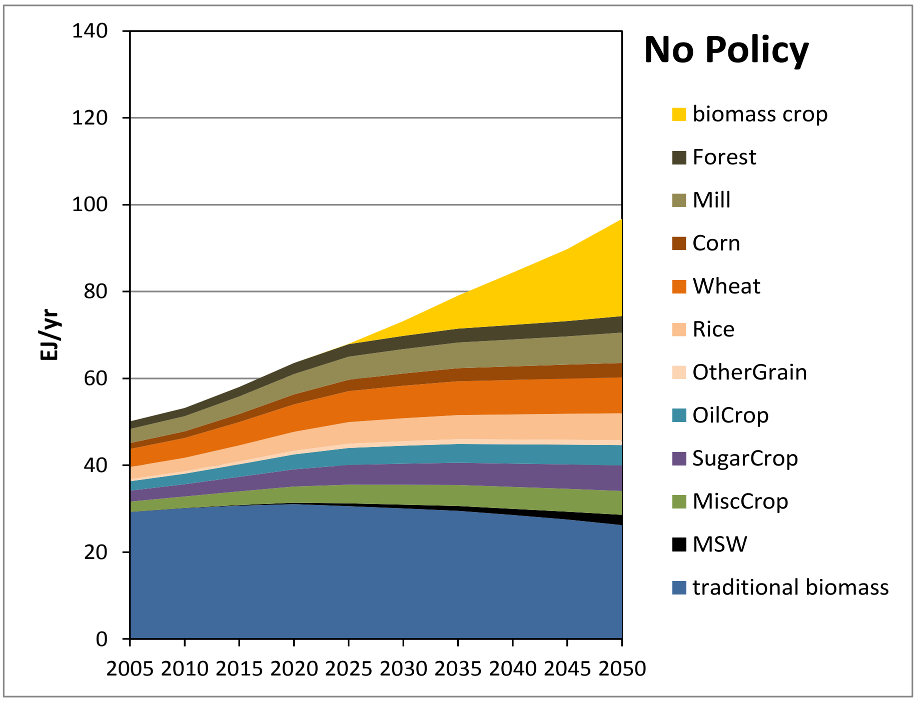


Figure 39: Global biomass supplied to the market under a no policy scenario.

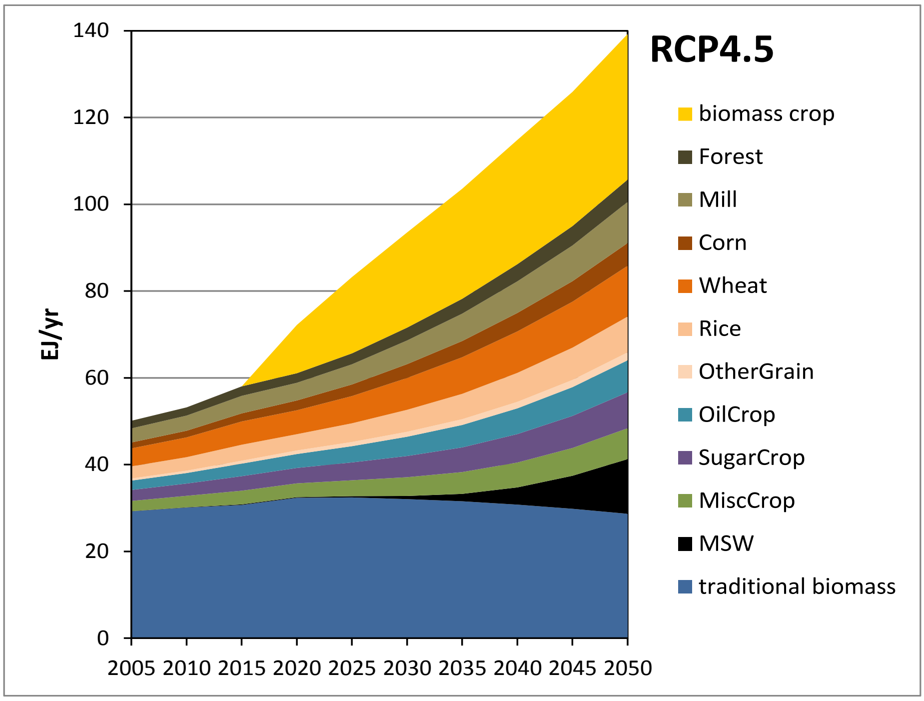


Figure 40: Global biomass supplied to the market under a RCP 4.5 scenario.

Yield assumptions did not have much effect on biomass supply, varying between 91 to 106 EJ/yr. by 2050 for the low yield and high yields respectively. These did make large difference for land use, however, where low yield assumptions caused a large expansion of crop land (Figure 41), where nearly half of the world's arable land is devoted to crop production by 2050 and forests are squeezed out.

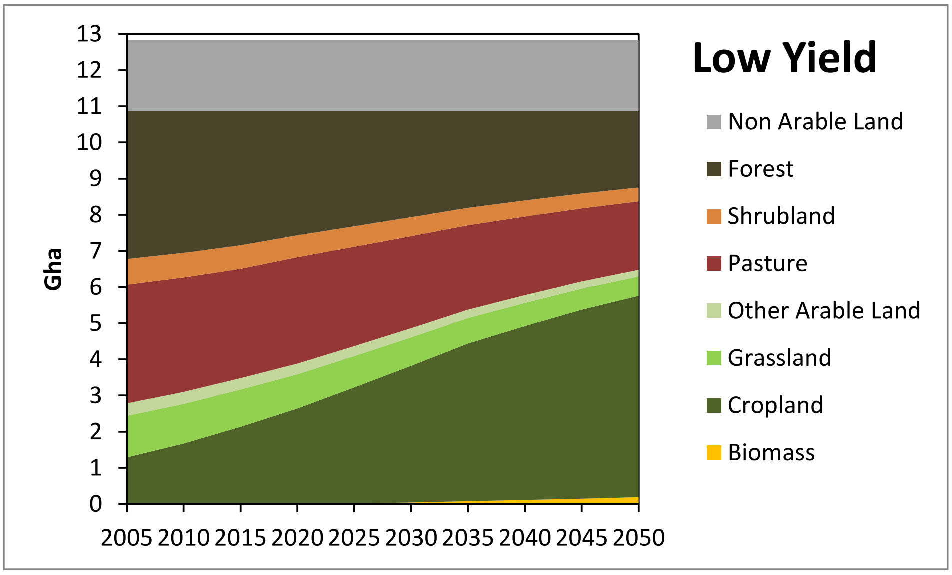


Figure 41: Land Use for the low yield scenario.

A similar effect is seen in the Western Diet scenario (Figure 42). In this scenario, even more land is dedicated to crop production than the low yield scenario, and approximately half of the world's forestland is converted to other uses by 2050. As such, this scenario does not allow much space for dedicated biomass crops, and nearly the entire supply of biomass (91 EJ/yr.) comes from residue sources (Figure 43).

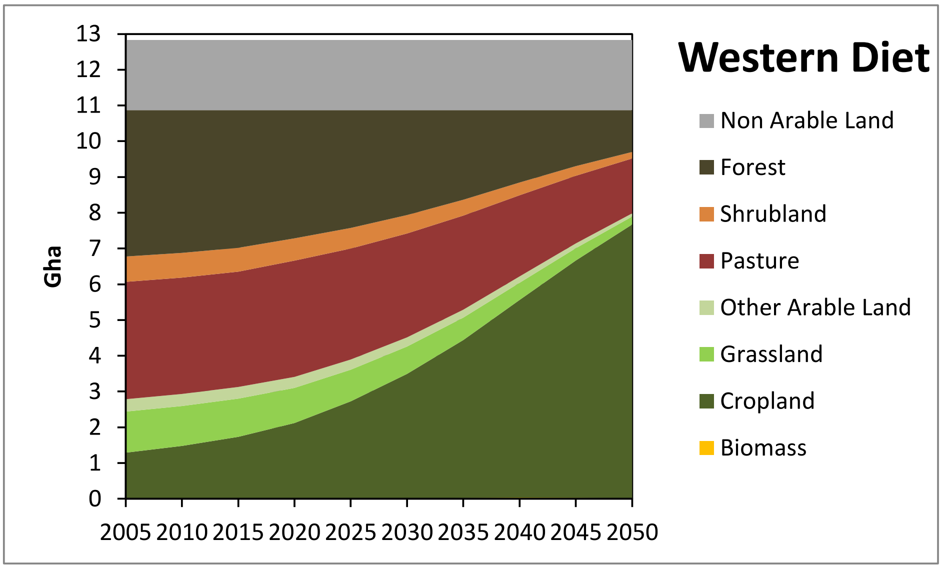


Figure 42: Land Use for the Western Diet scenario.

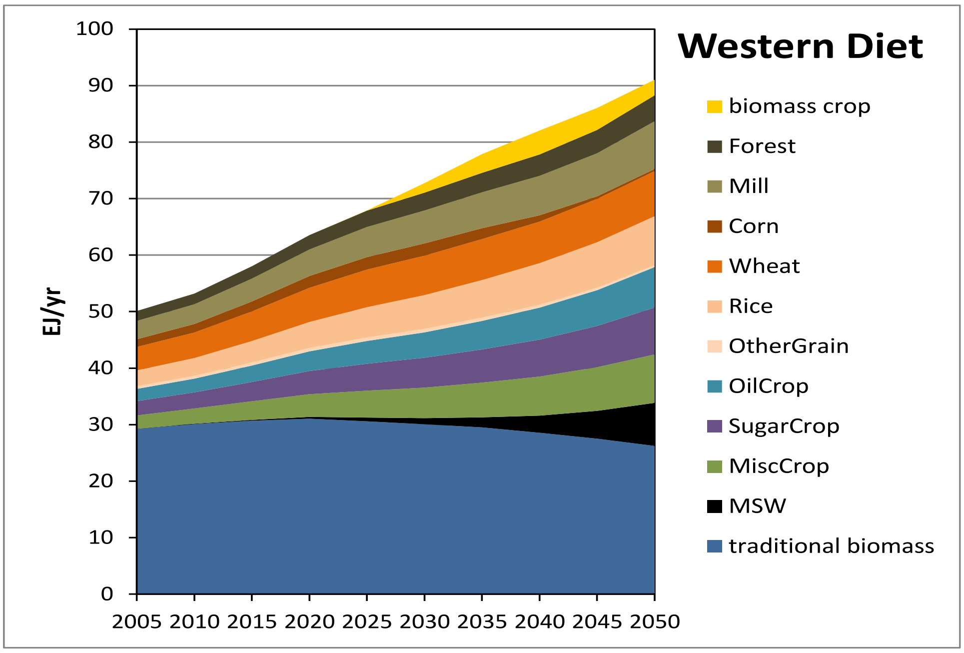


Figure 43: Biomass supplied to the global market in the Western Diet Scenario.

On the contrary, a vegetarian diet allowed for more bioenergy crops to be grown (97 EJ/ yr. by 2050), while preserving more forestland (Figure 44). The vegetarian diet scenario does not vary much from the no policy scenario.

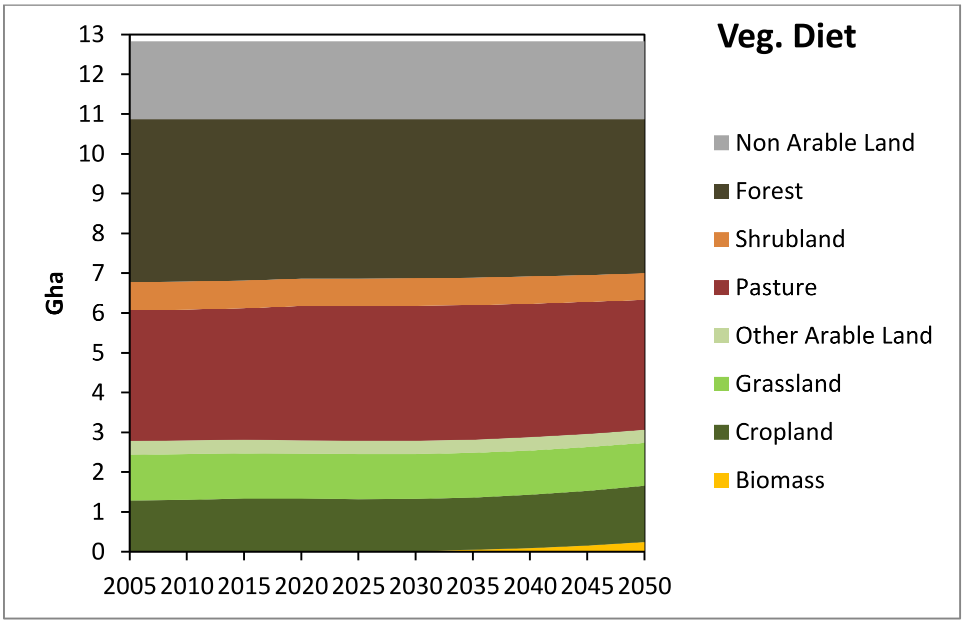


Figure 44: Land use with the vegetarian diet scenario.

In the context of the current study, however, the Low Yield and Western Diet scenarios should be considered as extremes and not necessarily reflecting realistic land use change future prospects (as illustrated in Table 29, the central scenario employed in this study, the Regional Policy scenario, results in 5.07

GHa forestland by 2050, comparable to that of Veg. Diet scenario). This is, among other things, due to the fact that GCAM-DTU version of the model does not employ land use change costs per se, and also does not explicitly account for protected lands (a feature available in GCAM version 3.0). Attempts to carry out the modelling for the purposes of the current study using GCAM 3.0 were, however, not successful for other operational reasons, hence GCAM-DTU version of the model is still based on GCAM 2.0 with its respective limitations.

The supply and land use results are summarised in Table 29. Because land carbon is valued in the policy scenarios, GCAM-DTU finds a solution where land is converted to forestry. Additionally, more land is dedicated to biomass crops in the policy scenario as they present a low-carbon fuel that can substitute for fossil fuels. The policy scenarios therefore have the highest biomass supply of all scenarios.

Scenario (year 2050)	No Policy	RCP 4.5	Reg. Policy	High Yield	Low Yield	Constant Diet	Western Diet	Veg. Diet
Total Biomass (EJ)	96.7	139.2	109.4	106.4	91.4	96.9	91.0	97.3
Biomass Crops (EJ)	22.4	33.5	28.7	31.8	15.1	23.0	2.8	25.0
Crop Residue (EJ)	35.0	49.8	38.0	35.5	30.8	34.6	41.4	33.4
Forestry/Mill Residue (EJ)	10.8	14.6	11.9	10.6	12.7	10.7	13.0	10.6
MSW/Traditional Biomass (EJ)	28.6	41.3	30.7	28.4	32.8	28.5	33.9	28.3
Biomass land (Gha)	0.24	0.17	0.33	0.32	0.19	0.25	0.02	0.25
Cropland (Gha)	1.80	1.10	2.47	1.45	5.57	1.69	7.65	1.41
Forestland (Gha)	3.60	5.07	5.07	3.71	2.11	3.68	1.17	3.87

Table 29: Supply and land use outcomes for the various scenarios for the year 2050.

The effect on biomass prices is shown in Figure 45. From GCAM-DTU we see that the factors that a climate policy, followed by diet, then by crop yield assumptions are what predominately affect the future price of biomass. Nevertheless, the solutions for the GCAM-DTU runs show the future biomass price to be rather stable, and most scenarios follow the same general upwards trend in prices.

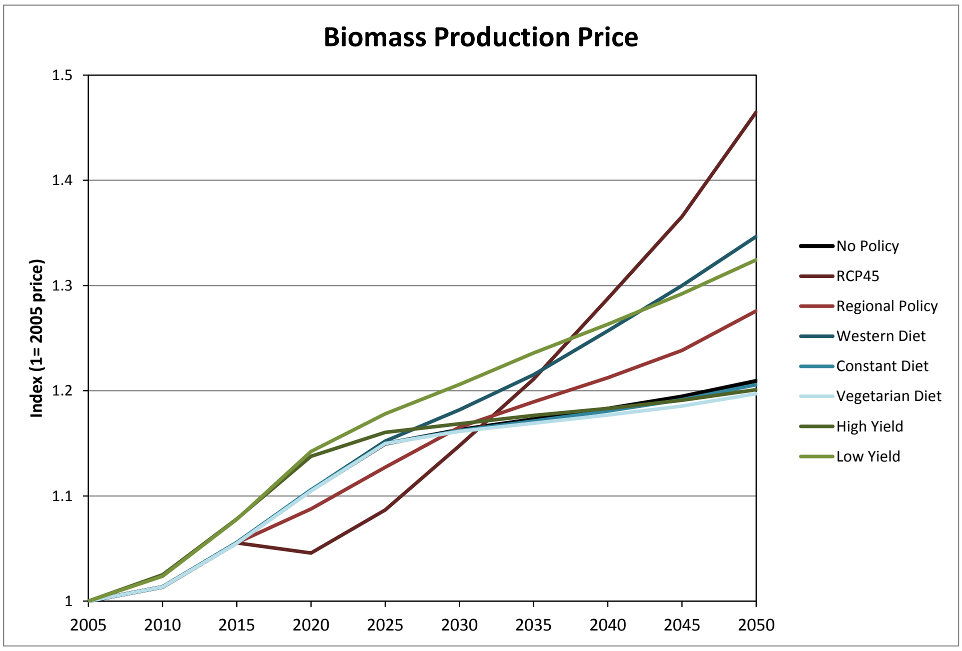


Figure 45: GCAM-DTU biomass price paths from the 8 scenarios, indexed to 2005.

8.5 GCAM output prices

The final output prices from GCAM for the 8 scenarios are presented below:

Scenario	2010	2015	2020	2025	2030	2035	2040	2045	2050
Base Scenario	0.67	0.70	0.73	0.76	0.77	0.77	0.78	0.79	0.80
RCP45	0.67	0.70	0.69	0.72	0.76	0.80	0.85	0.90	0.97
Regional Policy	**0.67**	**0.70**	**0.72**	**0.74**	**0.77**	**0.78**	**0.80**	**0.82**	**0.84**
Constant Diet	0.67	0.70	0.73	0.76	0.77	0.77	0.78	0.79	0.80
Western Diet	0.67	0.70	0.73	0.76	0.78	0.80	0.83	0.86	0.89
Vegetarian Diet	0.67	0.70	0.73	0.76	0.77	0.77	0.78	0.78	0.79
High Yield	0.68	0.71	0.75	0.77	0.77	0.78	0.78	0.79	0.79
Low Yield	0.68	0.71	0.75	0.78	0.80	0.81	0.83	0.85	0.87

Table 30: GCAM biomass output prices for the 8 different scenarios in 1975 USD. The scenario utilised in the price formation is indicated in bold text.

The scenario selected as the basis for the price formation step was the Regional Policy scenario. The reason for selecting this scenario is that it most closely resembled the New Policies Scenario in the IEA's World Energy Outlook (WEO), and it is this scenario that the Danish Energy Agency utilises as input for their socioeconomic fossil fuel prices. As such it was deemed important to have the same basis for the fossil and biomass price projections.

9 GCAM to CIF Denmark prices

In this chapter the cost components determining the final price of woody biomass CIF Denmark will be discussed. Calculation of the projected straw prices will be undertaken in the following chapter. As was described in the previous chapter, the GCAM output biomass price utilised in this study resembles the 'farm gate' price, i.e. the price of biomass at the farm, forest, or residue collection site.

Wood chips or wood pellets? This is a question that is often asked when contemplating the establishment of a new power plant. While this is a very important question for individual power plant designers, for long-term forecasts of demand it is perhaps adequate to just look at woody biomass, as opposed to differentiating between wood chips and wood pellets. Other than sawdust residues which can only be made to wood pellets, the rest of woody biomass can largely take either form. Thus it will be the long-term difference in cost between pre-treatment, transport, handling, and utilisation of the two type of woody biomass that will determine the form that the woody biomass is utilised in. For some power plants it will be more cost-effective to utilise one form over the other, but it is likely that the long-term price for the two will be highly correlated, with the price difference being a reflection of the factors listed above.

To get from the GCAM input price to the final CIF Denmark price it is necessary to add processing and transport costs. To do so an excel model was designed to capture the various cost components in the final CIF prices. An example for 2020 is displayed in Figure 46.

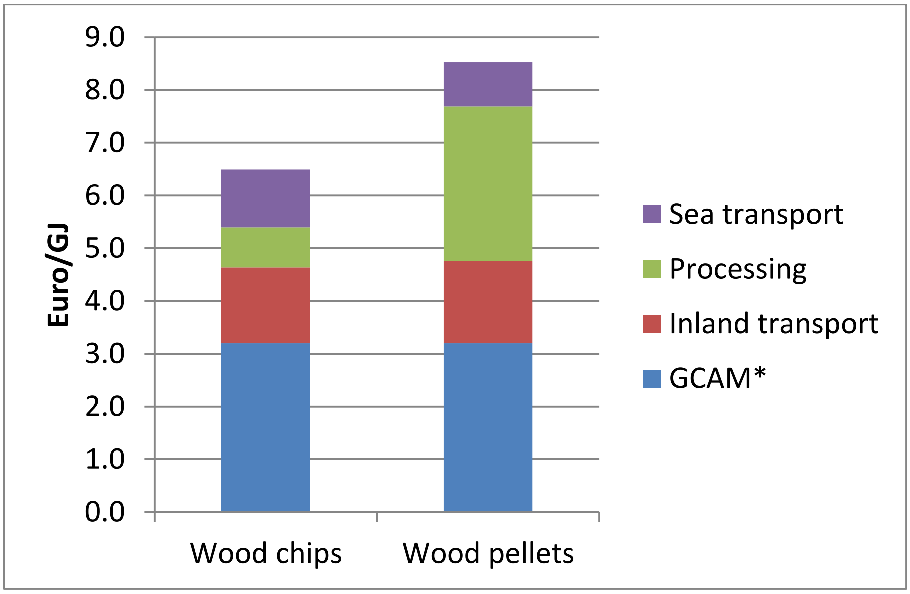


*Figure 46: Cost components for 2020 CIF Denmark prices for wood chips and wood pellets. *GCAM figure includes an adjustment value.*

Processing

For both wood chips and wood pellets the sea transport, processing, and inland transport components are comprised of sub-components. Examples for the processing component for the two fuels are displayed below.

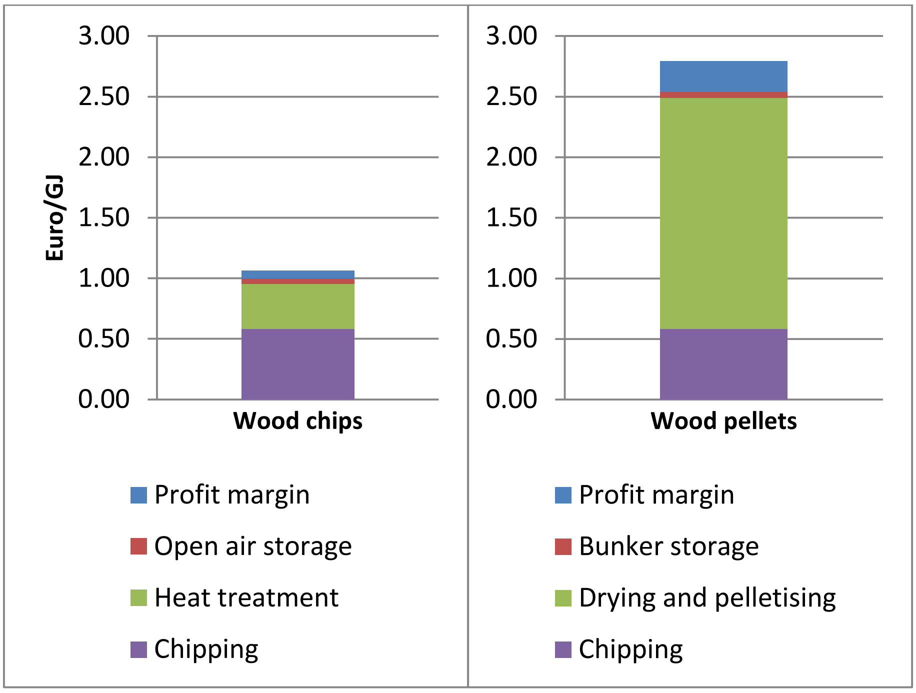


Figure 47: Processing costs for wood chips from North America and global wood pellets.[9]

Transport

In terms of transport, Figure 48 below depicts a simplified logistical transport chain for wood chips and pellets. In reality the picture may of course be more/less complex with additional/less transport links throughout, i.e. inland shipping, storage, etc.

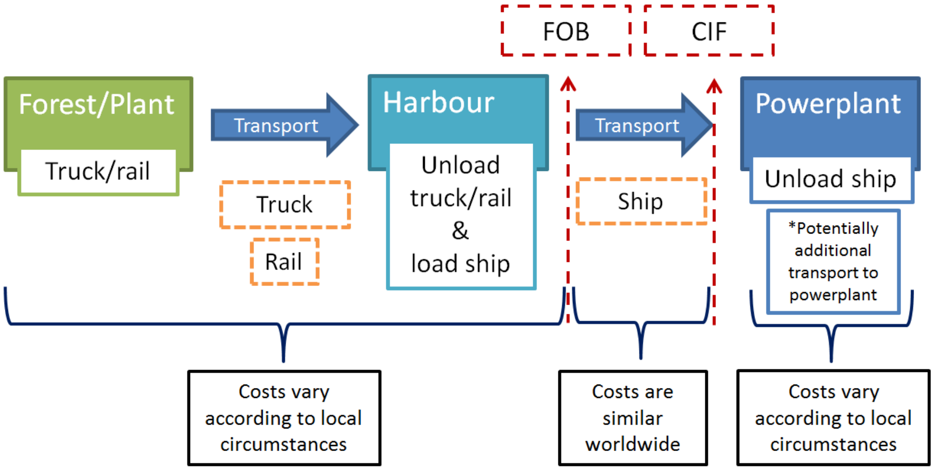


Figure 48: Simplified transport logistics for wood chips and wood pellets

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[9] Wood chips from North America are assumed to require heat treatment.

As the figure shows, the costs from forest to ship can vary from area to area, while costs incurred once on board the ship are essentially the same for similar distances and types of vessels. However, costs vary whether the biomass shipped is wood chips or wood pellets, and there are also different price structures for short sea vs. deep sea shipping. As a result, the following four major logistic supply chains were modelled:

- Wood chips deep sea
- Wood chips short sea
- Wood pellets deep sea
- Wood pellets short sea

For each of the above four logistic supply chains, variations of the transport distances were considered to see their effect on the final CIF prices. In addition to the 'medium' distances used in calculating the final prices displayed in the report, variations with 'short' and 'long' distances were also calculated. In the description below, all distances will refer to the medium distances scenario.

Supply chain

Each supply chain was comprised of the following categories of sub-components which will be described below:

- GCAM input
- Inland transport
- Processing
- Sea transport

9.1 Assumptions and clarifications

Within the study it was assumed that efficiency gains would take place in processing and transport logistics. In addition, all cost components were adjusted for projected oil price increases. This was done by assuming oil price elasticities for each component and applying future projected oil prices according to the IEA WEO New Policies Scenario as depicted below. (IEA 2012).

2012 USD / barrel	2012	2015	2020	2025	2030	2035	2040	2045	2050
Oil price	110.8	119.4	123.0	125.5	127.3	128.7	130.0	131.2	132.2

Table 31: Projected oil prices utilised in study from IEA WEO New Policies Scenario (IEA 2012)

9.2 GCAM Input

The excel spreadsheet has as an input from GCAM prices for the period 2010-2050 at 5 year intervals. These values are in 1975 USD/GJ, and the first step is thus to convert them to 2012 €/GJ. As detailed above, prices for each 5th year are available for 8 different scenarios, with the selected scenario being the 'Regional Policy scenario'.[10]

GCAM adjustment

The GCAM model was primarily utilised to give the slope of the price curve that would be used throughout the period of the analysis. To match current biomass resource costs it was then necessary to shift the curve, and through analysis of current biomass prices it was determined that a 20% shift of this curve resulted in prices that resemble those seen today. The chosen percentage adjustment is held constant over the period of the analysis.

A sensitivity analysis was done on this parameter, and due to the fact that the initial raw material price is quite a small portion of the total end price (particularly for wood pellets), and falls over the analysis period, the end price is rather insensitive to such changes. For example, the effect of altering this adjustment factor to 10% or 30% from the current 20% only alters the end price by a maximum of 4.5% for wood chips, and 3.5% for wood pellets.

Lastly, after the above GCAM adjustment has been made, a 10% profit margin for the biomass producer is applied.

9.3 Inland transport

Transport of whole trees

It is assumed that the marginal price for woody biomass will mainly come from dedicated forests/plantations, and as such the first step in the transport process is the transport of whole trees. For all 4 logistic supply chains this distance is assumed to be 50 km in 2012 and growing to 100 km in 2050 as increasing demand requires foresters to go further into the forest to acquire raw material. The cost of doing so is assumed to be 0.97 €/GJ/100 km in 2012, growing to 1.02 €/GJ/100 km in 2050.[11]

Wood chips

After having been converted to wood chips they must be transported to the destination port. Depending on the exporting area this may be via truck or rail, or in some cases not be required as the chipping may occur near a port facility. It is assumed that this transport distance is 50 km in 2012, and for deep sea it grows to 75 km by 2050, while it grows to 100 km for short sea by 2050.[12] For both short and deep sea the handling costs are assumed to be

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[10] Please see section 8, Description of model used in this study: GCAM for more on the policy scenarios.

[11] Please see the appendices for a more detailed description of transport related cost components and the assumptions taken.

[12] For both short and deep sea it is assumed that transport distances will increase as overall demand increases – buyers have to go further to accesses more distant markets. The study only assume a slight increase in transport distances of the chipped materials for deep sea, as large production facilities in the US or Latin America will likely go further to get the raw materials and utilise existing large scale chipping plants

roughly 0.23 €/GJ for the entire period, while the cost per 100 km is assumed to be 0.97 €/GJ in 2012, growing to 1.01 €/GJ km in 2050.

Wood pellets

In the case of wood pellets, in some situations transport may be required from the place of chipping to the pellet plant. For both short and deep sea pellets a transport distance of 10 km and handling costs of roughly 0.23 €/GJ over the entire time period have been assumed, while the cost per 100 km is assumed to be 0.97 €/GJ in 2012, growing to 1.01 €/GJ km in 2050.

For the processed pellets a distance to port of 50 km in 2012 for short and deep sea has been assumed. For deep sea this is expected to grow to 150 km by 2050, while for short sea it is expected to grow to 200 km.[13] For both deep sea and short sea a handling cost of 0.19 €/GJ is assumed for the entire period, while costs per 100 km are assumed to be 0.54 €/GJ in 2012, growing to 0.56 €/GJ km in 2050.

9.4 Processing

Wood chips

The costs associated with processing for wood chips include chipping, heat treatment (for wood chips coming from North America), storage and a profit margin. The chipping of woody biomass for short sea is assumed to cost 0.64 €/GJ in 2012 falling to 0.55 €/GJ in 2012. Chipping of woody biomass for deep sea is assumed to be roughly 5% less due to larger economies of scale utilised in the South Eastern United States. The cost of open air storage is assumed to be relatively constant over the period for both deep sea and short sea, and is 0.05 €/GJ.

To avoid potential problems with infested wood, EU regulations require that wood chips from North America undergo a heat treatment that achieves a wood temperature of at least 56°C for 30 minutes.[14] The estimated cost of this process is 0.39 €/GJ in 2012, falling to 0.32 €/GJ by 2050.[15]

Wood pellets

For wood pellet processing the costs are comprised of chipping, drying and palletising, bunker storage and profit margin. For the chipping component the costs as indicated above were utilised. For drying and pelletising the costs for deep sea are assumed to be 2.04 €/GJ in 2012 and falling to 1.64

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[13] For both short sea and deep sea it is assumed that transport distances will increase as overall demand increases. The study assumes a smaller increase in transport distances of pellets relative to short sea markets, as large production facilities in the US or Latin America will likely go further to get the raw materials and utilise existing large scale pellet plants close to rivers and the ocean. One could also assume a larger increase in this transport distance, and a lower transport of whole trees if one assumes that new pellet facilities are built close to the wood baskets.

[14] Wood pellets are not subject to these rules as the pelletisation process eliminates the risk of infection.

[15] For a more detailed cost breakdown of this process, please see the appendices.

€/GJ in 2050. For short sea the assumed costs are slightly higher as the 2012 and 2050 figures are 2.14 and 1.77 €/GJ respectively. As was the case for wood chips, the cost of bunker storage is assumed to be relatively constant over the period for both deep sea and short sea, and is 0.05 €/GJ.

Lastly, for both wood pellets and wood chips a profit margin of 10% has been assumed.

Total processing

As an example of one of the 4 woody biomass logistic supply chains, Figure 49 displays the total processing costs associated with deep sea wood pellets. Drying and pelletising is by far the largest component and overall processing reductions are largely due to cost reductions to this component.

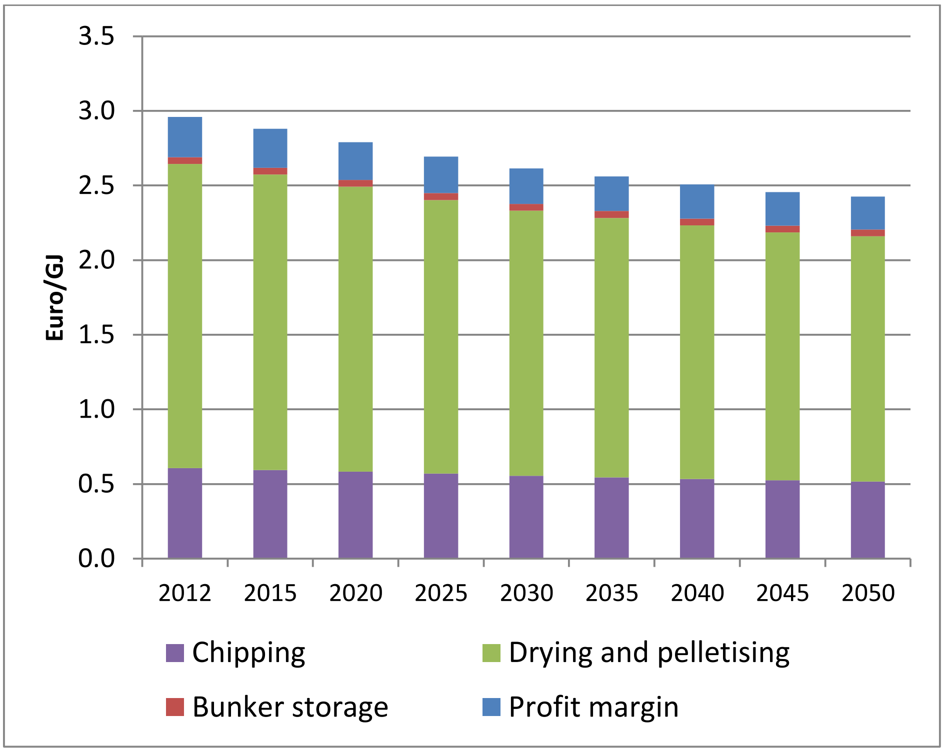

Figure 49: Evolution of total processing costs for deep sea wood pellets in 2012 €/GJ

Total processing costs for the 4 woody biomass logistic supply chains is displayed in Figure 50.

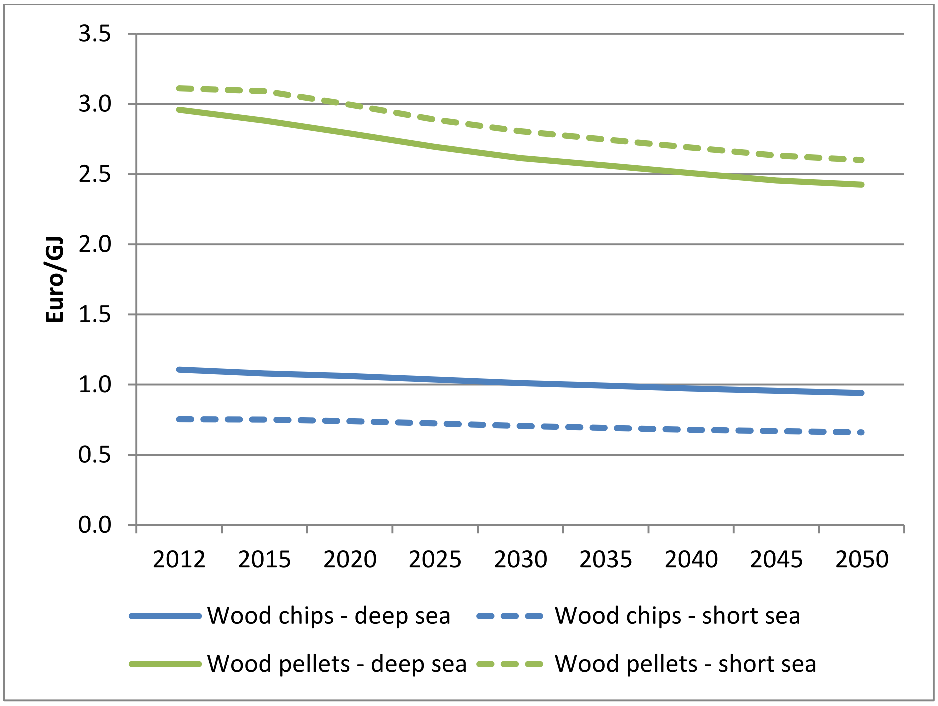

Figure 50: Processing costs for the 4 woody biomass logistic supply chains.

For both wood pellets and wood chips the chipping and storage costs are largely the same. The difference between the two is due to the drying and palletising costs, which are much higher than the heat treatment costs required of North American wood chips. Deep sea pellet production costs are slightly lower than short sea due to assumed larger economies of scale. Meanwhile, short sea wood chips have lower processing costs than deep sea wood chips as the former do not require heat treatment.

9.5 Sea transport

Once in wood chip or wood pellet form and transferred to a port, the last stage of the logistic chain is shipping of the biomass to Danish waters. This phase includes storage at the shipper, loading of the biomass, and the actual shipping cost. Within this study the shipping link has been classified as either deep sea (typically trans-Atlantic on large ships), or short sea (typically shorter intra-continental distances on smaller ships). For a more detailed description of the sea transport assumptions and figures used in the study, please see the appendices.[16]

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[16] One particular cost component worth noting is the use of bunker fuels for shipping of specification (IFO 180/IFO 380), which at the time of writing had a market price of roughly 675 USD/tonne. In the future it is expected that emissions from bunker fuels will have to be reduced, and this may result in a more expensive form of bunker fuel being utilised, and/or the installation of scrubbing equipment which would also increase shipping costs.

Deep sea

It is anticipated that the quantities of biomass that will be transported over long distances will greatly increase in the future, particularly for woody biomass and other pellets. As a result, the percentage that is transported via deep sea increases over the study period (see Table 32). The distance utilised for deep sea shipping within this study is 7,900 km, which is roughly the distance from Mobile, Alabama to Denmark.

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Wood chips Deep sea (%)	0	0	5	10	15	20	25	30	35
Wood pellets Deep sea (%)	20	24	31	37	44	50	57	63	70

Table 32: Proportion of transported woody biomass that is assumed to arrive in Denmark via deep sea shipping transport over the study period.

Due to the high volume of wood chips it is assumed that ships that specialise in high volume cargos (often referred to as wood chip carriers) are utilised for wood chips, while large Panamax sized ships are used for the long distance transport of wood pellets.

For deep sea wood chips, handling costs (storage and loading) are roughly 0.19 €/GJ over the entire time period, while the transport cost per 1,000 km stays relatively constant around 0.29 €/GJ from 2012 to 2050. The cost per km is largely unchanged as increased oil prices are offset by increases efficiencies related to transport logistics.[17]

For wood pellets, the handling costs are roughly 0.26 €/GJ over the study period, while the transport cost per 1,000 km of 0.09 €/GJ is nearly constant due to the same reasons highlighted above for wood chips. Relative to wood chips, the higher handling costs for wood pellets are due to the fact that they are more difficult to handle. Meanwhile, shipping costs for pellets are lower due to the much higher energy content per cubic meter.

Short sea

The distance utilised for short sea shipping within this study is 850 km, corresponding to a typical shipping distance from the Baltics to Denmark.

For short sea wood chips, handling costs (storage and loading) are roughly 0.33 €/GJ over the entire time period, while the transport cost per 1,000 km falls slightly from 0.79 €/GJ in 2012 to 0.77 €/GJ in 2050.

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[17] It is for example assumed that the % of time ships will sail back empty or partially laden will fall over the period studied.

For wood pellets, the handling costs are roughly 0.40 €/GJ over the study period, while the transport cost per 1,000 km hovers close to 0.43 €/GJ from 2012 to 2050.

Total shipping costs

Figure 51 displays an example of the allocation of shipping costs for the four different logistic supply chains in 2020. The large per GJ difference in shipping transport for deep sea wood chips relates to the aforementioned low energy density of wood chips (roughly 3 GJ/m^3), which is less than 1/3 of that for wood pellets (roughly 11 GJ/m^3).[18]

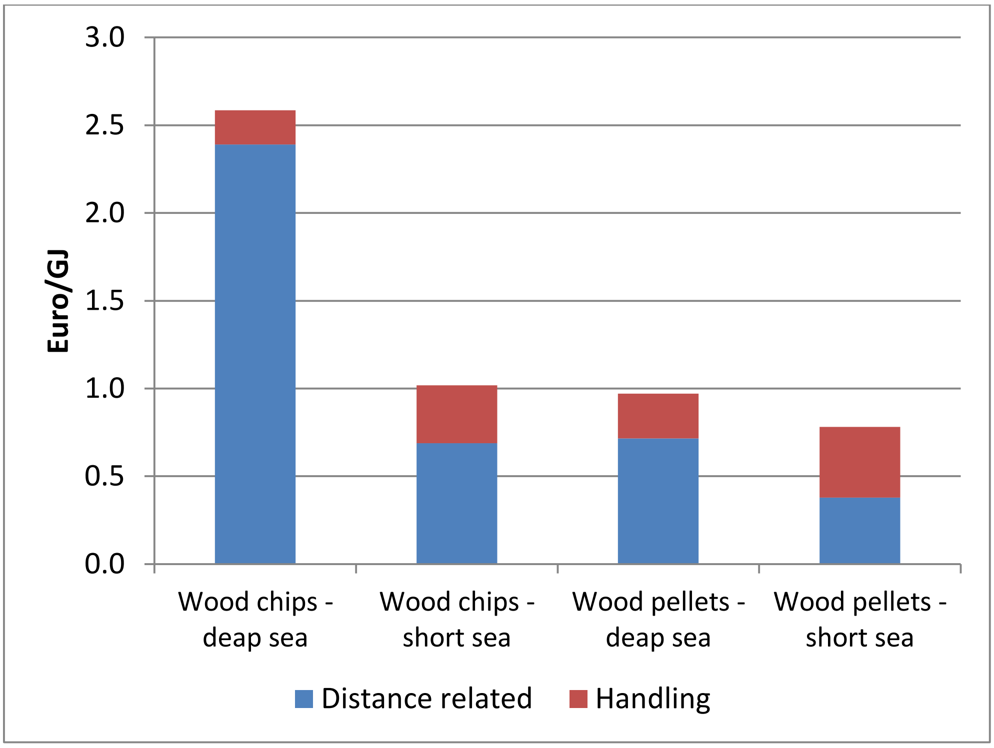

Figure 51: Allocation of shipping costs for the four different logistic supply chains in 2020.

Meanwhile, the anticipated price development of the total shipping portion for the 4 logistic supply chains is displayed below.

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[18] Please see appendix 12.4 for more on energy density of shipped biomass.

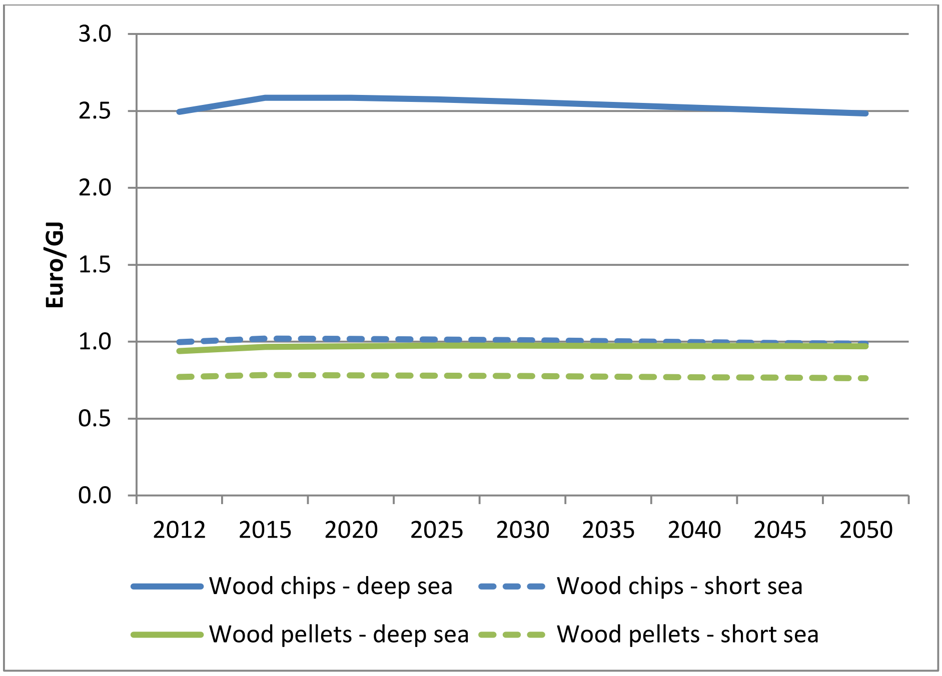

Figure 52: Sea transport costs for the 4 woody biomass logistic supply chains

As was indicated above, the sea transport cots are fairly constant throughout the period as projected oil price increases are offset by projected increases in transport efficiency logistics.

9.6 Complete price forecast

Assembling the above price components gives wood chip and wood pellet price projects as displayed in the following two figures.

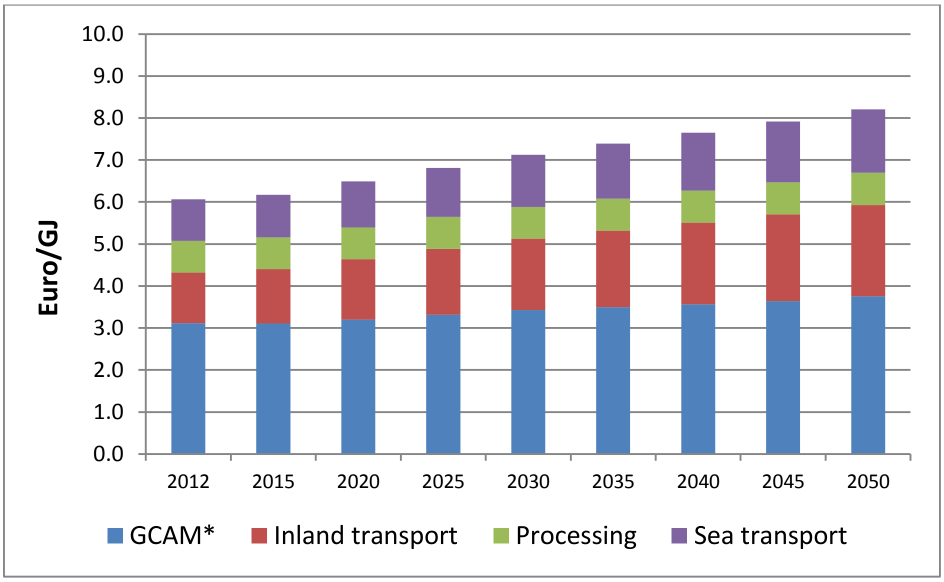

*Figure 53: CIF Denmark price projects for wood chips according to price component. *GCAM figure includes an adjustment value.*

The total CIF Denmark price for wood chips increases steadily over the study period, a tendancy that can largely be attribuited to increased transportation costs.

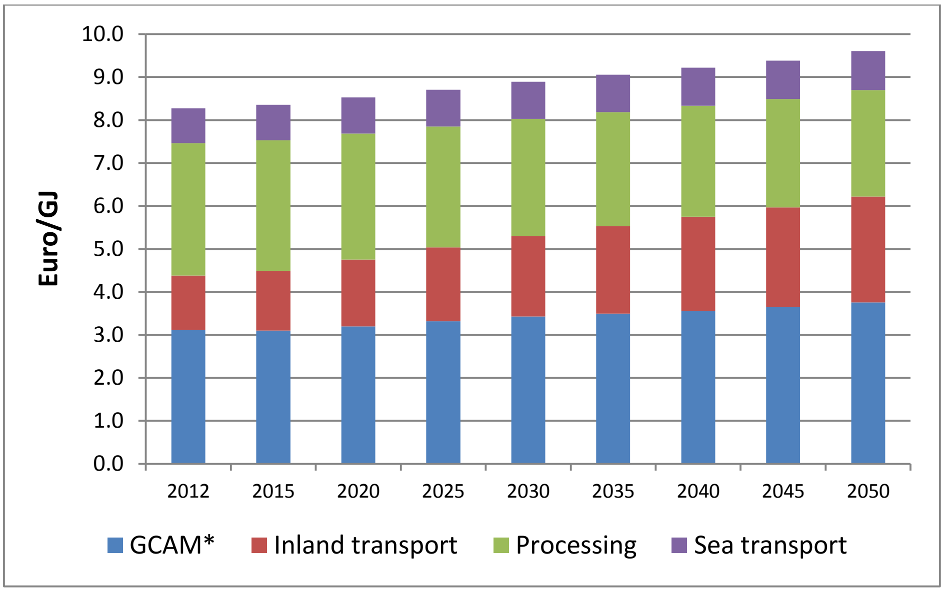

*Figure 54: CIF Denmark price projects for wood pellets according to price component. *GCAM figure includes an adjustment value.*

For wood pellets the increase in price is less significant because the relatively large processing portion is reduced due to efficiency improvements, and because the transport cost component does not increase as much due to wood pellets higher energy content both per cubic meter and per tonne.

As a result, the per GJ cost difference between the two fuels decreases over the study period, but wood chips are roughly 1.4 €/GJ cheaper in 2050.

10 Straw price formation

In Denmark more than 60% of the residue from the fields is gathered and utilised for different purposes. In Figure 55 it can be seen that 25% is used for fuel, and the rest is primarily used for bedding and fodder in animal production farms.

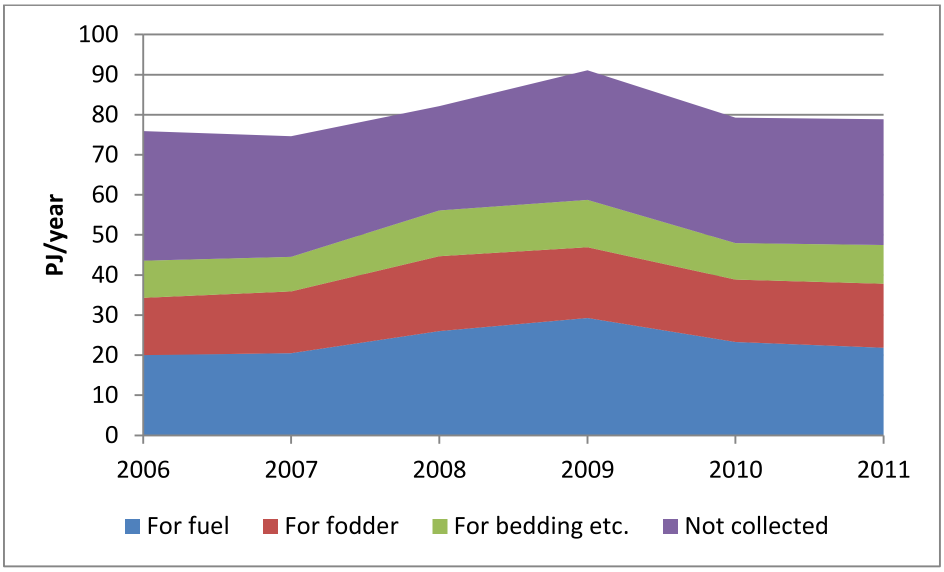

Figure 55: Production and utilisation of agricultural residue (straw) in Denmark 2006 – 2011. (Danmarks Statistik n.d.)

Roughly 50% of the straw used for fuel purposes is used at centralised heat plants, and the main part of the rest is used in decentralised heat only boilers. A minor part is used at single farm boilers.

In (Ea Energy Analyses 2010), the marginal production price of straw for energy purposes is calculated to be 2.4 – 2.6 €/GJ, including profits. Comments from the Danish Agriculture & Food Council point at higher cost calculations.

As was shown in Figure 11, the price of straw delivered at the district heating plants have been quite stable for the last 10-15 years, always being 5%-15% lower than the price of wood chips (measured on an energy basis), and currently around 5.5 €/GJ including transport.

It is generally acknowledged that straw is a more complex fuel for use in power plants than woody biomass due to higher volumes and chemical contents. Particular when used in high temperature steam boilers (centralised CHP plants) the content of chlorides and potassium has proven to increase maintenance costs. Therefore it is the simple assumption in this report, that straw will continue to be priced (at point of delivery) between production costs and the price of wood chips. It is thus assumed that the price will continue to be 10% below the price of wood chips.

In addition, we see no indications of straw becoming an internationally traded commodity in the foreseeable future. Therefore the calculation of a CIF Denmark price on straw is a theoretical value to be quoted with utmost care.

11 Biomass price projection to 2050

The CIF Denmark woody biomass prices arrived at are for the Regional GCAM Policy scenario and assume medium transport distances and a growing increase in woody biomass coming from 'deep sea' as indicated in Table 32. To give an indication of the potential range of future prices if these assumptions were altered, two alternative scenarios are presented below, a 'low price' scenario, and a 'high price' scenario.

11.1 Scenario assumptions

Low price scenario

In the low price scenario the GCAM input scenario is the 'Vegetarian' scenario, as this results in the lowest 2050 GCAM biomass input price.

With respect to the portion of woody biomass that comes from deep sea, in the low price scenario this portion is held constant from 2012 and thus in contrary to the other scenarios, sees no growth.

In terms of the transport distances, in the low price scenario they are lower and do not grow much over the course of the study period.

High price scenario

In the high price scenario the GCAM input scenario is the 'RCP45' scenario, as this results in the highest 2050 GCAM biomass input price.

Regarding the portion of woody biomass that comes from deep sea, in the high price scenario this is considerably larger and sees more growth than in the 'medium' transport distance scenario.

In terms of the transport distances, in the high price scenario they are longer and grow significantly over the course of the study period.

The main assumptions for the scenarios are summarised below:

Parameter	2012	2015	2020	2025	2030	2035	2040	2045	2050
GCAM price input (2012 Euro/GJ):									
Low: Vegetarian Diet	2.8	2.8	3.0	3.1	3.1	3.1	3.1	3.2	3.2
Medium: Regional Policy	2.8	2.8	2.9	3.0	3.1	3.2	3.2	3.3	3.4
High: RCP45	2.8	2.8	2.8	2.9	3.1	3.2	3.4	3.7	3.9
Wood chips Deep sea (%):									
Low	0	0	0	0	0	0	0	0	0
Medium	0	0	5	10	15	20	25	30	35
High	0	5	10	20	30	40	50	60	70
Wood pellets Deep sea (%):									
Low	20	20	20	20	20	20	20	20	20
Medium	20	24	31	37	44	50	57	63	70
High	20	26	37	47	58	68	79	89	100
Transport distances in various logistic stages									
Low					Short				
Medium					Medium				
High					Long				

Table 33: Core assumptions in the various pricing scenarios.

The resulting prices are presented in Figure 56 and Table 34 below. Please note that from 2035 to 2050 price estimates are solely on a 5 year basis.

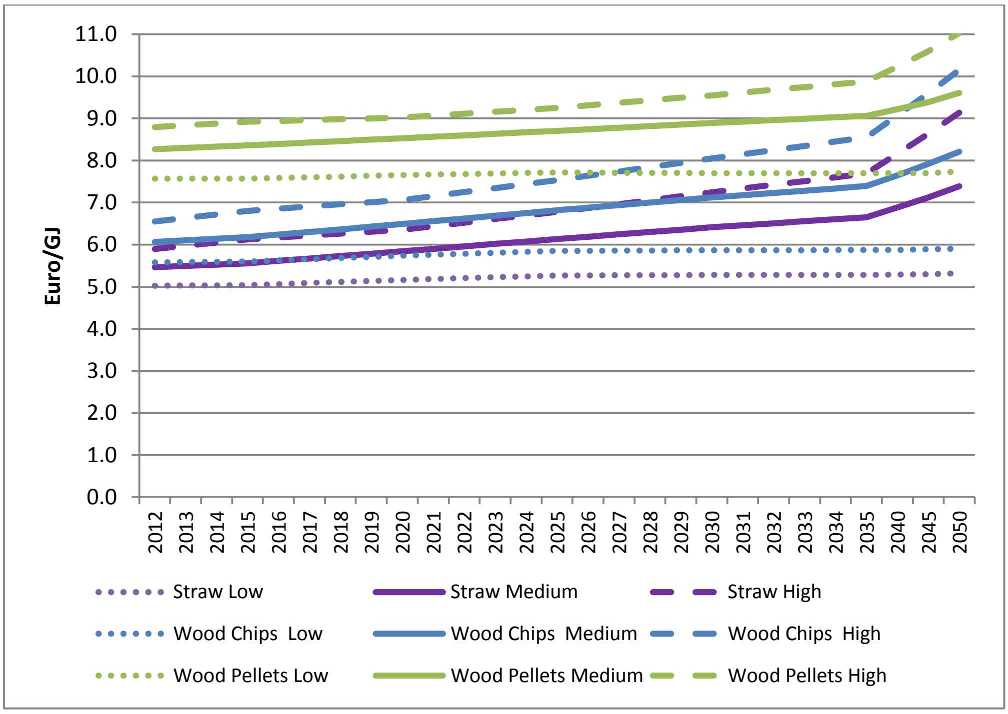

Figure 56: Projected biomass prices CIF Denmark in given three scenarios (€/GJ).

The following table displays the CIF Denmark prices for straw, wood chips and wood pellets under 3 different scenarios. Please note that in the case of locally used straw and wood chip resources the prices can be below CIF prices. Straw is assumed to be a local fuel throughout the period, with prices set by the price of local wood chips (see discussion below).

Euro/GJ		**Straw**			**Wood Chips**			**Wood Pellets**	
Year	Low	**Med**	High	Low	**Med**	High	Low	**Med**	High
2012	5.0	**5.5**	5.9	5.6	**6.1**	6.6	7.6	**8.3**	8.8
2013	5.0	**5.5**	6.0	5.6	**6.1**	6.6	7.6	**8.3**	8.8
2014	5.0	**5.5**	6.0	5.6	**6.1**	6.7	7.6	**8.3**	8.9
2015	5.0	**5.6**	6.1	5.6	**6.2**	6.8	7.6	**8.4**	8.9
2016	5.1	**5.6**	6.2	5.6	**6.2**	6.9	7.6	**8.4**	8.9
2017	5.1	**5.7**	6.2	5.7	**6.3**	6.9	7.6	**8.4**	9.0
2018	5.1	**5.7**	6.3	5.7	**6.4**	7.0	7.6	**8.5**	9.0
2019	5.1	**5.8**	6.3	5.7	**6.4**	7.0	7.6	**8.5**	9.0
2020	5.2	**5.8**	6.4	5.7	**6.5**	7.1	7.7	**8.5**	9.0
2021	5.2	**5.9**	6.4	5.8	**6.6**	7.2	7.7	**8.6**	9.1
2022	5.2	**6.0**	6.5	5.8	**6.6**	7.2	7.7	**8.6**	9.1
2023	5.2	**6.0**	6.6	5.8	**6.7**	7.3	7.7	**8.6**	9.2
2024	5.2	**6.1**	6.7	5.8	**6.7**	7.4	7.7	**8.7**	9.2
2025	5.3	**6.1**	6.8	5.9	**6.8**	7.5	7.7	**8.7**	9.2
2026	5.3	**6.2**	6.9	5.9	**6.9**	7.6	7.7	**8.7**	9.3
2027	5.3	**6.2**	7.0	5.9	**6.9**	7.7	7.7	**8.8**	9.4
2028	5.3	**6.3**	7.1	5.9	**7.0**	7.8	7.7	**8.8**	9.4
2029	5.3	**6.4**	7.1	5.9	**7.1**	7.9	7.7	**8.9**	9.5
2030	5.3	**6.4**	7.2	5.9	**7.1**	8.0	7.7	**8.9**	9.5
2031	5.3	**6.5**	7.3	5.9	**7.2**	8.1	7.7	**8.9**	9.6
2032	5.3	**6.5**	7.4	5.9	**7.2**	8.2	7.7	**9.0**	9.7
2033	5.3	**6.6**	7.5	5.9	**7.3**	8.3	7.7	**9.0**	9.7
2034	5.3	**6.6**	7.6	5.9	**7.3**	8.4	7.7	**9.0**	9.8
2035	5.3	**6.7**	7.7	5.9	**7.4**	8.5	7.7	**9.1**	9.9
2040	5.3	**6.9**	8.2	5.9	**7.6**	9.1	7.7	**9.2**	10.2
2045	5.3	**7.1**	8.6	5.9	**7.9**	9.6	7.7	**9.4**	10.6
2050	5.3	**7.4**	9.1	5.9	**8.2**	10.2	7.7	**9.6**	11.0

Table 34: Projected biomass prices CIF Denmark in given three scenarios (€/GJ).

The variance in the biomass prices in the low, medium, and high scenarios is largely due to transport related assumptions, both respect to the % that is short and deep sea, and the distances. Meanwhile, the GCAM scenario selection has a much lesser effect.

11.2 Methods for calculation of local wood chip and straw prices (delivered to plant).

Use of local resources

The CIF Denmark price for wood chips and straw is not likely to adequately reflect the delivered cost of wood chips or straw at a decentralised inland power plant in Denmark that has access to local resources. In this regard, the above prices, plus a transport cost, would act as price cap, and the raw production costs including transport would act as a price floor. The actual price at a given end-use location will depend on the distance to local resources and the local demand supply balance. When supply is abundant, the local production costs including transport will determine prices. Only in the case where the local and regional demand exceeds local supply, the CIF Denmark price including transport from harbour can be expected to determine prices.

It is therefore recommended that alternative pricing approaches are utilised to calculate local straw and wood chip prices. Below a simple suggestion for two calculation methods are presented. Other methods could include the development of a national biomass market model.

A: Scenarios where inland supply of straw and wood chips exceed demand

- Use updated price statistics as presented in Figure 11, combined with the general price development calculated in this report (slope of price curve).

B: Scenarios where inland demand of straw and wood chips exceed supply

- Use CIF Denmark prices calculated in this report and add average transport costs as calculated in previous price projection report (EA Energianalyse and Wazee 2011).

12 Appendices

12.1 Appendix I Key parameters in wood pellet standardisation

As far as woodfuels are concerned, the critical parameters that need to be defined in a specifications list of a standard are as follows (Biomass Energy Centre 2012), (Kofman 2010):

1) Moisture content
    - Denoted as a percentage of the total weight of the wet sample (wet basis) or with the weight of the water given as a percentage of the mass of dry biomass (dry basis).
    - Different types of boilers have different tolerance limits as to the moisture content of the solid biofuel
2) Dimensions
    - For wood pellets the diameter is the most important parameter, accompanied by an acceptable range of lengths for each diameter
    - For woodchips range of sizes of 75% of the sample are usually given, measured using sieves
    - Dimensions of e.g. woodchips are crucial both from combustion efficiency perspective (abundance of small, fine material would reduce the efficiency) as well as from the operational perspective of the feed system (too large pieces would jam the system)
3) Origin
    - States what the wood fuel is made of and where it comes from. E.g., whether it is woody biomass, herbaceous biomass, fruit biomass or a blend. Each of the groups is further divided into subgroups, e.g. for trees, it can be stemwood, branches, stumps etc.
4) Ash content and properties
    - Ash content is denoted in percentage on a dry basis, and occasionally ash melting temperature is also provided
    - Permissible ash content depends on whether the boiler/stove is equipped with automatic de-ashing. In addition, low ash melting temperature can give rise to formation of lumps of clinker or slagging.
5) Calorific value
    - Denoted as the energy content per unit of weight. Alternatively, energy density can be indicated, i.e., energy content per unit of volume.

12.2 Appendix II Torrefied and black pellets

Torrefaction

Torrefaction is the process of heating biomass so as to remove moisture, as well as some volatiles, thereby producing a higher density product. The thermochemical process is typically carried out at roughly 300°C (though can vary from 250-350) in an extremely low oxygen environment, thereby resulting in the biomass being 'roasted' as opposed to burned.

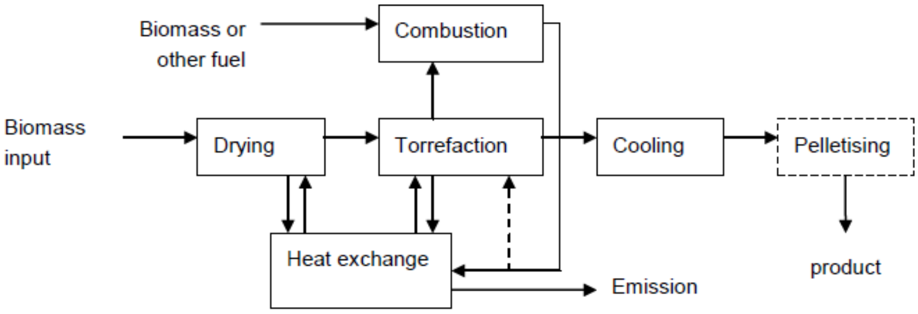

Figure 57: Process diagram for a typical torrefaction process (Koppejan, et al. 2012)

The process results in the partial breakdown of the cellulose, hemicellulose and lignin, thus altering the chemical composition to a torrefied product. For torrefied pellets, after the moisture from the biomass has been removed, and the torrefied product cooled, the biomass is ground and then fed through a pellet mill where water and binders are added to create a torrefied pellet.

The reported benefits of torrefaction include (Koppejan, et al. 2012):

- Relative to regular wood pellets they are more moisture resistant, making handling easier.
- Biological activity is ceased, thus risks related to fire and decomposition are reduced.
- It's much higher energy density (15-19 GJ/m^3)[19] relative to conventional wood pellets (8.5-10 GJ/m^3) reduces transport costs.
- A heating value of 20 – 24 GJ/tonne.
- Torrefied pellets grind very similar to coal and therefore are easier to utilise in existing coal plants.
- Due to the higher energy content, higher co-firing ratios with coal can be achieved.
- Allows for various biomass feedstocks.

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[19] This correlates to a bulk density of 800 kg/m^3

Meanwhile, the drawbacks of torrefaction are the cost and energy losses associated with the process. The energy 'loss' to the process is generally estimated to be around 10% of initial biomass energy content.

Zilkha black pellets

A trademarked black pellet called the 'Zilkha Black Pellet' claims to utilise an alternative process to develop a somewhat similar product.[20] They describe their process as one that utilises an external energy source to drive the process, thus not using energy from the biomass itself. They state that this process uses less energy than torrefaction and that it does not utilise bindings or additives. Their end product is stated to typically have a moisture content of 2%, a heating value of 19.5 GJ/tonne, and a density of 770 kg/m^3. In addition, the product is reportedly waterproof, thus allowing for outdoor storage and the usage of water to extinguish fires. It is claimed to be very durable, thus allowing for bulldozing to trim loads, as well as having less dust, thus reducing explosion risk during handling. In addition to various traditional softwood and hardwood biomass inputs, Zilkha has also experimented with bamboo, sweet sorghum, switchgrass, mesquite, miscanthus and eucalyptus and bagasse (Weick 2012).

12.3 Appendix III Pre-treatment of biomass

Phytosanitation

Technically speaking the wood chips do not need to be dried to live up to the EU regulations, but by heating them to at least 56°C for 30 minutes will result in a partial drying of the chips. Here we have assumed that the chips are dried from 45% to 40% via the heat treatment. The energy consumption associated with heating and drying 1 tonne of wood chips (9.46 GJ) to 40% moisture content is displayed in Table 35 below. In addition, the energy consumption as a % of the dried wood chips is also calculated.

	Energy consumption for 1 tonne of wood chips with 45% m/c	Energy consumption as a % of dried wood chips
Heating to 56 °C	185 MJ	1.9 %
Drying to 40% m/c	201 MJ	2.1 %
Total	**386 MJ**	**4.0 %**

Table 35: Energy required for heating and drying wood chips with moisture content (m/c) of 45%

It is estimated that the heating and drying of the wood chips to a moisture content of 40% utilises roughly 4% of the dried wood chips energy content. If the wood chips have to be heated to satisfy EU and US requirements, it may prove cost-effective to continue the process and further reduce the moisture

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[20] http://www.zilkha.com/our-waterproof-pellet/

content, thereby reducing transportation costs. As such, additional calculations were undertaken where the moisture content was further reduced. If the process is continued to 30% moisture content the total energy consumption is estimated to be 6.9%, and at 20% moisture content it is 8.9%.

In addition to the energy consumption calculations, the costs of undertaking this process was also estimated. It is assumed that a facility for heating and drying can be established for the same cost as a wood chip drier without condensation heat recovery. Such a drier with a capacity of 50 tonnes/hour is estimated to cost approximately 23 million DKK.[21] The annual cost of capital is based on an interest rate of 10% and a 5 year term. Operations and maintenance are estimated to be 10% of the annual capital costs. It is assumed that the wood chips are heated and dried via natural gas, and that this process has a 90% efficiency. The natural gas price is based on the current price of gas at the Henry Hub exchange, plus transportation costs, thus totalling approximately 30 kr./GJ.

	Cost of phytosanitation
Investment	1.4 kr./GJ
Natural gas	1.3 kr./GJ
Various O&M	0.1 kr./GJ
Total	**2.9 kr./GJ**

Table 36: Costs of heating and drying wood chips with an initial 45% moisture content to 56 °C and drying them to 40% moisture content.

If the drying is to be further carried out to 30% and 20% moisture content, the estimated respective costs of doing so would be 3.6 and 4.1 kr./GJ.

12.4 Appendix IV biomass transport

The following section will sketch out the most common transport logistics for the various biomass types in focus and highlight some of the assumptions and elements that were taken into consideration.

Wood chips – To port

In the case of wood chips, the first link in the supply chain is either the forest or a plant, as the chips can be sourced either directly from the forest, or as residues from the wood and paper industries. In the forest (or plant) the trees must either be chipped or transported as whole logs.

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[21] Assessed in conjunction with TK Energi.

In many cases, transport from the forest to the port will be carried out by large trucks. The cost of transporting wood chips via truck depends on the vehicle type, capacity and specific country/region. A rough rule of thumb in the transport industry is 1 kr./tonne/ km, however market actors interviewed have indicated slightly lower figures. A 2010 Ea Energy Analyses survey of 30 district heating plants in Denmark indicated that truck transportation costs for wood chips in Denmark was on average 7-10 kr. / GJ, equivalent to 65-95 kr. / tonne.

In countries with well-developed rail infrastructure between forest areas and port facilities (for example in British Columbia, Canada), the transportation of wood chips from forest to port takes place via rail. The cost of transportation of wood chips via rail will largely depend on local conditions such as rail capacity and competing goods, however the per km/tonne cost can be assumed to be cheaper than transport via truck.

Upon arrival at the port, the truck or railcar must be unloaded and the wood chips either transported to a temporary storage, or loaded directly to a waiting ship. The cost and duration of the offloading/storage/loading can vary substantially depending on the local conditions. In some ports the loading of a small ship may take the better part of a day, while others such as the terminal in Vancouver, Canada can load up to 1,000 metric tonnes per hour (Fibreco 2010).

Wood pellets – To port

For wood pellets there is an extra initial step as the input material (whether it be wood from dedicated forests, or residues from another industry) are first transported to a pellet plant for pelletisation. Once in pellet form the pellets must either be transported by bulk trucks or rail cars, with bottom-discharging or walking floor systems being some of the most often used due to the minimal wood pellet damage (Janzé 2010). Rail cars for transport of wood pellets can typically carry 100 tonnes and represent a much cheaper alternative for long distance transport. Pacific Bioenergy in Canada for example uses railcars to transport its wood pellets 900 km from Prince George to Vancouver port for shipment.

It is worth noting that for pellets in particular, the more they are handled, the more they break up. This has two main repercussions; firstly this produces a fine dust that comprises a fire and explosion risk, and secondly, the more the pellets break up, the greater the fibre loss. As such it is highly preferable and cost-effective to limit the number of times wood pellets are handled.

Ship transport

Bulk shipping can generally be categorised as either ‘deep sea’ or ‘short sea’. Deep sea typically involves large ships transporting goods on intercontinental routes and/or across oceans, while short sea generally encompasses smaller ships travelling shorter distances.

In a previous study Ea Energy Analyses carried out a bottom up cost analysis of both categories, with the point of departure being a deep sea route consisting of North America to Europe, and short sea referring to routes such as those from Scandinavia, the Baltics and Russia to Denmark.

Deep Sea

Figure 58 illustrates the evolution in average freight rates over a five year period for three ship types. As can be seen, rates have a tendency to vary dramatically from year to year, thus making it difficult to base a projection of future rates on current rates.

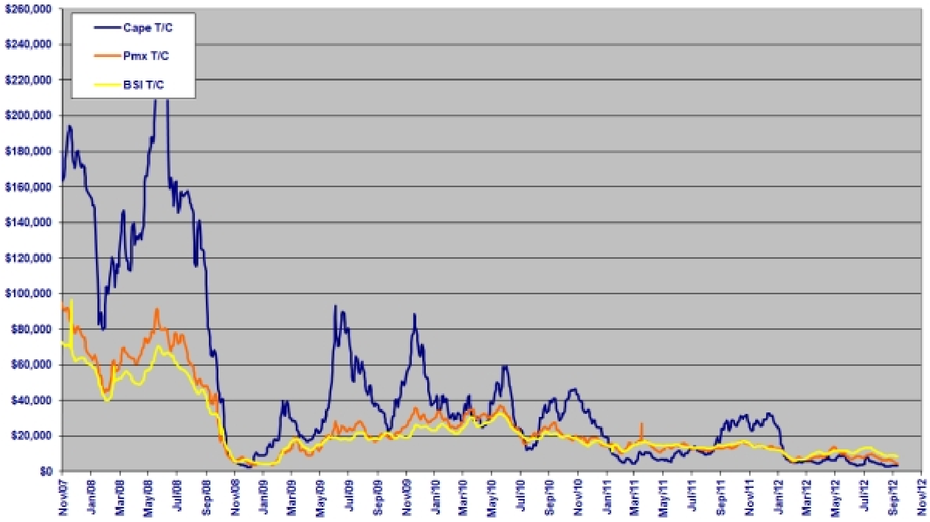

Figure 58: Average daily spot prices for the four main shipping routes over a 5 year period for three different ship classes (Cape, Panamax, Handy). (www.drywhips.com)

Due to this volatility a bottom up cost analysis of freight rates was undertaken involving a variety of ship sizes and types. The results of this analysis are displayed in Table 37, while a brief description of the components follows below:

- Ship size - Ship sizes are often given in 'deadweight tonne' (dwt). Dwt is neither an expression of the weight of the ship or cargo capacity per se, but rather a measure of how much a ship can carry *including* all the necessary elements required to operate the vessel. As such dwt is a measure of the maximum weight of: cargo + provisions + crew +

+passengers+ fuel + ballast water, etc. The maximum cargo weight is therefore typically within a range of 85-95% of the reported deadweight tonnes.[22]

- Ship volume - For biomass, cargo volume is often a more appropriate measure than ship size (particularly for wood chips) as it usually is this value which determines how much cargo a ship can carry.
- Stowage factor - Stowage factor expresses how much space one tonne of a specific type of cargo occupies, and is typically measured in m^3/tonne (or cubic feet / tonne). This factor can vary significantly between different products. For example, typical stowage factors measured in m^3/tonne for selected commodities include: iron ore (0.4), coal (1.4), pellets (1.5), palm kernel shells (1.7) wood chips (2.5-3.5)[23] and straw (7.2). This variation has a significant impact on how much of a given commodity can be loaded on a particular type of ship. As a result, specially designed ships are utilised, particularly for goods with considerably low or high stowage factors, i.e. iron ore carriers, or, of greater relevance in this context, wood chip carriers.
- Draft – Draft is a measure of the vertical distance from the waterline to the bottom of the ships lowest point when fully loaded.

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[22] "Technically speaking, the deadweight tonnage (DWT) is the difference between the number of tonnes of water the vessel displaces when submerged to its load line and the number of tonnes of water the vessel displaces light. The DWT is usually given at full summer saltwater draught (referred to as the scantling draught), but can also correspond to the design draught, thus resulting in a lower value". (MAN Diesel, 2010).

[23] The density can vary significantly depending on the moisture content and type of tree. In these calculations a moisture content of 45% and density of 3.08 (325 kg/m^3) was used. The moisture content (MC) figure was in line with what actors in the Eastern states indicated the shipped wood chips would likely be at, while the density of 325 kg /m^3 was selected as this is roughly the density of Pine wood chips at 45% MC. (Franceescato, Antonini and Bergomi 2008) Pine was selected as the reference wood as the majority of softwood from the South-eastern states used for wood chips is likely to be pine. (Pöyry Managment Consulting (UK) 2012)

	Handymax	Panamax	Chip carrier
Ship size (tdw)	51,000	65,000	53,896
Ship volume (m^3)	64,935	80,000	115,687
Length (m)	190	220	204[24]
Width (m)	32.3	32.6	37.2
Draft (m)	12.0	13.1	10.9
Wood chips:			
Cargo wood chips (tonnes)[25]	21,104	26,000	37,598
Cargo wood chips (GJ)[26]	197,743	243,620	352,296
Ship transport costs (kr./GJ/1,000 km)[27]	**2.46**	**2.34**	**2.17**
CO_2 emissions (kg CO_2 pr. tonne wood chips/1,000 km)	9.9	8.9	8.7
CO_2 emissions (kg CO_2 pr. GJ wood chips/1,000 km)	1.05	0.95	0.92
Energy usage relative till cargo pr. 1,000 km (%)	1.45	1.31	1.27
Wood pellets:			
Cargo wood pellets (tons)[28]	42,466	52,318	45,394
Cargo wood pellets (GJ) [29]	721,920	889,407	791,231
Ship transport costs (kr./GJ/1,000 km)	**0.67**	**0.64**	**0.97**
CO_2 emissions (kg CO_2 pr. tonne wood pellets/1,000 km)	4.9	4.4	7.0
CO_2 emissions (kg CO_2 pr. GJ wood pellets /1,000 km)	0.29	0.26	0.41
Energy usage relative till cargo pr. 1,000 km (%)	0.40	0.36	0.57

Table 37: Various deep sea ship sizes and characteristics. Data based on current prices and actual ships from each category.

Regarding the costs of shipping, the most important factor is fuel costs, as this is estimated to constitute approx. 2/3 of operating costs, and more than half of the total shipping costs (excluding loading and unloading).[30]

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[24] Some are also 210 meters.

[25] Based on a stowage factor of 109 cubic feet/tonne (3.1 m^3/ tonne or 325 kg / m^3) (Franceescato, Antonini and Bergomi 2008)

[26] Based on a heating value of 9.37 GJ/tonne

[27] Shipping Costs (CAPEX + OPEX) related to ship transport. Does not include loading and unloading. Entails a number of assumptions, including capital costs, personnel, engine size, efficiency, speed, etc. Particularly important variables include oil prices, and the % of time a ship sails back empty. In this analysis it is assumed that Handymax, Panamax, and Wood chip Carriers sail empty, i.e. without return cargo, 15, 20, and 50% of the time respectively. As ships get bigger and more specialised, it is assumed that it will be difficult to use them 100% of the time.

[28] Based on a stowage factor of 54 cubic feet / tonne (1.5 m^3/ tonne or 667 kg / m^3) (Melin 2008)

[29] Based on a heating value of 17.0 GJ/tonne

[30] Based on today's fuel prices. In the future, these are expected to be higher and, therefore, will constitute a higher share of the total transport costs.

Short Sea

In the Baltic Sea area, vessels that sail with wood chips typically have a maximum capacity of 2,200 – 2,600 tonnes, while ships sailing with wood pellets typically have a capacity of up to 4,000 tonnes. These ships are usually 100-110 meters in length and have a draft of 5-7 meters. In an earlier study carried out by Ea Energy Analysis the cost of ship transport alone from a typical Baltic harbour was estimated to be roughly 5.0 kr./GJ for wood chips, and a little over half of that for wood pellets.

The size of short sea ships have traditionally been largely determined by the size and capacity of port infrastructure in the Baltic countries. In recent years some of these ports undergone renovations and can now easily accommodate larger ships. It is likely that this trend will continue and that short sea vessels in the future will be larger. On the other hand, some other players the in short sea market, such as Copenhagen Merchants, indicated that it may not necessary be cost effective to operate on the shorter distances with ships much larger than those used today.

Transport costs: selected examples

Table 38 takes the above transport cost figures and applies them to four selected biomass supply regions, thus giving approximate costs of transport to a Danish harbour for both wood chips and pellets.

From	Wood chips (kr./GJ)	Wood pellets (kr./GJ)
Maine, USA	13.7	4.1
Savannah, USA	17.1	5.1
Mobile, USA	21.3	6.3
Baltics	5.0	2.7[31]

Table 38: Cost of shipping to a Danish harbour from selected biomass supply ports.[32] Costs are for shipping alone, and do not include loading/unloading, port fees, etc.[33]

As revealed by the table, the transportation cost in kr./GJ terms is almost twice as much for wood chips relative to wood pellets, with the difference growing in accordance with the trip distance. The above figures are solely transport costs, and as such do not incorporate the difference in FOB prices which arise due to costs associated with drying and pelletizing wood pellets, and the costs of heat treatment for North American wood chips.

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[31] Estimate

[32] The nautical shipping distances from the North American destinations to Denmark are 6,300 km. from Maine, 7,900 km from Savannah, Georgia and 9,800 km from Mobile, Alabama.

[33] Ships are assumed to sail empty or partially empty part of the time (50% for small vessels, 15% for Handymax, 20% for Pannamax, and 50% for wood chip carriers.)

Straw and other agricultural residues

While there is no specific limit on how far straw is transported from farm to plant, the price of straw is sensitive to the transport distance, which is why contracts are most often entered into with farms close to the plant.

For both straw and other agricultural residues it is not unthinkable that more long distance transport could take place if sufficient financial incentives are in place. However, one important difference between wood chips and straw is that wood chips are well suited to bulk handling (i.e. conveyor belts or pneumatic transfer), whereas straw is transported in large bales. This makes the handling of straw much more expensive, and according to a 2007 study, the per tonne fixed costs (i.e. loading and unloading) for shipping straw is over 3 times higher than that for wood chips (Flynn, Searcy og Ghafoori, et al. 2007).

Another big drawback with straw is its extremely low energy density. Hay bales typically have an energy density of 139 kg/m^3 (equivalent to a stowage factor of 7.2 m^3/tonne) which means that vessels with extremely high ship volume would be required to make long distance sea transport cost effective on a kr./GJ basis (Videncenter for Halm- og Flisfyring 2002). If for example we utilised the same chip carrier as outlined in Table 37, which had a wood chip shipping cost of 2.12 kr./GJ/1,000 km, the costs of shipping hay bales with an energy density of 139 kg /m^3, and a moisture content of 15% would be 3.17 kr./GJ/1,000 km. Combined with the aforementioned higher costs associated with loading and unloading the straw means that the initial input cost would have to much lower for straw relative to woody biomass.

Due to the fact that shipping is usually limited by the volume of the vessel, in computing the above transport costs two of the most important factors are the aforementioned stowage factor, and energy content of the fuels. If we combine these two factors we have the energy density per cubic meter as displayed in Table 39.

Fuel	Energy content (GJ/tonne	Stowage factor (kg/m3)	Stowage factor (m3/tonne)	Energy density (GJ/m3)	Ship transport costs* (kr./GJ/1,000 km)
Wood pellets	17.0	650[34]	1.5	**11.1**	**0.64^A**
PKS	16.9[35]	600[36]	1.7	**10.1**	**0.70^A**
Wood chips	9.4	325[37]	3.1	**3.0**	**2.17^B**
Straw	15.0[38]	139[39]	7.2	**2.1**	**3.17^B**

*Table 39: Energy contents, volumes, and resulting energy density and transport costs for selected fuels. *Does not include loading and unloading, harbour fees, etc. ^{A}With the panamax ship indicated in Table 37. ^{B} With the wood chip carrier indicated in Table 37.*

The table explains why the transport costs for wood pellets are lowest, and why transport costs are so much higher for straw than wood chips. Despite the fact that wood chips and straw utilise a high volume chip carrier in the cost calculations, due to their low energy content per m^3, they still incur higher transport costs.

As was noted earlier, palm kernel shells (PKS) are already today shipped over long distances and as such they were included in Table 39. Their relatively high energy content (in GJ/tonne) and stowage factors (in kg/m^3), result in PKS having a high energy density, and thus relatively low shipping costs (excluding loading and unloading). Looking forward, agricultural residues with similar characteristics will be relevant to look at.

Other pellets

The transport of other pellets, whether they be torrefied or not, will be quite similar to that of wood pellets, however there are some potential differences.

Firstly, depending on the material used, the pellets may have a higher energy density, and as a result the GJ/ship ratio is higher, thus reducing transport costs. The question for torrefied pellets for example will then be whether this additional cost related to torrefaction can be recouped by the reduction in transportation costs and/or through other benefits derived through utilising torrefied pellets.

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[34] Interview with Norden, some other sources indicate higher figures, i.e. 705 kg/m^3 (Melin 2008)
[35] (Flynn, Searcy and Ghaffori, et al. 2007)
[36] (West Biofuels n.d.)
[37] See (Franceescato, Antonini and Bergomi 2008)
[38] (Videncenter for Halm- og Flisfyring 2002)
[39] (Videncenter for Halm- og Flisfyring 2002)

If torrefied pellets prove to be hydrophobic in nature then one major difference would be that they would not have to be stored under cover, thus reducing the storage costs. In addition, this could potentially also allow for transport on open barges, thus reducing the transport cost.

Traditional wood pellets also have risks associated with potential explosions due to dust, and as a result dry bulk carriers are now installing CO_2 systems in their transatlantic ships. If the risks and problems with dust can be reduced or eliminated via torrefaction this will lower the costs associated with both transport and storage.

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