Ea Energy Analyses

SSCM Analysis of the Bioenergy Resources in Randers, Norddjurs and Syddjurs

Report carried out by Ea Energy Analyses on behalf of CMBI as part of an Enercoast project, with support from the Interreg IVB North Sea Region Programme and Region Midtjylland.

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1 Opsamling og konklusioner

Dette projekt hører under ENERCOAST, hvis overordnede formål er at stimulere øget anvendelse og produktion af biomasse og at skabe et marked for biomasse i Nordsøregionen. Enercoast projektet er finansieret af EU's Interreg program IVB med partnere fra Danmark, Tyskland, Storbritannien, Sverige og Norge. Den danske projektleder er AgroBusiness Park/ CBMI / Center for Bioenergi og Miljøteknologisk Innovation. Region Midtjylland medfinansierer 34 % af den danske del af projektet, mens Norddjurs, Syddjurs og Randers Kommuner bidrager til projektet med arbejdstimer.

Den danske del af Enercoast projektet fokuserer på Randers, Norddjurs og Syddjurs Kommuners muligheder for at opnå sine lokale klima- og energimål ved øget anvendelse af biomasse. Projektet er opdelt i 6 faser, hvoraf denne rapport leverer et bidrag til anden og tredje fase, som indeholder analyser af relevante biomasseressourcer på lokalt niveau, herunder en SSCM analyse af disse ressourcer.

Målet med nærværende rapport er at vurdere bæredygtigheden af forsyningskæderne for udvalgte, tilgængelige biomasse ressourcer i de tre kommuner. De udvalgte ressourcer omfatter husdyrgødning til biogas, halm, resttræ samt energiafgrøder til kraftvarmeproduktion.

Analyse af forsyningskæder

Forsyningskæde analyse (Sustainable Supply Chain Management - SSCM) er et begreb, der har mange definitioner, og tilsvarende findes der utallige metodiske tilgange knyttet til begrebet. I denne rapport bruges SSCM analysen til at besvare følgende spørgsmål:

Hvad er mulighederne for øget anvendelse af biomasse til energiproduktion i de tre kommuner, og hvilke konsekvenser er forbundet med udnyttelsen af hver enkelt af de i case studierne udvalgte ressourcer?

For hver enkelt af de udvalgte ressourcer er et overblik over forsyningskæden skitseret via en matrix. Hvert enkelt led i forsyningskæden analyseres med henblik på at afdække:
- Økonomiske aspekter
- Miljømæssige aspekter
- Sociale aspekter

1.1 Energiforbruget i de tre kommuner

Tabellen nedenfor opsummerer energisystemets hovedtal i de tre kommuner og sammenholder dem med den nationale energistatistik.

Bruttoenergiforbruget i de tre kommuner er 2,4 % af det danske bruttoenergiforbrug. De tre kommuner har et markant højere forbrug af fast biomasse (28-35 %) end det gennemsnitligt er tilfældet for hele landet (9,5 %). Den primære årsag hertil er, at der i kommunerne bliver anvendt en meget stor andel af biomasse i både individuel opvarmning og i fjernvarmesystemerne. Desuden har Syddjurs Kommune en stor industriel producent, Novopan, som anvender biomasse til procesvarme og til elproduktion.

Indikator	Norddjurs	Syddjurs	Randers	De 3 kommuner	Danmark	Kommunernes andel
Bruttoenergiforbrug (PJ)	5,4	5,7	9,7	20,8	863,5	2,4 %
Endeligt energiforbrug (PJ)	4,6	5,5	8,3	18,4	685,2	2,7 %
Total biomasse (PJ)	1,5	1,9	3,4	6,8	82,2	8,3 %
Total biomasse (% af bruttoenergiforbrug)	28	33	35	-	9,5	-
Halm(PJ)	0,74	0,31	0,15	1,2	18,3	6,6 %
Træ (PJ)	0,77	1,62	3,17	5,6	60,0	9,3 %
Biogas (PJ)	0	0,005	0,07	0,075	3,9	1,9 %
Fjernvarmeproduktion (PJ)	1,21	0,64	2,09	3,9	121,5	3,2 %
Fjernvarmeproduktion fra biomasse (PJ)	0,66	0,49	1,49	2,6	19,7	13,4 %
Individuel opvarmning (PJ)	1,17	1,50	2,05	4,7	115	4,1 %
Individuel opvarmning fra biomasse (PJ)	0,64	0,75	0,77	2,2	N/A	-
Anden biomasse (PJ)	0	0,71	0	0,7	N/A	-

Tabel 1: Opsummering af energiforbruget i de 3 kommuner sammenlignet med gennemsnitstal for hele landet i 2007 (data for Energi Randers fra 2009). Biomasse omfatter ikke affald.

I Norddjurs Kommune dækkes mere end 50 % af fjernvarmeproduktionen af bioenergi, og langt over halvdelen af den samlede opvarmning (fjernvarme og individuel) er baseret på biomasse. I Syddjurs Kommune produceres er over 75 % af fjernvarmen baseret på biomasse, og knap 60 % af det samlede varmeforbrug kommer fra bioenergi. I Randers viser tal fra 2009 at ca. 75 % af fjernvarme nu er baseret på biomasse, og knap 55 % af det samlede varmeforbrug kommer fra bioenergi. Således er der kun et begrænset potentiale for at erstatte nuværende fossil energiproduktion med biomasse til kraftvarme og fjernvarme.

Lokal fjernvarmeundersøgelse

Som en del af SSCM analyserne blev der gennemført en telefonrundspørge omkring det lokale biomassemarked i perioden 15.-28. juni 2010. Repræsentanter fra mere end 30 lokale fjernvarmeværker blev stillet en række spørgsmål omhandlende den nuværende produktion og planer for fremtiden. 8 af selskaberne bruger primært halm, 11 bruger primært træflis, 6 bruger primært træpiller, 6 bruger naturgas og resten anvender kombinationer af forskellige brændsler. Et større værk (Grenå Forbrændingsanlæg) forbrænder endvidere affald til kraftvarmeproduktion.

Resultaterne fra analyserne kan summeres i følgende udsagn og konklusioner:

- HedeDanmark A/S er hovedleverandør af træflis til selskaberne men lokale leverandører er også i spil. Lokale landmænd er hovedleverandører af halm. Hovedleverandøren af træpiller er Grenii A/S, og HMN Naturgas I/S er hovedleverandør af naturgas.

- De gennemsnitlige brændselspriser er 45-47 DKK/GJ for træflis, 31-41 DKK/GJ for halm og ca. 80 DKK/GJ for træpiller.
- Adskillige selskaber arbejder aktivt for at tilslutte flere kunder til fjernvarmenettet. Potentialet for at udvide fjernvarmenettet i nye områder er som hovedregel ikke analyseret i detaljer.
- De fleste selskaber, som i dag bruger biomasse, planlægger at fortsætte hermed, mens de selskaber, der anvender naturgas gerne overveje mulighederne for at skifte til biomasse eller solvarme i fremtiden. Dette skydes især de høje priser på naturgas samt høje energiafgifter på fossile brændsler.

1.2 Visioner, mål og incitamenter

På såvel internationalt, nationalt og lokalt plan er der en række målsætninger for forøgelse af anvendelsen af vedvarende energi og reduktion af CO_2. Målsætningerne kan være med til at stimulere en øget anvendelse af biomasse.

EU

Den primære driver for brugen af vedvarende energi i EU er den såkaldte Klima- og Energipakke med målene for 2020 om 20 % CO_2 reduktion og en andel på 20 % vedvarende energi af energiforbruget. VE-direktivet sætter et mål for hvert medlemsland, og det bindende mål for Danmark er 30 % vedvarende energi i 2020. Ifølge direktivet skal mindst 10 % af transportbrændslerne i hver medlemsstat endvidere baseres på vedvarende energikilder (EU, 2009).

En af de væsentligste mekanismer på EU niveau er det europæiske CO_2-kvote system (EU ETS). Denne mekanisme pålægger de store udledere i EU, som er ansvarlige for ca. 40 % af de totale CO_2 emissioner, at købe udslipstilladelser (EU Emission Allowances – EUA). En EUA, ofte kaldet et kvotebevis, svarer til ét ton CO_2. Den nuværende kvotepris er ca. 15 € pr. ton CO_2. Eftersom biomasse per definition er CO_2 neutralt udgør kvotesystemet et vigtigt incitament til at skifte fra fossile brændsler til biomasse og anden vedvarende energi. Ved 15 € pr. ton CO_2 tildeler kvotesystemet eksempelvis en ekstraomkostning på kul på 2 € pr. GJ.

Danmark – nationale mål og incitamenter

De nationale danske mål for energisektoren følger de bindende EU-mål. De primære nationale mekanismer til øget brug af bioenergi er undtagelse fra energiafgifter på varmesiden samt pristillæg eller feed-in tariffer på elsiden. Afgiftsfritagelsen har en indirekte støtteværdi på ca. 8-10 € /GJ biomasse til varme. Omregnet til pristillæg, svarer incitamentet på elsiden til ca.5 €c /kWh for biogas og 2€c /kWh for fast biomasse.[1] Den nuværende markedspris for el er ca. 5 €c /kWh.

Norddjurs og Syddjurs Kommuner

Norddjurs og Syddjurs Kommuner har etableret et samarbejde indenfor områderne klima og energi, og i initiativet "Djurs Energiland"[2] blev i 2009 udarbejdet en fælles handlingsplan for klima og energi i de to kommuner.

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[1] Ifølge dansk lovgivning kan biogasanlæg modtage støtten som feed-in tarif eller som et tillæg til den nuværende markedspris for el. Hvis biogas samfyres med fossile brændsler bliver støtten givet som et tillæg.

[2] http://www.djursenergiland.dk/index.htm

Handlingsplanen præsenterer en vision for den mulige energifremtid med radikalt lavere CO_2 emissioner. Handlingsplanen indeholder 9 konkrete initiativer, som fokuserer på energibesparelser, øget brug af vedvarende energi og omstrukturering af transportsektoren. Blandt de vigtigste langsigtede visioner for de to kommuner er 20 % reduktion af varmeforbruget, 75 % reduktion af olieforbruget og helt konkret planlægning af to nye biogasfællesanlæg.

Randers Kommune

I 2009 udgav Randers Kommune ”Klimahandlingsplan 2030”, som beskriver kommunens tiltag for at imødegå klimaforandringer. Planen indeholder både kortsigtede (2010) og langsigtede (2030) mål for reduktion af drivhusgasser i kommunen som geografisk område. De primære målsætninger er 75 % reduktion i CO_2 emissioner i forhold til 1990-niveau i 2030 og en andel på 75 % vedvarende energi i energiforbruget i 2030. Planen består af 54 specifikke initiativer, som skal iværksættes indenfor de kommende 5 år, primært fokuseret på landvindmøller og etablering af nye skovområder og vådområder.

Yderligere lægger planen op til en kommende varmeplan og en biogasplan. Klimaplanen er i øjeblikket i offentlig høring.

1.3 Ressourcer og nuværende energibalance

For at kunne vurdere potentialet for øget brug af biomasse i de tre kommuner er de estimerede bæredygtige ressourcer sammenlignet med den nuværende brug af biomasse til energiformål. Balancen fremgår af nedenstående tabel.

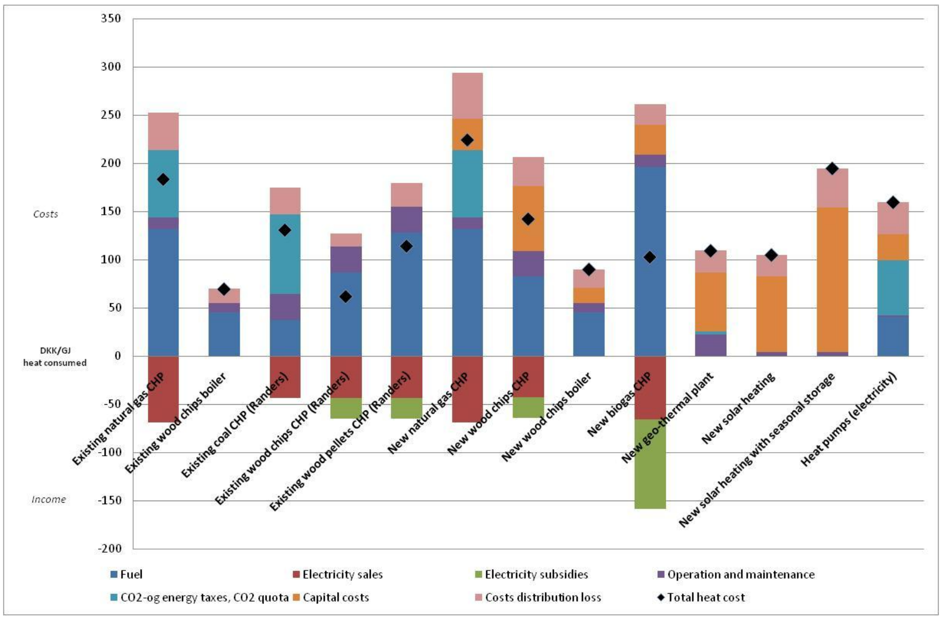
Brændsel (TJ)	Potentiel energi ressource	Nuværende energiforbrug i kommunerne	Balance
Halm i dag	3.441	1.200	2.241
Halm med 15 % pil	2.771	1.200	1.571
15 % pil på landbrugsjord	1.789	0	1.789
Biomasse fra skov	815	5.560	-4.745
Biogas fra husdyrgødning	833	12	821
Total uden energiafgrøder	**5.089**	**6.772**	**-1.683**
Total med energiafgrøder	**6.209**	**6.772**	**-563**

Tabel 2: Potentielle biomasseressourcer, nuværende anvendelse, og potential biomasse energibalance for de tre kommuner. Værdierne for biogas dækker udelukkende biogas fra husdyrgødning.

Ifølge lokale vurderinger er der betydelige uudnyttede ressourcer, specielt for halm, biogas og energiafgrøder – men også resttræ fra skovene (træflis). Dog overstiger det nuværende forbrug af biomasse i dag i betydeligt grad de lokale ressourcer. Dette skyldes primært de store mængder importeret biomasse (både fra andre kommuner og fra udlandet) med Randersværket som det mest prominente eksempel på international import. For halm og biogas fra husdyrgødning er det lokale forbrug betydeligt lavere end ressourcepotentialet.

1.4 Sammenligning af omkostninger til varmeproduktion

De primære incitamenter for lokale aktører at øge deres forbrug af biomasse er typisk af økonomisk karakter. Aktørerne vil vælge teknologier og brændsler der, indenfor det eksisterende rammeværk, kan producere varme og strøm mest omkostningseffektivt.



Figur 1: *Omkostninger ved varmeproduktion ved forskellige fjernvarmeteknologier. Figuren viser omkostningerne ved varmeproduktion i DKK/GJ ved levering til forbruger inkl. Afgifter og andre relevante virkemidler. Den totale varmeproduktionsomkostning (sum af indtægter og omkostninger) er markeret med en* ***sort prik****. Til sammenligning er omkostningerne ved individuelle løsninger ca. DKK 265/GJ for olie og naturgas og DKK 225/GJ for træpiller og varmepumper. Investeringer til etablering af fjernvarmenet er ikke inkluderet.*

I figuren er vist de totale omkostninger for varmeproduktion fra et udvalg af generaliserede varmeproduktionsteknologier. Figuren viser, at biomasse kraft-varme (CHP) og biomasse varmekedler (Heat Only Boilers, HOB) har lavere varmeproduktionsomkostninger sammenlignet med andre teknologier. Hoved-årsagen til dette ligger i følgende tre elementer i rammeværket: a) Afgiftsfrita-gelsen på varmesiden, b) EU's kvotesystem der øger omkostningen for fossile brændsler og c) Pristillæg og feed-in tariffer på elsiden. Ydermere er træflis og halm relativt billige brændsler sammenlignet med olie og naturgas. Af figuren kan også ses, at mindre kraftvarmeværker baseret på faste biobrændsler har forholdsvis høje varmeproduktionsomkostninger på grund af høje investerings- og drifts- og vedligeholdsomkostninger. Andre vedvarende energiteknologier som biogas, geotermi og solvarme kunne også vise sig interessante i et øko-nomisk perspektiv.

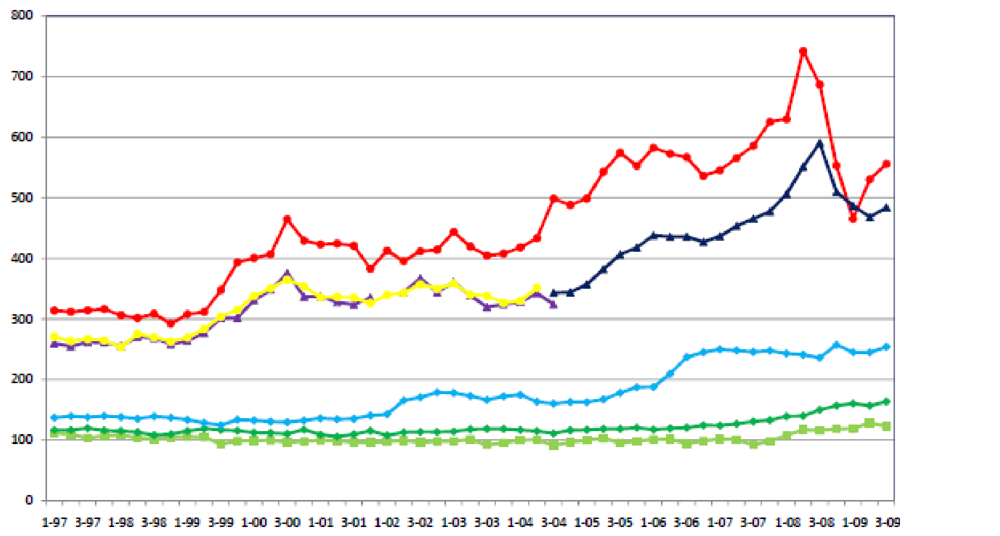
Sammenlignes omkostningerne ved eksisterende biomassefyrede værker på 60-70 DKK/GJ med omkostningerne for individuelle teknologier på 225-265 DKK/GJ, og medtages de forventede omkostninger for tilslutning til fjernvarme-nettet på 40 – 110 DKK/GJ, kunne der ligge en stor økonomisk værdi i at konvertere individuelle kunder til fjernvarme. Dog kan omkostningerne ved tilslutning til nettet variere markant, og potentialet bør vurderes fra sag til sag.

En vigtig konklusion at drage fra figuren er, at biogas med de anvendte forudsætninger kan levere fjernvarme til betydeligt lavere priser end eksisterende naturgas kraftvarmeværker. Det er her antaget, at biogas til levering på et kraftvarmeværk kan produceres til 100 kr./GJ. Det fremgår også tydeligt, at omkostningerne ved biogasproduktion kun behøver at falde marginalt (eller prisen på fast biomasse behøver kun at stige marginalt), før biogas kraftvarme er sammenlignelig med en træflis-fyret varmekedel.

1.5 Udviklingen i biomassemarkeder

Tendenser i markedet

Betragtes tendenserne i de nationale og internationale biomassemarkeder har der været en betydelig stigning i efterspørgslen særligt for træpiller og træflis til energiproduktion. Ifølge markedsanalyserne i dette studie vil efterspørgslen på biomasse stige dramatisk i Europa, primært som en konsekvens af politiske mål på national, europæisk og international niveau.



Figur 2: Nominelle brændselspriser i DKK/MWh an værk, eksklusiv moms, men inklusiv andre afgifter fra januar 1997 til tredje kvartal af 2009. Den røde linje viser olie, den gule og mørkeblå naturgas, den lyseblå træpiller, den mørkegrønne træflis og den lysegrønne halm. Fossile brændsler pålægges en afgift på ca. 200 DKK/ MWh, mens biomasse ikke er pålagt afgifter. (Boldt, 2009)

Figuren viser udviklingen i brændselspriser på det danske marked fra 1997 til tredje kvartal af 2009, inklusive energi- og CO_2-afgifter men uden moms. Figuren viser tydeligt, at der er et betydeligt og indtil nu voksende økonomisk incitament til at anvende biomasse til varmeproduktion.

Ressourcer og priser

Der pågår megen diskussion om omfanget af nationale skovressourcer der kan anvendes til energiformål. Skovdyrkerne og HedeDanmark fremfører, at der er et betydeligt uudnyttet potentiale for øget træflisproduktion fra de danske skove. Dertil kommer, at dyrkning af energiafgrøder på landbrugsjord kan øge biomasseressourcen. Imidlertid viser interviews med købere af træflis, at flere af disse indkøber træflis over stadigt stigende afstande grundet stigende lokale priser og/eller mangel på udbud. Større forbrugere med adgang til havnefaciliteter importerer i øjeblikket tillige træflis fra de baltiske lande for at sikre forsyningssikkerheden og for at holde omkostningerne til råmaterialer nede. Som et resultat af den stigende efterspørgsel er priserne på biomasse (særligt træpiller) steget over de seneste 3-9 år.

Halm

Udviklingen i, forbruget af halm til kraftvarme og fjernvarmeproduktion lader til at være stagneret og faktisk faldet de seneste år på nationalt niveau. Hvis denne tendens fortsætter, vil det tvinge halmleverandørerne til at genoverveje deres produktionsstrategier. Alternativer for landbruget kan eventuelt være at erstatte dele af kornproduktionen med produktion af energiafgrøder eller at sigte på afsætning af halm til andre formal, fx biobrændsler til transportsektoren. Det bør i den sammenhæng dog nævnes, at det på nuværende tidspunkt stadig er tvivlsomt, om såvel 1. som 2. generation af biobrændstoffer kan blive omkostningseffektive.

1.6 Potentialer for øget anvendelse og produktion af biomasse og biogas i de tre kommuner

Udvide efterspørgslen på fjernvarme

Strukturen i varmeforsyningen er afgørende for mulighederne for effektivt at anvende mere biomasse lokalt til kraftvarmeproduktion. I vurderingen af potentialet for øget brug af biomasse er varmeplanlægning derfor et vigtigt værktøj for kommunerne. I henhold til dansk lovgivning er varmeplanlægningen kommunernes ansvar baseret på samfundsøkonomiske vurderinger. Potentialet for at udvide fjernvarmenettet er ikke grundigt vurderet i denne rapport, men ifølge den tidligere nævnte rundspørge blandt fjernvarmeværker forekommer potentialet begrænset.

Individuelt varmeforbrug

Denne rapport fokuserer på biomasse til kraftvarmeproduktion. Imidlertid er der i kommunerne stadig et betydeligt potentiale for at fortrænge olie til individuel opvarmning. Med et stort vindkraftpotentiale i regionen og i kommunerne, er varmepumper endvidere et relevant alternativ til individuelle oliekedler. Da varmepumper producere varme (eller køling) baseret på vedvarende energi og pga. deres lagringspotentiale af el som varmt vand bliver varmepumper ofte set som en nøgleteknologi i det fremtidige dynamiske energistystem. En biomasse baseret mulighed er lokale træpillekedler. Det skal i den forbindelse bemærkes, at disse er afhængige af biomasse der importeres til området og ikke nødvendigvis er den mest effektive måde at anvende biomassen på, eftersom effektiviteten er markant lavere, end hvis biomassen udnyttes i store kraftvarmeværker.

Eksport af biomasse

Der er ikke noget usædvanligt i, at områder med et højt produktionspotentiale for biomasse ikke har de største fjernvarmeområder, eftersom det største ressourcepotentiale forefindes i landområderne, mens fjernvarmeområderne typisk er knyttet til byområderne. Det relativt begrænsede potentiale for øget forbrug af biomasse i de tre kommuner efterlader imidlertid stadig et potentiale for øget produktion af biomasse til eksport til andre kommuner.

1.7 SSCM analyserne

Der er gennemført en SSCM analyse af mulighederne for at øge biogasproduktionen i de 3 kommuner og anvende flere lokale, faste biobrændsler (halm, træ og energiafgrøder). Hovedkonklusioner fra SSCM analyserne er præsenteret nedenfor.

Biogas

Råvare

Et muligt virkemiddel, for optimering i den første del af forsyningskæden, er at øge det potentielle gasudbytte i selve biomassegrundlaget ved at mindske vandindholdet. Dette kan i nogle tilfælde gøres i den daglige drift på husdyrbrugene ved at reducere vandspildet. Lokalt kan det endvidere være en barriere for udnyttelse af biomassegrundlaget, hvis dyreholdene er for små eller for spredte til, at det kan betale sig at inkludere dem i et biogasfællesanlæg.

Produktionen af energiafgrøder

Med henblik på produktionen af energiafgrøder, herunder majs, er de største nuværende barrierer selve prisen på råvaren, herunder konkurrencen i forhold til anden arealanvendelse. Desuden er de hidtidige erfaringer med biogas produktion på energiafgrøder i Danmark temmelig begrænsede. Det kan være et incitament for anvendelse af energiafgrøder til biogasproduktion, at landmændene får en mere diversificeret afsætning for deres produkter med mulighed for langvarige fastpriskontrakter med biogasanlægget. Det kan være et særligt incitament, hvis leverandøren af afgrøden, f. eks. majs samtidig er medejer af biogasanlægget.

Transport

Forsyningskædens tredje led, transport af husdyrgødning fra gård til biogasanlæg er omkostningstung og udgør en betydelig økonomisk barriere for biogasanlæggets samlede økonomi. Det er derfor et væsentligt tiltag i selve den fysiske planlægning, at transportafstandene minimeres. I visse tilfælde kan det være en fordel at decentralisere biogasproduktionen således, at der etableres gårdanlæg placeret ved de største landbrug, og at biogassen transporteres herfra til udnyttelse i et fælles kraftvarmeanlæg. En anden løsning kan være at separere gødningen ude på gårdene, således at kun den faste del udnyttes til biogasproduktion. Imidlertid er der betydelig risiko for, at separeringsomkostningerne for den enkelte landmand overstiger de sparede transportomkostninger for fællesanlægget. Et andet incitament til at separere gylle på gårdene er, dog at landmanden ved at fjerne den faste og fosforholdige fraktion kan øge sit husdyrhold indenfor den gældende miljølovgivning.

Produktionen af biogas

Med hensyn til selve etableringen af biogasanlægget er en væsentlig barriere at skaffe den nødvendige finansiering, især i lyset af finanskrisen og den økonomiske afmatning. Hertil kommer udfordringen ved at få afsat biogassen på tilstrækkelig fordelagtige vilkår, således at den samlede projektøkonomi med stor sandsynlighed vil være positiv over hele låneperioden. Hertil kommer problemer med at finde gode anlægsplaceringer samt problemer med langvarige forhandlings- og godkendelsesprocesser.

Et muligt virkemiddel med hensyn til finansieringen er kommunegaranti. I denne sammenhæng kunne staten bidrage, f. eks ved at re-garantere for en del af lånebeløbet. Vedrørende den fysiske planlægning er det afgørende for projektøkonomien, at anlægget placeres geografisk rigtigt i forhold til husdyrgrundlaget. Godkendelsesprocessen bør være så enkel som muligt, og det er vigtigt at opnå lokal accept gennem samarbejde og dialog. Oprettelse af Biogassekretariatet i februar 2010 kan forhåbentlig fungere som et virkemiddel for at opnå en mere smidig godkendelsesproces og lokal accept.

Projektøkonomien udgør som nævnt en barriere for øget udnyttelse af biogasressourcen på grund af høje investeringsomkostninger, høje driftsomkostninger samt vanskeligheder ved at få en god pris for biogassen. Et vigtigt virkemiddel er at fortsætte udviklingsindsatsen mod billigere anlæg og lavere transportomkostninger for husdyrgødningen.

Salg af biogas

Ofte er det en barriere for biogasprojektet at få adgang til salg af biogas til et lokalt kraftvarmeværk på langsigtede kontrakter, der kan sikre projektøkonomien. Usikkerhed om det fremtidige rammeværk for anvendelse af biomasse og naturgas til fjernvarme og kraftvarme gør det vanskeligt at få langsigtede aftaler. Udarbejdelse af standardkontrakter mellem biogasanlæg og kraftvarmeværk kan være et nyttigt virkemiddel.

Som beregningerne i denne rapport viser, er det en tydelig selskabsøkonomisk fordel at anvende biogas frem for naturgas, mens det kan være vanskeligt at konkurrere med halm og flis under de nuværende økonomiske rammer. Hertil kommer, at biogas ofte produceres jævnt over året, og ikke følger svingningerne I varmebehovet. Et muligt virkemiddel her er at øge fleksibiliteten i biogasproduktionen, således at produktionen, i højere grad kan følger prissving I elmarkedet og forbrugsudsving på varmesiden.

Halm

Udbudssiden

Der lader til at være et stort potentiale for øget bjærgning af halm i de tre kommuner.

Efterspørgselssiden

Den største barriere for øget udnyttelse af halm lader dog til at være et begrænset afsætningsmarked indenfor kommunerne og stagnation i den overordnede efterspørgsel efter halm i Danmark. Selv ved relativt lave halmpriser foretrækker de store centrale kraftvarmeværker af tekniske grunde (korrosion mm.) at anvende træpiller i deres kedler.

Mere halm kunne blive anvendt i lokale fjernvarmeværker og centrale kraftvarmeværker som erstatning for kul og træbiomasser. Dette ville muligvis gavne den samlede lokale økonomi. Det er dog beslutninger der skal tages af dem der ejer kraftvarmeværkerne og varmeværkerne. Sådanne beslutninger skal sandsynligvis baseres på langvarige leveringsaftaler.

På længere sigt kan den stigende efterspørgsel efter biomasse i energisektoren forventes at påvirke efterspørgslen, også efter halm. Halm kan anvendes uden større komplikationer i centrale kraftvarmeværker, såfremt de er konstrueret til formålet fra starten.

Energiafgrøder (Pil)

Udbudssiden

Efterspørgslen efter særligt træbiomasse i energisektoren forventes at vokse betydeligt i Danmark og i Europa frem mod 2020. Priserne på disse typer af biomasse forventes derfor også at stige over de kommende 10 år. Denne stigende efterspørgsel er den primære driver for energiafgrøder på efterspørgselssiden.

Lokal dialog og samarbejde om fremtidige projekter kunne føre til øget erstatning af importeret biomasse med lokalt producerede brændsler.

Efterspørgselssiden - økonomiske aspekter

Etableringen af pileplantager er omkostningsfuldt på grund af høje investeringsomkostninger til plante- og høsteudstyr. Der ydes i øjeblikket statsligt tilskud til investering, hvilket betyder, at omkostningerne til høst-maskineri udgør den største investeringsrisiko for landmændene. Denne risiko kunne håndteres gennem indgåelse af langtidskontrakter med grossister eller direkte med fjernvarmeselskaberne eller større kraftvarmeværker.

Efterspørgselssiden - miljømæssige og etiske aspekter

Visse miljømæssige og etiske problematikker knytter sig til dyrkning af energiafgrøder som pil. Lokalt og nationalt kan natur og biodiversitet blive truet, såfremt energiafgrøder bliver plantet på brakarealer. Hvis energiafgrøder erstatter marker, som i dag anvendes til fødevare- eller foderproduktion, vil det påvirke den globale fødevareproduktion og arealanvendelse, hvilket på sigt kan føre til en stigning i anvendelse af regnskov eller andre naturarealer til landbrugsmæssige formål.

Såfremt piletræer bliver plantet på marginale jorde, som i dag anvendes til produktion af afgrøder, kan pilen have en positiv effekt på kvælstofudledning, primært på grund af et reduceret gødningsbehov.

Eftersom aske fra pil indeholder relativt høje koncentrationer af tungmetaller, bør sådanne afgrøder potentielt kunne fungere som ”sinks”, hvis separationsteknologier bliver udviklet. Hermed menes, at pil under væksten optager tungmetaller, der dermed kan fjernes fra jorden.

Træflis

Udbudssiden

Som tidligere nævnt forventes efterspørgslen efter særligt træbiomasse til energisektoren at vokse betragteligt i Danmark og i Europa. Denne stigende efterspørgsel er også den primære driver for træflis på efterspørgselssiden

Efterspørgselssiden

De fleste større skove producer allerede en vis mængde træ til energiformål. Skovejerne vil fremadrettet have et økonomisk incitament til yderligere at tilpasse deres plantnings og dyrkningsstrategi med henblik på at optimere produktionen af træflis. Der pågår en del debat omkring omfanget af bæredygtige træ ressourcer, der kan udvindes af skovene til energiformål. Yderligere forskning og dokumentation af, hvordan udbyttet kan øges på bæredygtig vis er påkrævet. En barriere for øget brug af restprodukter fra skovene kan være, at de danske skove generelt er forholdsvis små og spredte sammenlignet med andre lande, der producerer træflis i større mængder. Virkemidler i denne sammenhæng kunne være bedre information omkring driften af skovene med større fokus på at optimere energiressourcen.

1.8 SSCM Indikatorer og virkemidler

Hovedudfordringer

For halm er den primære udfordring på efterspørgselssiden. For biogas er der betydelige udfordringer på både efterspørgsels- og udbudssiden. For energiafgrøder og træflis stiger efterspørgslen og de primære udfordringer findes på udbudssiden.

Tabellen på næste side giver et overblik over de primære virkemidler og indikatorer for øget produktion og udnyttelse af biomasse. De vigtigste virkemidler skal forstås som de handlinger, der vurderes at være af størst betydning for at øge brugen af hver enkelt ressource.

Mål	Virkemidler	Indikatorer	Måleenheder
BIOGAS			
Reducere omkostninger ved biogas produktion	Reducere kapitalomkostninger og transportomkostninger	Reduktion i omkostninger sammenlignet med eksisterende anlæg	€/M^3
Rimelige salgspriser for biogas	Langtidskontrakter med fjernvarmeselskaber	Salgspris	€/M^3
Fortrængning af CO_2 ved høj effektivitet	Effektiv brug af biogas til både el & varme	Energieffektivitet	Energi input (biogas)/Energi output (El & varme).
Faktisk mængde gødning brugt til biogasproduktion > 50%	Reduktion af omkostninger, lokal planlægning, tilskyndelser	Andel af gødning til biogas	%
HALM			
Høj drivhusgaseffekt ved fortrængning af kul.	Øget brug til kraftvarme – eksport til større kraftvarmeværker	Mængde sparede drivhusgasser	Kg CO_2 pr. ton
Optimere lagerfaciliteter	Lokalt samarbejde	Lagerkapacitet for halm i kommuner	Måneders kapacitets.
Total udnyttelse af ressource til energiproduktion	Høj og stabil efterspørgsel (og priser)	Totalt forbrug af halm til energi i regionen	Ton halm til energi i Jylland.
ENERGIAFGRØDER (Pil)			
Mere end 10 år	Langtidskontrakter	Varighed af salgskontrakter	År
Reduceret sivning af kvælstof	Fokus på kvælstofudledning	Reduceret brug af kunstgødning på marginale jorde	% reduceret kunstgødning
TRÆFLIS			
Øge udbytte fra lokale skove hvor det er bæredygtigt	Viden om bæredygtig produktion	Salg til energiformål	Ton pr. hektar
Øget bevidsthed blandt skovejere	Information til skovejere om fordele ved produktion af træ til energi	Undersøgelse blandt skovejere om deres tilgang til energi-produktion	Resultater fra undersøgelse
Mere fokus på levering til energiformål	Stabile og høje salgspriser	Gode officielle statistikker om priser og mænger	

Tabel 3: Primære virkemidler og indikatorer for øget produktion og udnyttelse af biomasse

1.9 Anbefalinger

Der er betydelige uudnyttede ressourcer i kommunerne, især husdyrgødning til biogasproduktion og halm, der ikke bjærges. De muligheder, der bør overvejes positivt i den videre proces, er:

- **Biogas:** For at nyttiggøre biogas bedst muligt ud fra en økonomisk og energimæssig synsvinkel, bør den anvendes til produktion af kraftvarme, med høj virkningsgrad, så varmen ikke går til spilde. I Randers er der naturgas, der kan erstattes af biogas, men en væsentlig del af de lokale varmemarkeder forsynes med faste biobrændsler, der producerer fjernvarme uden elproduktion. Biogas er dyrere at transportere over store afstande end faste biobrændsler. Muligheden for at ændre forsyningen i nogle af disse byer fra fjernvarme baseret på faste biobrændsler til kraftvarme baseret på biogas kan vise sig at være den mest omkostningseffektive mulighed for at udnytte biogasressourcen og de faste biobrændsler samlet set. Denne mulighed bør indgå i den lokale, langsigtede energiplanlægning.
- **Halm**. Der er betydelige uudnyttede halmressourcer i kommunerne. Det største potentiale for anvendelse af halm i energisektoren er på de store centrale kraftvarmeværker. Disse værker drives med høje damptemperaturer og foretrækker derfor at anvende træagtige biomasse frem for halm af tekniske grunde, herunder især korrosion, belægningsdannelse i kedler etc. Det er derfor vanskeligt at afsætte større mængder halm til eksisterende kraftværker. Kraftvarmeværker, der fra starten designes til at anvende halm, har ikke disse problemer. Kommunerne derfor kunne som et led i den langsigtede energiplanlægning bidrage til debatten om brændselsanvendelse til kraftvarmeproduktion, herunder perspektiver for at den næste generation af kraftvarmeværker i regionen etableres med mulighed for anvendelse af halm i højere grad.

Konkret er der et potentiale for øget anvendelse af biomasse til fjernvarme. De vigtigste anbefalinger er:

- I henhold til oplysninger fra DONG Energy kan Grenå Kraftvarmeværk teknisk anvende op til 60 % halm i sit brændselsmix, hvilket det ikke gør i dag. På den baggrund er der muligvis et potentiale for øget anvendelse af halm på dette værk, som vil fortrænge kul. Det anbefales derfor at gå videre i undersøgelser af muligheder for større anvendelse af biomasse i Grenå Kraftvarmeværk.
- Randersværket anvender i dag ca. 80 % biomasse og 20 % kul. Det er teknisk muligt at anvende 100 % biomasse på kraftvarmeværket. Lagerbegrænsninger nævnes som en barriere for at øge biomasseanvendelsen til 100 %.
- Fjernvarmeselskaberne kunne samarbejde om en samlet vurdering af mulighederne for at udvide fjernvarmenettene I de tre kommuner, hvilket kunne øge anvendelsen af biomasse. Rundspørgen til 30 fjernvar-

meværker, som er foretaget i dette projekt har ikke afsløret et stort potentiale, men ved at samarbejde om et fælles projekt kunne mulighederne vurderes mere systematisk på et ensartet grundlag, og til rimelige omkostninger.

For at sikre en samordnet udnyttelse af de lokale ressourcer i energisystemet og vurdere det i forhold til energibesparelser mm. foreslås:

- At kommunerne gennemfører en samordnet, strategisk energiplanlægning i tråd med anbefalingerne fra KL og Energistyrelsen (fra "Oplæg om strategisk energiplanlægning", 2010). Planlægningen bør indeholde overvejelser om sammenhængen mellem energi- og klimamål, planer for energibesparelser, fremtidig struktur og udvikling af varmemarkedet og udnyttelse af lokale ressourcer. Særligt perspektiverne og økonomien i udvidelser af fjernvarmenettet bør vurderes.
- At planlægningsprocessen foregår i samarbejde mellem kommunerne og i dialog med interessenter fra landbrug, varme- og elproducenter samt erhvervsliv.
- At kommunerne etablerer en formel platform for samarbejde med de lokale landboforeninger, skovbrug samt energiselskaber, for at identificere de nødvendige konkrete projekter, som er nødvendige for at nå energi- og klimamålene.
- At kommunerne initierer et demonstrationsprojekt med etablering af energipil i samarbejde med landbruget og energiselskaber hvor energiselskaber og landmændene deler investeringsrisici. Der kan hertil hentes inspiration i Assens projektet.

2 Summary and conclusions

This project has been commissioned by ENERCOAST whose overall aim is to stimulate increased use and production of biomass, and create a market for bio energy in the North Sea region. The Enercoast project has been financed by the EU Interreg IVB with partners from Denmark, Germany, United Kingdom, Sweden and Norway. The Danish project leader is AgroBusiness Park/ CBMI /Innovation Centre for Bioenergy and Environmental Technology. Central Region Denmark is co-financing 34% of the Danish portion of the project, while the municipalities of Norddjurs, Syddjurs and Randers are contributing to the project with their working hours.

The Danish portion of this project focuses on three Danish municipalities, Randers, Norddjurs, and Syddjurs, and the possibilities to reach local energy and climate targets by increasing the use and production of biomass. The project is divided into 6 phases of which this report is part of the second and third phase which focus on analyses of various biomass resources on a local level including carrying out SSCM analyses of these resources.

The aim of this report is to assess the sustainability of relevant bio energy supply chains related to the resource accessibility in the three municipalities with main focus on biogas, straw, wood residues and energy crops for combined heat and power production.

Sustainable Supply Chain Management

Sustainable Supply Chain Management (SSCM) is a concept that has many definitions and the methodologies used to approach this are numerous. In this report the SSCM analysis is used to answer the following question:

What are the possibilities of increased use of biomass for energy production in the three municipalities, and what consequences are associated with the utilisation of each of the selected resources described through our case studies?

For each of the resource case studies an overview of the supply chain is illustrated through a matrix. Each step of the supply chain from the primal material production in on end to heat and electricity deployment in the other end is analysed with regard to three key aspects:

- Economic aspects
- Environmental aspects
- Social aspects

2.1 Energy balance in the three municipalities

The table on the following page summarises the energy situation in the 3 municipalities and compares them with the energy situation in Denmark.

The total gross energy use in the 3 municipalities is 2.4% of the Danish total gross energy consumption. The 3 municipalities have a much higher share of solid bioenergy use (28-35%) than that of the national average for Denmark (9.5%). The main reason is that there is a very high share of biomass use in both individual and district heating systems. Furthermore, Syddjurs has the large industrial manufacturer Novopan, which uses biomass for the production of process heat and power.

Indicator	Norddjurs	Syddjurs	Randers	Three municipalities	Denmark	Municipalities share
Gross energy (PJ)	5.4	5.7	9.7	20.8	863.5	2.4 %
Final energy (PJ)	4.6	5.5	8.3	18.4	685.2	2.7 %
Total biomass (PJ)	1.5	1.9	3.4	6.8	82.2	8.3 %
Total biomass (% of gross energy)	28	33	35	-	9.5	-
Straw (PJ)	0.74	0.31	0.15	1.2	18.3	6.6 %
Wood (PJ)	0.77	1.62	3.17	5.6	60.0	9.3 %
Biogas (PJ)	0	0.005	0.07	0.075	3.9	1.9 %
District heating production (PJ)	1.21	0.64	2.09	3.9	121.5	3.2 %
District heating production from biomass (PJ)	0.66	0.49	1.49	2.6	19.7	13.4 %
Individual heating (PJ)	1.17	1.50	2.05	4.7	115	4.1 %
Individual heating from biomass (PJ)	0.64	0.75	0.77	2.2	N/A	-
Other biomass (PJ)	0	0.71	0	0.7	N/A	-

Table 4: Summary of energy use in the 3 municipalities compared with the Danish average consumption in 2007 (data for Energi Randers from 2009). Biomass does not include municipal waste.

In Norddjurs, over 50% of the district heating is covered by bioenergy, and well over half of the total heating (district and individual) is produced via biomass. In Syddjurs over 75% of the district heating is produced via bioenergy, and nearly 60% of the total heat demand comes from bioenergy. Lastly, in Randers, 2009 figures from Randersværket indicate that roughly 75% of district heating from the municipality now comes from biomass, and nearly 55% of total heat demand comes from bioenergy. As a result there is only a limited potential for replacing any of the current fossil energy production with biomass in CHP and district heating.

Local district heating survey

As a part of the SSCM analysis, a phone questionnaire regarding the local biomass market was completed during the period 15-28th June, 2010. Representatives from more than 30 local DH plants in the three municipalities were asked a series of questions regarding current operations and plans for the future. 8 of these companies primarily use straw, 11 use primarily wood chips, 6 use primarily wood pellets, 6 mainly utilise natural gas, and the rest of the companies use a combinations thereof. One larger facility (Grenå Forbrændingsanlæg) incinerates municipal solid waste (MSW) for CHP production.

The outcome from the survey can be outlined in the following main statements and conclusions:

- HedeDanmark A/S is the main supplier of wood chips to the companies but also local suppliers are in the game. Local farmers are the main suppliers of straw. The main supplier of wood pellets is Grenii A/S and HMN Naturgas I/S is the main supplier of natural gas.

- The fuel prices vary, but the average prices are 45-47 DKK/GJ for wood chips, 31-41 DKK/GJ for straw and app. 80 DKK/GJ for pellets.
- Several companies are actively working on connecting more consumers to the grid. The potential for grid expansion into new areas is often not analysed in detail.
- Most companies that use biomass today plan to continue with biomass, while those currently using natural gas tend to consider the possibilities of using biomass or solar heat due to the high prices of natural gas and high energy taxes on fossil fuels.

2.2 Visions, goals and incentives

At the international, national and local levels there are a series of targets aimed at both increasing renewable energy use and reducing CO_2 emissions. These goals and targets are likely to stimulate greater use of biomass.

EU

The primary driver for renewable energy use within the EU is the so called Climate and Energy package, with the 2020 goals of 20% CO_2 reduction and a renewables share in energy consumption of 20% (There is an ongoing discussion in EU about increasing the CO_2 goal to 30%). The Renewable Energy Directive establishes a target for each member country and the mandatory target for Denmark is 30% renewables in 2020. According to the Directive, at least 10% of transport fuel in each member state must be from renewable sources (green electricity, hydrogen, and biofuels all qualify, with second generation biofuels and green electricity counting double) (EU, 2009).

One of the major EU-level mechanisms is the European Union Greenhouse Gas Emission Trading System (EU ETS). According to this scheme major emitters in EU responsible for app. 40% of total CO_2 emissions have to buy Allowances to emit greenhouse gases. One EU Allowance Unit (EUA) equals one tonne of CO_2. The current EUA price is approximately 15 € per tonne CO_2. As biomass per definition emits zero CO_2, the ETS is an important incentive to switch from fossil fuels to biomass and other renewables. At 15 € per tonne CO_2 the ETS inflicts a 2 € per GJ extra cost on coal.

Denmark - National goals and incentives

The Danish national goals in the energy sector closely follow the mandatory targets laid out by EU: 20% reduction of CO_2 from 2005 to 2020 (NON-ETS sectors), 30% renewable in final energy including transport and 10% renewables in transport.

The major national incentives for increased use of bioenergy are exemption from energy taxes and price supplement or feed-in tariffs for electricity production. The tax exemption has an indirect support value of app. 8-10 € /GJ biomass used for heat production. When calculated as a supplement to the current electricity market price, price supplement and feed in tariffs for electricity production correspond to approximately 5 €c /kWh for biogas and 2€c /kWh for solid biomass.[3] The current market price is approximately 5 €c /kWh.

Norddjurs and Syddjurs

The municipalities of Norddjurs and Syddjurs have been co-operating in the field of climate energy and in the initiative called Djurs Energiland.[4] In 2009, an energy and climate action plan was drawn up.

The action plan presents a vision for a possible energy future with radically lower emissions of CO_2. The action plan encompasses 9 concrete initiatives with focus on energy savings, increased use of renewable energy and restructuring of the transport sector. Some important long term visions for those two Municipalities are a 20% reduction in heat consumption, 75% reduction in oil consumption for heating and the establishment of new biogas plants.

Randers

In 2009, the Municipality of Randers published a plan describing its measures for mitigating climate change in 'Climate Action Plan 2030'.[5] The plan consists of both short term (2010), and long term targets (2030), for reducing the greenhouse gas emissions in the municipality as a geographical area. The major long term targets of the municipality are 75% reduction of CO_2 emissions relative to the 1990 level by 2030 and a 75% share of renewable energy in the energy supply by 2030. The plan consists of 54 specific initiatives which are to be launched in the next 5 years, mainly focused on wind turbines on land, and the establishment of new woodlands and wetlands.

Furthermore, the plan lays the ground work for a heat plan, and a plan for biogas. The plan is currently in a public hearing process.

2.3 Resources and current Energy Balance

In order to evaluate the potential for increased use of biomass in the three municipalities the assessed sustainable resources were compared to the current use for energy purposes. The balance is presented in Table 5 on the following page.

According to local estimates there are substantial unused resources of especially straw, biogas and energy crops – but also residues from the forest (wood chips). However, due to the large quantities of imported biomass (both from other municipalities and abroad), with Randersværket being the most prominent example of international import, the current use of solid biomass today is considerably greater than the local resource.

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[3] According to Danish legislation the biogas plants can receive the subsidy as a feed in tariff or as a supplement to the current electricity market price. If biogas is co-fired with fossil fuels the subsidy will be given as a supplement.

[4] http://www.djursenergiland.dk/index.htm

[5] 'Climate Action 2030' can be found at, http://www.randers.dk/site.aspx?MenuID=3&Langref=1&Area=&topID=&ArticleID=19092&expandID=12&moduleID=

Fuel (TJ)	Potential Energy Resource	Current energy use in municipalities	Balance
Straw Today	3,441	1,200	2,241
Straw with 15% willow	2,771	1,200	1,571
15% willow on farmland	1,789	0	1,789
Forest Biomass	815	5,560	-4,745
Biogas from slurry	833	12	821
Total without willow crops	**5,089**	**6,772**	**-1,683**
Total with willow crops	**6,209**	**6,772**	**-563**

Table 5: Potential biomass resources, current utilisation, and potential biomass energy balance for the three municipalities. The biogas value is solely for biogas from animal slurry.

For straw and slurry based biogas the local use is significantly below the resource potential.

2.4 Economy of biomass for heat production

The main driver for local actors to increase their production or use of biomass for energy purposes is likely economy. The actors will chose those technologies and fuels that, within the existing framework, will supply heat and electricity in the most cost efficient way.

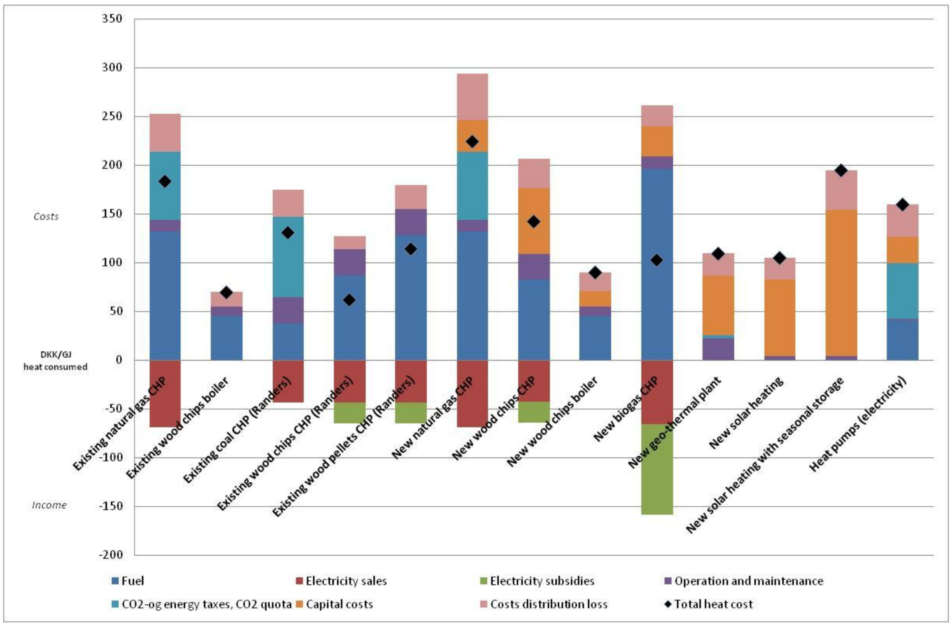

Figure 3: *Cost of heat production from different District Heating technologies. The figure shows heat production costs in DKK/GJ at the consumer inc. Taxes and other relevant incentives. The total heat production cost (sum of income and costs) is marked with a* ***black dot****. For comparison the cost for individual solutions is app. DKK 265/GJ for oil and natural gas and DKK 225/GJ for pellets and heat pumps.*

In Figure 3 the total cost of heat production from a range of generalised district heating technologies is shown. The figure shows that biomass CHP and biomass Heat Only Boilers (HOB) have rather low heat production costs compared to other technologies. The main reason for this is: a) the tax exemption on the heating side; b) the EU quota system which increases the costs of fossil fuels; and c) RE subsidies and feed-in-tariffs on the electricity side. Further-more, wood chips and straw are relatively cheap as a fuel compared to oil and natural gas. From the figure it can also be seen that small-scale biomass CHP fired via solid biomass have fairly high heat production costs because of the high investment and O&M costs. Other renewable energy technologies, biogas, geothermal and solar heating could also prove interesting from an economic point of view.

Comparing the costs of existing biomass fired plants of 60-70 DKK/GJ with the costs of individual technologies of 225-265 DKK/GJ and taking into account the assumed costs for connecting to district heating networks of 40 – 110 DKK/GJ there could certainly be an economic value of converting some individual customers to district heating. However, the costs for connecting to the grid can vary substantially and the potential should be evaluated on a case by case basis.

One important conclusion to be drawn from the figure is that with the assumptions taken, biogas can supply district heating at substantially lower prices than even existing natural gas CHP. It is also evident that the cost of biogas production only has to decrease marginally (or the price of solid biomass only has to increase marginally) before biogas CHP is compatible with even a wood-chip fired heat only boiler.

2.5 Development of the biomass markets

Market Trends

Looking at the trends in the national and international biomass markets there has been a substantial increase in biomass demand, particularly for wood pellets and wood chips for energy production.

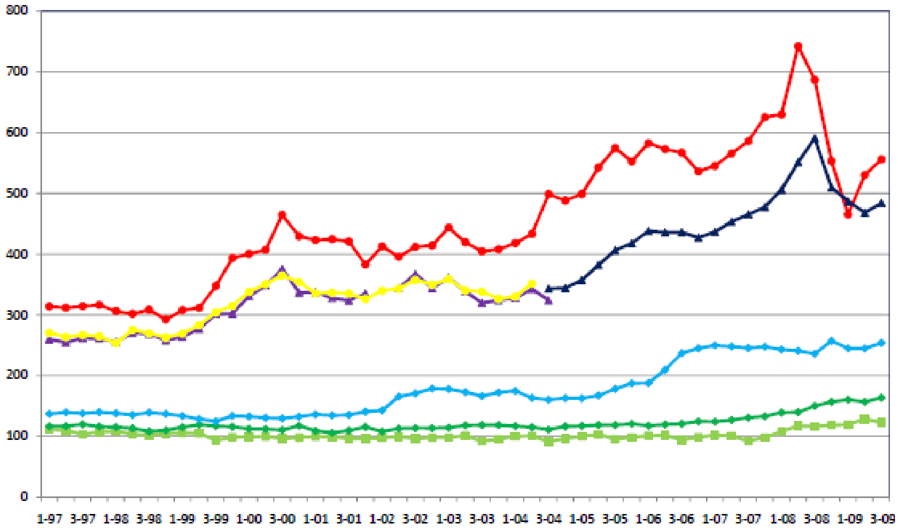

Figure 4: Nominal fuel costs in DKK/MWh at the plant gate, exclusive VAT, but including other taxes from January of 1997, till the 3rd quarter of 2009. The red line depicts oil, the yellow and dark blue natural gas, the light blue wood pellets, the dark green wood chips, and the light green straw.

Fossil based fuels incur a tax of roughly 200 DKK/ MWh, while biomass does not incur any taxes (Boldt, 2009).

Based on the market analyses of this study, the demand for biomass will increase dramatically in Europe, primarily as a result of political climate targets on national, EU and international levels, with the EU 2020 targets being a primary driver.

Figure 4 shows the development of fuel prices in the Danish market from 1997 to third quarter 2009, including energy and CO_2 taxes but excluding VAT. The figure shows very clearly that there is a substantial and until now growing economic incentive towards the use of biomass for heating purposes.

Resources and price

There is much discussion about the availability of national forest resources. The Danish forest and wood trading industry argue that there is a substantial unused potential for increased wood chip production from Danish forests. In addition, the growing of energy crops on farmland can increase the resource. However, in interviews with several buyers of wood chips, it was revealed that some are purchasing wood chips from ever increasing distances due to increasing local prices and/or shortages. In addition, large consumers located near harbours are currently importing wood chips from the Baltics to ensure security of supply and to keep their raw material costs down. As a result of the increasing demand, the prices for biomass (especially pellets) has increased over the past 3 – 9 years.

Straw

The growth in consumption of straw as a fuel in DH boilers for heat and CHP production seems to have halted and actually decreased in recent years at the national level. This is evident from the national energy statistics and it is also the impression from conversations with farmers and the agriculture association locally.

If this tendency continues it will force the deliverers of straw to rethink their production strategies. Alternatives for the agriculture sector might be to either replace some of their grain production with energy crops, or to aim at producing straw for other purposes, for example biofuels in the transport sector. However, it should be noted that at this time it is still questionable whether 1^{st} or 2^{nd} generation bio ethanol production is cost-effective.

2.6 Potentials for increased production and use of biomass in the three municipalities

Expanding demand for district heating

The structure of the heat demand is crucial for the possibilities of using more biomass for CHP production. In the process of estimating the potential for increased use of biomass, the so-called heat planning is an important tool for the municipalities. According to Danish legislation it is the role of the Municipalities to define the prioritised heat supply in different geographic areas based on Socio Economic calculations. The potential for expanding the district heating networks is not thoroughly evaluated in this report, but according to the aforementioned survey the potential might be limited.

Individual heat demand

The study is focused on biomass for CHP production. However, the use of oil for individual heating in the three municipalities leaves a rather large potential for replacement. With a large potential for wind power within the municipalities, heat pumps are a relevant option for displacement of individual oil boilers. Due to their ability to both generate heat (or cooling) based on renewable energy, and, to store electricity and hot water, heat pumps are often seen as one of the key technologies in the future energy system. A biomass option is local wood pellet stoves, however it is worth noting that these rely on imported biomass and are not necessarily the most efficient way to utilise biomass resources as the overall efficiencies are much lower than when utilised in large CHP facilities.

Export of biomass

It is not unusual that the areas with the highest production potential for biomass are not the largest district heating areas, as the main resource potential is in rural areas, while the district heating areas are more conducive to urban areas. The relatively small potential for increased biomass usage in the three municipalities still leaves a potential for increased production of biomass for export to other municipalities.

2.7 The SSCM analysis

An SSCM analysis was undertaken which focused on the possibility of increasing biogas production in the three municipalities, and utilising more local and imported solid biomass (straw, woody biomass, and energy crops). The main conclusions from this analysis are presented below.

Biogas

Feedstock

A possible enabler and economic benefit in the first part of the supply chain is optimisation of the slurry for biogas production, thereby increasing the gas yield in the biogas production per ton of slurry. This can in some cases be done in the day-to-day running of the farm by reducing water spillage. Locally it can be a barrier if livestock farms are too small or too scattered to be feasible to include in a co-operative biogas production system.

Energy crop production

In regard to the production of energy crops, including maize, in the second part of the supply chain, the main existing barrier is the production costs and competition with other land use. Furthermore, the experience with energy crops for biogas production is quite limited in Denmark. Possible enablers and economic benefits is that maize may be used by the farmers to diversify their business from only food and fodder towards energy with possibilities of long term price agreements or even common ownership.

Transport

In the third part of the supply chain, transportation of feedstock, the main exiting barrier is the fixed and variable costs of transport. Transportation has a substantial impact on the economy for the individual farmers as well as the total economy of the co-operative biogas plant. A possible enabler is reducing the transport distances travelled and the costs. Reducing the distance travelled can be done by careful geographic planning of the location of the biogas plant, or in some cases by decentralising the biogas production into several plants to be situated directly on the largest farms. In the second case the gas will probably have to be transported over a longer distance to the CHP plant instead of transporting the slurry to the biogas plant. Another enabler might be to separate the slurry and only transport the more solid part. However, the cost of separation might be higher than the saved cost of transport. Another incentive for separation is for the farmer to be able to increase their livestock production under current environmental legislation.

Production of biogas

With regard to the actual establishment of biogas plants, the main barriers consist of financing (access to venture capital), a lengthy authorisation process, the project economy, and access to a local heat market. Currently, it can be difficult to take out a loan from the banks due to the ongoing financial crisis, uncertainty in biogas projects and unsuccessful biogas projects in the past. A possible enabler could be loans guaranteed by the municipalities, perhaps with partial re-guarantees from the State.

For the time being, it is a complex and time-consuming process to get a construction permit for a biogas plant. Particularly the localisation of biogas plants can be a barrier due to local resistance. It is important that biogas plants can get constructions permits in a land-zone close to the slurry production and far from residential neighbours. A possible enabler regarding constructions permits could be a development of a more smooth planning process. In achieving local acceptance it is important to incorporate dialogue and participation. In addition, the establishment of Biogassekretariatet in February 2010 comprises an enabler regarding localisation and local acceptance.

The project economy comprises a main barrier due to high investment costs (service of debt) and operational-and transportation costs. A possible enabler could be further development towards lower investments and reduced transport costs.

Sale of biogas

Currently, lack of access to a local heat market with the possibility of long-term agreement for heat sale at reasonable prices can be a main barrier. A possible enabler could be more flexible biogas production according to the heat demand, as well as making it more attractive for the local heat plants to produce their heat via biogas. Stability in the incentive framework (taxes and subsidies) is important here. Another possibility is injection of biogas into the natural gas network either by upgrading the biogas (costly) or by redefining the gas specifications in local gas-networks to biogas quality. A preparation of a standard contract for disposal of heat produced on biogas should also be mentioned.

Straw

Supply side

There appears to be a large potential for increased collection of straw from the grain fields in all three municipalities.

Demand side

However, the greatest barrier towards increased utilisation of straw is the limited sales market within the municipalities and stagnation in the overall demand for straw in Denmark. Even at relatively low straw prices, for technical reasons (corrosion etc.) the large centralised power plants prefer to use substantial amounts of wood based pellets in their boilers.

More straw could be used in local DH plants and centralised CHP plants by replacing coal and woody biomass. Such replacements might benefit the overall local economy by increasing the resource base. However, it is a long term decision by the plant owners if they see a benefit to change from partly imported woody biomass to locally produced straw. Such changes should probably be based on long term contracts.

In the longer term the increased demand for biomass in the energy sector can be expected to affect the demand for straw as well. Straw can be used without major complications in centralised CHP plants if they are constructed with that purpose (lower steam temperature).

Energy Crops (Willow)

Demand side

The demand for especially woody biomass in the energy sector is expected to grow substantially in Denmark and in Europe. Prices for these types of biomass are therefore expected to increase over the coming 10 years. Market structures for such types of biomass are reasonably developed and must be expected to develop even further. This growing demand is the major enabler on the demand side.

Local discussions and co-operation about future prospects could lead to increased replacement of imported biomass with locally produced fuels.

Supply side economic aspects

The establishment of willow plantations is rather expensive due to the high investment costs related to planting and harvesting equipment. Investment subsidies are available, which leaves the harvesting machinery to be the highest risk for the farmers. These risks could be handled by entering into long – term contracts with wholesalers or directly with DH companies or larger power companies.

Supply side environment and social aspects

Some environmental and ethical issues remain to be solved. Locally and nationally, nature and biodiversity can be threatened if energy crops are planted on set-aside fields. If the energy crops replace fields that are used for food or fodder production today this will affect the global food resource, and can in turn increase the demand for using rainforest areas, etc. for agricultural purposes.

If willow trees are planted in marginal lands which are today used for grain production, the willow can have a positive effect on nitrogen leaching, mainly due to reduced demand for fertilizers.

As ashes from willow have relatively high concentrations of heavy metals, such crops could potentially serve as ‘sinks’ if separation technologies are developed. ‘Sinks’ in this respect refers to the fact that willow absorbs heavy metals from the soil, and thus they can be removed from the ground.

Forest wood chips

Demand side

As was mentioned previously, the demand for woody biomass in the energy sector is expected to grow substantially in Denmark and in Europe. This growing demand is the major enabler on the demand side.

Supply side

Most of the larger managed forests produce a certain amount of wood for energy purposes, which contributes to forest economy. The managers of these forests will have a good incentive to change their forest management strategy to increase the production of wood chips. There is some debate about the amount of sustainable resource that can be extracted from forestry. More research and documentation on how to increase yield in a sustainable manner is needed. A barrier for increased use of forest residues could be that Danish forest areas in general are relatively small and scattered compared to other countries that produce wood chips in large quantities. Enablers in this aspect could be more information about forest management with higher focus on optimising the energy resource.

2.8 SSCM Indicators and enablers

Main challenges

For straw the main challenge is on the demand side. For biogas there are substantial challenges on both the demand side and on the supply side. For energy crops and forest wood chips the demand is growing, and the main challenges are on the supply side.

In the table on the following page an overview of the main enablers and indicators for increasing production and utilisation of biomass is displayed. The main enablers are those actions thought to be of highest importance to increase the use of the relevant resource.

Target	Main enablers	Indicator	Level units
		BIOGAS	
Reduce cost of biogas production	Reduce capital costs and cost of slurry transport	Cost reduction compared to existing plants	€/M^3
Reasonable sales prices for biogas	Long term contract with DH companies	Sales price	€/M^3
Abatement of CO_2 by high efficiency	Efficient use of biogas for both electricity & heat	Energy efficiency	Energy input (biogas)/Energy output (Electricity & heat).
Actual slurry used for biogas production > 50%	Cost reduction, local planning, incentives	Share of slurry to biogas	%
		STRAW	
High GHG- effect by displacement of coal.	Increased use for CHP production – export to larger CHP plants	Amount of displaced GHGs	Kg CO_2 per tonne
Optimise storage and transport	Local co-operation	Storage capacity of straw in municipalities	Months capacity
Total utilisation of resource for energy purposes	High and stable demand (and prices) in energy sector	Total use of straw for energy in region	Tonnes of straw for energy in Western Denmark
		ENERGY CROPS (WILLOW)	
More than 10 years	Long term sales contracts	Duration of sales contracts	Years
Reduced nitrogen leaching	Focus on Nitrogen leaching	Reduced fertilizers on marginal lands	% reduced fertilizers
		FOREST WOOD CHIPS	
Increase yield from forests where it is sustainable	Good knowledge of sustainable production base	Sales to energy purposes	Tonnes per hectare
Increased awareness among forest owners	Information to forest owners about benefits of tree production for energy purposes	Survey among forest owners regarding their approach as energy producers	Survey results
More focus on energy supply	Stable and high sales prices	Good official statistics on prices and amounts	

Table 6: Main enablers and indicators for increasing production and utilisation of biomass

2.9 Recommendations

There are substantial unused resources in the municipalities, particularly biogas and straw. Options that should be considered in the ongoing planning process are:

- **Biogas:** To utilise biogas in the most cost-effective manner, it should be used in CHP production with its higher total efficiency so the heat is not wasted. In Randers there is natural gas that can be replaced with biogas, however, most of the heat markets in the municipalities are serviced by boilers using solid biomass that produce district heat without electricity. Over longer distances, biogas is more costly to transport than solid biomass. Replacing some of the woody biomass in existing district heating plants with biogas CHP may be the cost-efficient option for utilising both the biogas and solid biomass resources. This possibility should be included in the local evaluation and long-term energy planning process.

- **Straw:** There is a substantial amount of unused residues from agriculture in the form of straw. The greatest potential for use of straw in the energy sector is in the large centralised CHP plants. However, these CHP plants are operated at high steam temperatures, and therefore plant operators generally prefer woody biomass because of technical issues related to straw (corrosion, ash, etc). It is therefore difficult to sell larger quantities of straw to existing power plants. CHP plants that are initially designed to use the straw do not have these problems. Municipalities could therefore enter into regional and national dialogue regarding the prospects and timing for the next generation of centralised CHP plants that utilise straw as fuel.

In more concrete terms, there exists potential for increasing the usage of biomass in district heating. The main recommendations in this regard are:

- The district heating companies could cooperate on a comprehensive assessment of the feasibility of expanding the district heating grid in the three municipalities; as such an expansion could lead to greater biomass usage. An interview based survey of representatives from nearly 30 different district heating plants has not revealed large unexploited possibilities for this. However, by cooperating on a joint project, opportunities could be assessed more systematically and at reasonable costs.
- According to Dong's website, the Grena Kraftvarmeværk can utilise up to 60% straw in its fuel mix. As such there could be a potential for an increased use of straw to displace some coal. It is therefore recommended to investigate options for greater biomass utilisation at Grena.
- Randersværket currently uses roughly 80% biomass and 20% coal. Within the near future it will be technically possible to utilise 100% coal, however storage capacity for wood chips has been mentioned as a potential barrier to fulltime100% biomass utilisation.

To ensure a coordinated use of local resources in the energy system and assess it in relation to energy conservation, CO_2 reductions, etc. it is proposed that:

- The municipalities should carry out a strategic energy planning process in line with the recommendations of KL and the Danish Energy Agency (from ”Oplæg om strategisk energiplanlægning,” 2010). Planning should include consideration of the correlation between energy and climate targets, plans for energy savings, future structure and development of heat demand, environmental goals, and resource availability. Specifically, the prospects and cost efficiency of expanding the district heating grids should be evaluated.

- The planning process takes place in cooperation between municipalities and in dialog with relevant stakeholders from the agriculture, heating and electricity, and industrial sectors.

- The municipalities establish a formal platform for collaboration with local farming associations (landboforeninger), and local forestry and energy producers to identify the necessary concrete projects needed to achieve the energy and climate targets.

- The municipalities initiate a demonstration project involving a willow plantation in cooperation with local farmers and an energy producer such as the energy producer and farmers split the investment costs and risks. The Assens project could serve as inspiration for such a project.

3 Introduction/background

In cooperation with the three municipalities of Randers, Norddjurs and Syddjurs CBMI has asked Ea Energy Analyses to carry out Sustainable Supply Chain Management analyses (SSCM) of the utilisation of biomass resources for local energy production.

This project has been commissioned by ENERCOAST whose overall aim is to create a market for bio energy in the North Sea area. The Enercoast project has been financed by the EU Interreg IVB with partners from Denmark, Germany, United Kingdom, Sweden and Norway. The Danish project leader is AgroBusiness Park/ CBMI /Innovation Centre for Bioenergy and Environmental Technology. Central Region Denmark is co-financing 34% of the Danish portion of the project, while the municipalities of Norddjurs, Syddjurs and Randers are contributing to the project with their working hours.

The Danish portion of this project focuses on three Danish municipalities, Randers, Norddjurs, and Syddjurs, and the possibilities to reach local energy and climate targets by increasing the use and production of biomass. The project is divided into 6 phases of which this report is part of the second and third phases which focus on analyses of various biomass resources on a local level including carrying out SSCM analyses of these resources.

The aim of the project is to assess the sustainability of relevant bio energy supply chains related to the resource accessibility in the three municipalities. Two main areas will be in focus in the analyses:

- Bio energy for biogas plants (slurry and energy crops)
- Bio energy for combined heat and power generation (straw, wood, energy crops)

The main environmental, social and economic aspects of sustainability will be addressed for a number of resource cases under these two areas.

The analyses are used for a discussion of the potential for increased use and production of biomass within the municipalities and the report leads to recommendations for the further decision making.

4 Randers, Norddjurs and Syddjurs municipalities

4.1 Introduction

The municipalities of Norddjurs, Syddjurs and Randers are located in the north-eastern part of Central Denmark Region. In the figure below, the 19 municipalities in the region are highlighted in white.

Figure 5: Municipalities in Central Denmark Region (Central Denmark Region, 2010).

The population of the Central Denmark Region is 1.25 million and its total area is 13,124 km^2, corresponding respectively to 23% of the total Danish population, and around 30% of the total area of Denmark.

4.2 Current energy use and production units

The following section will briefly introduce the energy consumption profiles in the municipalities of Randers, Norddjurs and Syddjurs.

Data

The data is primarily based on analysis done for Central Denmark Region in a regional development project. The analysis of data in the regional development project was done with a focus on the municipalities. An energy balance was made for the region, and for 13 of its 19 municipalities, among these were the municipalities of Randers, Norddjurs and Syddjurs.

Energy producers in Denmark 2007

The primary source of data for the collective heat supply and electricity production in the energy balances is the Danish Energy Agency's data on energy producers in Denmark from 2007, which was divided into electricity, heat, type of fuel and plant, etc. Final energy consumption is then calculated by deducting the estimated plant efficiency and distribution losses.

Individual heating

In addition, fuels for individual heating purposes are calculated based on the amount of small local boilers from chimney sweepers and general estimates of their fuel consumption e.g. straw, firewood, wood chips, etc. The consumption of diesel and petrol is calculated on the basis of the amount of motorised vehicles, while fuel consumption for trains, ships and planes is allocated according to the number of inhabitants in proportion to the total Danish consumption.

Energy consumption in Norddjurs

In 2007, the gross energy consumption and the final energy consumption in the Municipality of Norddjurs was 5,379 and 4,599 TJ respectively.

Gross energy consumption

The figure below displays the gross energy consumption (fuel consumption and other types of energy, for example wind power) in the Municipality of Norddjurs for 2007.

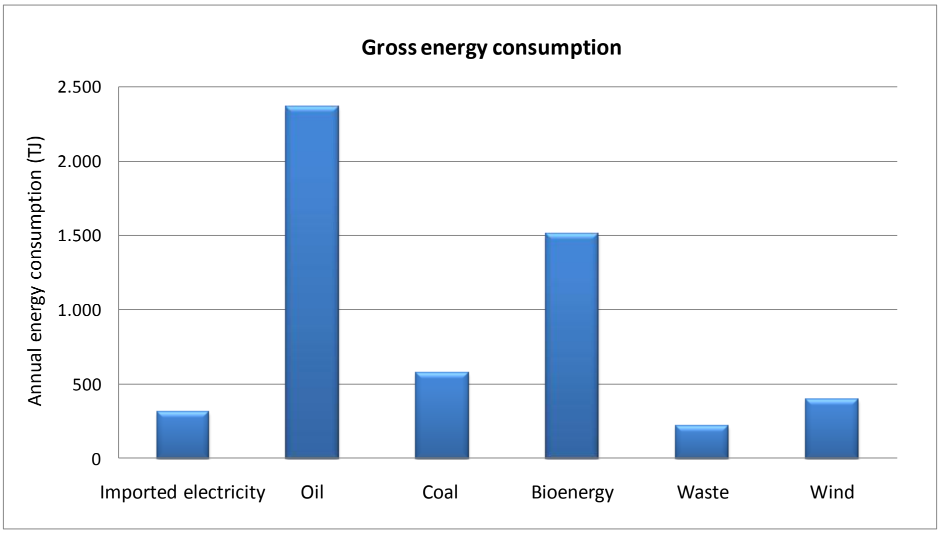

Figure 6: Gross energy consumption, Municipality of Norddjurs 2007.

The consumed bioenergy resources consist of straw, firewood, wood chips, wood pellets and waste wood. The share of bioenergy is significant (nearly 28%) with 1,500 TJ out of 5,379 TJ in the total gross energy consumption, thus helping to contribute to an overall high share of renewable energy in the municipality. The amount of renewable energy in the gross energy consumption is about 2,000 TJ, which depending on the amount of non-biodegradable material in the waste, corresponds to a share of renewable energy of ca. 40%. Most notable is the high consumption of oil, roughly 2,300 TJ. It should also be noted that there is no consumption of natural gas in the municipality, because there is no natural gas grid in Djursland.

Final energy consumption

The final energy consumption (end-use) allocated according to sector and energy products in the municipality of Norddjurs, is shown in the figure below. The final energy consumption covers energy supplied to the final consumer for all energy uses.

The figure reveals that the transport and household sectors are the sectors with the largest consumption, representing ca. 1,600 and 1,400 TJ respectively in 2007. Furthermore, it is worth noting that there is a relatively high share of renewable energy and oil used in the household sector, which is most likely primarily used for individual heating.

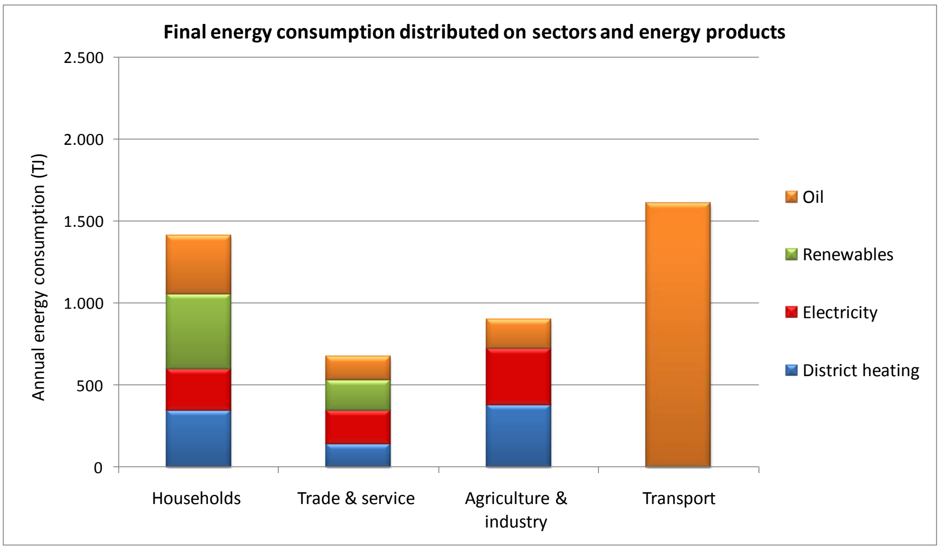

Figure 7: Final energy consumption distributed on sectors and energy products, Municipality of Norddjurs 2007.

The total fuel consumption for heating purposes is shown in the figure below. Over 2/5 of the heat is supplied from district heating, roughly 1/4 by oil, and slightly less than 1/3 from bio energy in form of individual heating (primarily firewood and wood chips). The consumption of electricity, solar power and heat sources for heat pumps (air or ground heat) is marginal. The bioenergy used for individual heating is primarily local firewood, wood pellets and straw.

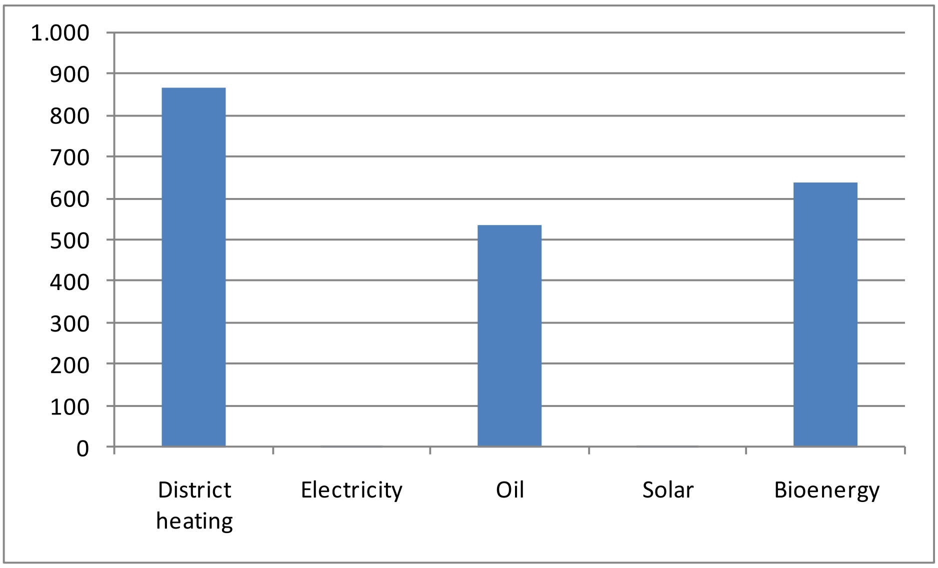

Figure 8: Heat consumption by energy source (TJ final energy), Municipality of Norddjurs 2007. Heat consumed in industries is not included.

A high share of both bioenergy and oil is used for individual heating purposes. With respect to the district heating production, well over half comes from bioenergy, with the majority of this consisting of straw. As such bioenergy covers over half of the total heat production (individual and collective) in Norddjurs.

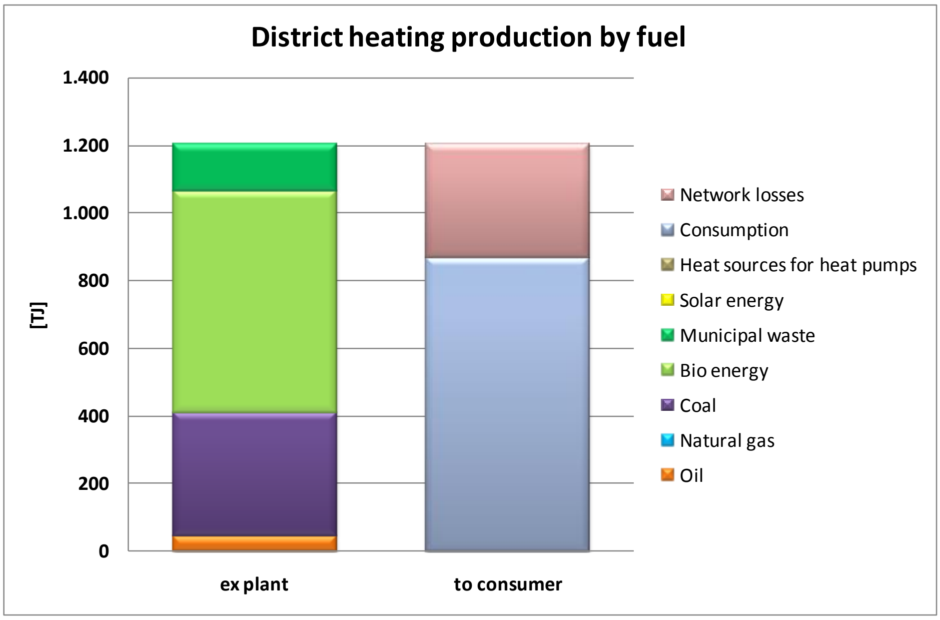

Figure 9: Total district heat production by fuels, Municipality of Norddjurs 2007. Of the district heating figure, well over half is produced via biomass. As such, over 50% of the total heat consumption (individual and collective) is derived from bioenergy

District heating plants in Norddjurs

The largest district heating plant is Grenå Kraftvarmeværk, which uses straw and coal. The other district heating plants in Norddjurs are mainly smaller district heating boilers using wood chips. The district heating plants include:

	Coal (TJ)	Fuel oil (TJ)	Gas oil (TJ)	Straw (TJ)	Wood Chips (TJ)	Wood and biomass waste (TJ)	Waste (TJ)	Gross Fuel (TJ)
Allingåbro Varmeværk			0.7		54.6			55.3
Anholt Elværk			16.9					16.9
Auning Varmeværk				116.0				116.0
Gjerrild					20.7			20.7
Glesborg Fjernvarmeværk					21.5			21.5
Grenå Forbrændingsanlæg							231.0	231.0
Grenå Kraftvarmeværk	526.9	17.7	5.1	563.4		9		1,122.1
Ørsted Fjernvarmeværk				55.5				55.5
Ørum Varmeværk			0.8		23.8			24.6
Stenvad varmeværk			0.4		9.5			9.9
Trustrup-Lyngby Varmeværk					40.3			40.3
Vivild Varmeværk			2.3		47.3			49.5
Voldby Varmeværk					11.3			11.3
Total	**526.9**	**17.7**	**26.2**	**734.9**	**229**	**9**	**84.2**	**1774.6**

Table 7: Fuels used in district heating plants in Norddjurs in 2007

Energy consumption in Syddjurs Municipality

Gross energy consumption

The figure below displays the gross energy consumption (fuel consumption and other types of energy for example wind power) in the Municipality of Syddjurs for 2007.

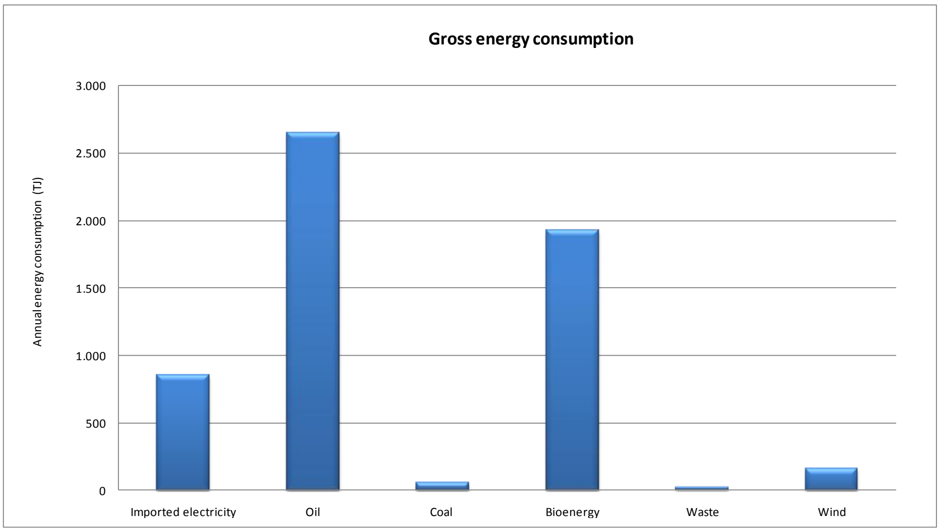

Figure 10: Gross energy consumption, Municipality of Syddjurs 2007.

The share of bioenergy is significant with 1,931 TJ out of 5,676 TJ in the total gross energy consumption, thus contributing to a high share of renewable energy in the municipality overall. The consumed bioenergy resources consist of straw, firewood, wood chips, wood pellets and waste wood.

Final energy consumption

The final energy consumption (end-use) distributed on sectors and energy products in The Municipality of Syddjurs, is shown in the figure below. The final energy consumption covers energy supplied to the final consumer for all energy uses.

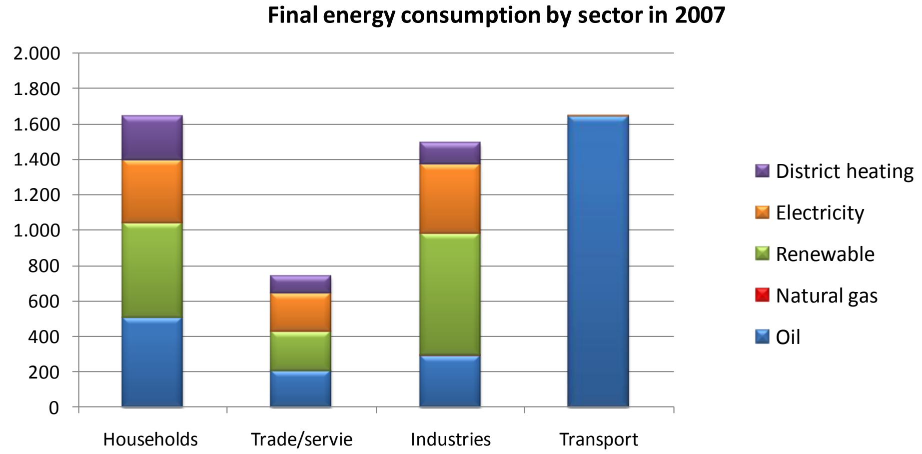

Figure 11: Final energy consumption distributed via sectors and energy products, Municipality of Syddjurs 2007.

The figure reveals that the transport and household sectors are those areas with the largest consumption, with approx. 1,600 TJ each in 2007. Furthermore, it appears that there is a relatively high share of both renewable energy and oil used in the household sector, a great deal of which is likely from individual heating.

The total heat consumption divided on energy sources is shown in the figure below. Roughly 1/4 of the heat is supplied from district heating and 37-38% each by oil and bio energy in form of individual heating. The consumption of electricity, solar power and heat sources for heat pumps (air or ground heat) is marginal. The bioenergy used for individual heating is primarily local firewood, wood pellets and straw.

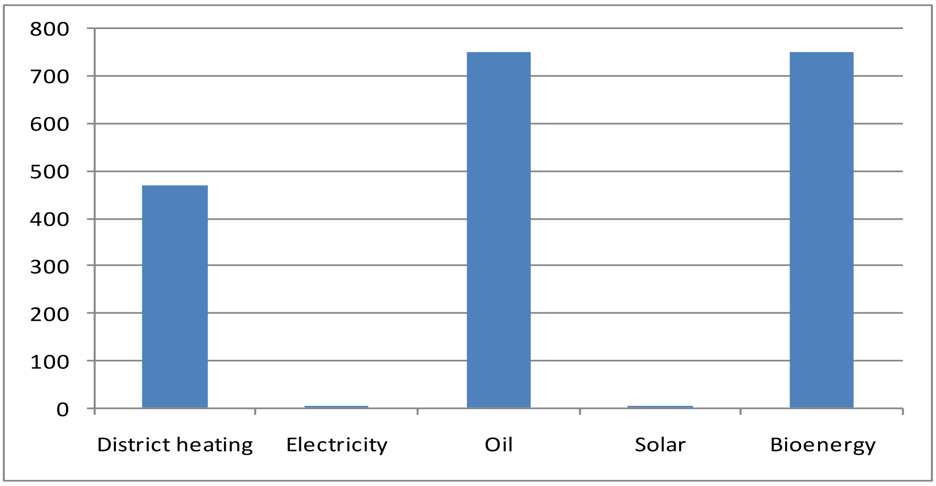

Figure 12: Heat consumption by energy source (TJ final energy), Municipality of Syddjurs 2007. Heat consumed in industries is not included.

The district heating production by fuels is shown in the figure below. In addition to the individual heating, of the district heating portion, roughly 75% comes from biomass. Therefore the total heating (individual and district) in Syddjurs is nearly 60% derived from bioenergy.

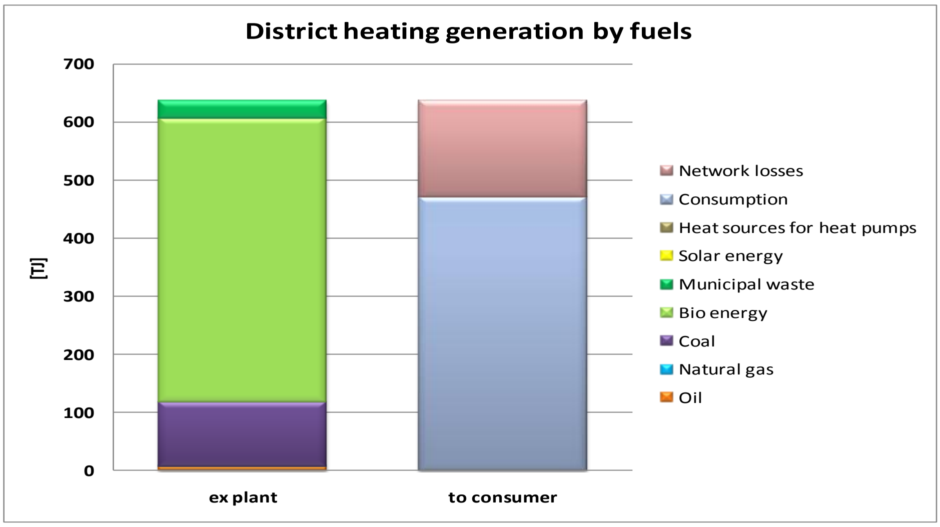

Figure 13: Total district heat production by fuels, Municipality of Syddjurs 2007. Of the district heating, over 75% is from bioenergy. As a result, nearly 60% of the total heat demand (individual and district) is met via bioenergy in Syddjurs. The coal fired district heating is heat imported from Århus (Studstrupværket to Hornslet).

A more comprehensive breakdown of the district heating plants in Syddjurs is provided below. They consist of one large industrial provider, and a number of smaller district heating boilers using wood chips or straw. The district heating plants include:

	Coal (TJ)	Fuel oil (TJ)	Gas oil (TJ)	Straw (TJ)	Wood Chips (TJ)	Wood and biomass waste (TJ)	Wood Pellets (TJ)	Gross Fuel (TJ)
Balle Varmeværk (Glatved Losseplads)		0.3	10.4		8.4		5.0	24.1
Ebeltoft Fjernvarmeværk					190.0			190.0
Kolind Halmvarmeværk				41.2				41.2
Mesballe							5.2	5.2
Mørke Fjernvarmeværk					12.0			
Nimtofte Fjernvarmeværk				50.8				50.8
Novopan Træindustri A/S	120.2	1.1				710.9		832.2
Rosmus Varmeværk		0.2					5.3	5.5
Ryomgaard Fjernvarmeværk				61.6				61.6
Rønde By's Fjernvarmeværk				94.2				94.2
Thorsager Fjernvarmeværk				24.9				24.9
Tirstrup Varmeværk					17.6			17.6
Total	**120.2**	**1.6**	**10.4**	**272.7**	**228.0**	**710.9**	**15.5**	**1359.3**

Table 8: Fuels used in district heating plants in Syddjurs in 2007. Wood and biomass waste for Novopan also includes a significant amount of wood chips. Novopan produces heat for industrial processes as well as some surplus heat (~ 30 TJ) for Pindstrup Varmeværk. Pindstrup Varmeværk

is not mentioned in the table as it uses very little fuel but receives surplus heat from Novopan. Hornslet Fjernvarme imports heat from Århus but has no own production and is therefore not included.

It is worth noting that the largest heat supplier in Syddjurs is Novopan, a particle board manufacturer, thus the heat generated here is process heat, not heat primarily generated for household heating purposes.

Energy consumption in Randers Municipality

For Randers municipality as a whole, data for 2007 has been utilised. However, in recent years, Energi Randers (now Verdo), the main energy producer in Randers, has made a conversion from coal to biomass at the Randers CHP. Therefore, fuel use and production for Energi Randers is based on data for 2009. Due to the fact that the majority of other data has not changed drastically, all other data is from 2007. The decision to integrate more recent data for Randers CHP is based on the desire to present an accurate picture of the current energy usage situation.

Gross energy consumption

The figure below displays the gross energy consumption (fuel consumption and other types of energy for example wind power) in the Municipality of Randers for 2007.

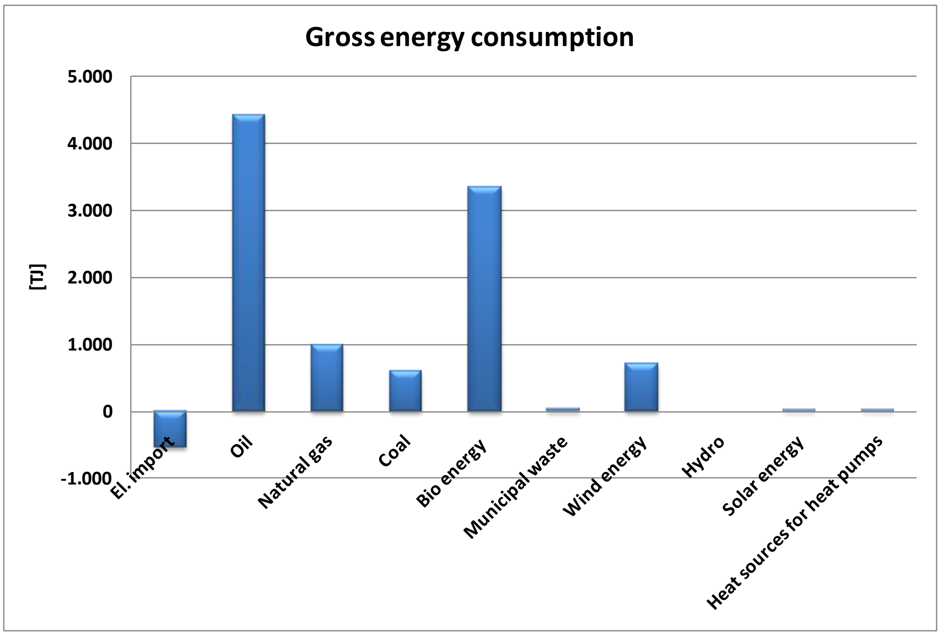

Figure 14: Gross energy consumption, Municipality of Randers 2007 (Energi Randers 2009 data).

The share of bioenergy is around 3,400 TJ out of approx. 9,700 TJ in the total gross energy consumption, corresponding to a 35% share. The consumed bioenergy resources consist of straw, firewood, wood chips, wood pellets and waste wood. Most of the biomass is used at the Energi Randers CHP plant.

The municipality of Randers was a net exporter of electricity in 2007, which explains the negative figure for electricity import.

Final energy consumption

The final energy consumption (end-use) distributed via sectors and energy products in the municipality of Randers, is shown in the figure below. The final energy consumption covers energy supplied to the final consumer for all energy uses. The total final energy consumption in Randers was 8,345 TJ.

The figure reveals that the transport and household sectors are the sectors with the largest consumption, with approx. 3,600 and 2,500 TJ respectively in 2007. Furthermore, there is a relatively high share of renewable energy used for heating in the household sector.

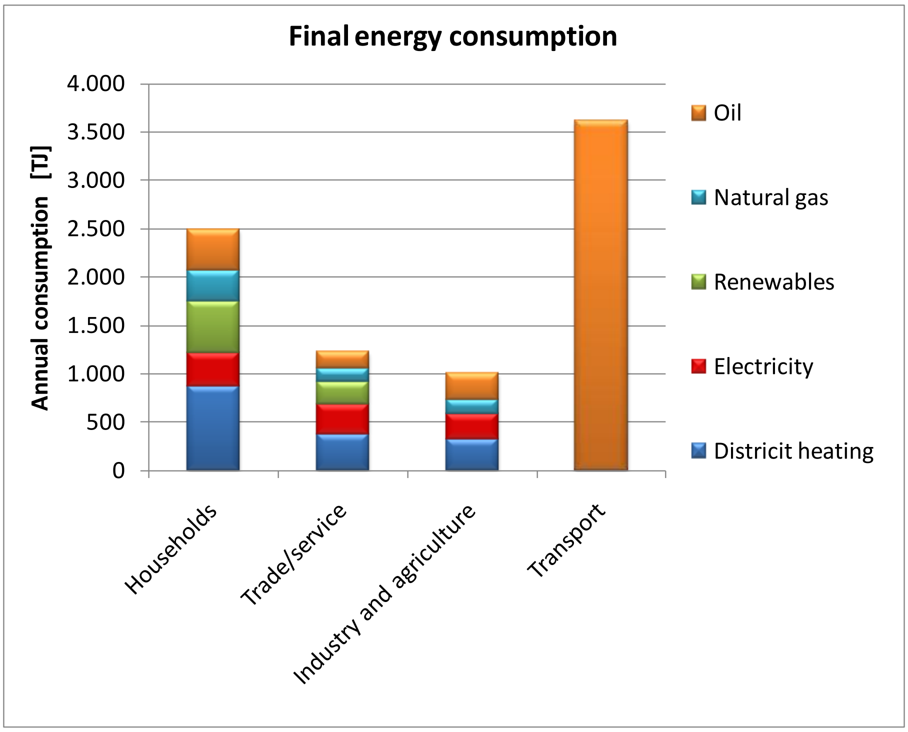

Figure 15: Final energy consumption distributed on sectors and energy products, Municipality of Randers, 2007.

The heat consumption by energy source is shown in the figure below. Roughly 45% of the heat is supplied from district heating and 17% each by oil and natural gas, and 20% from bio energy in form of individual heating (primarily firewood and wood chips).

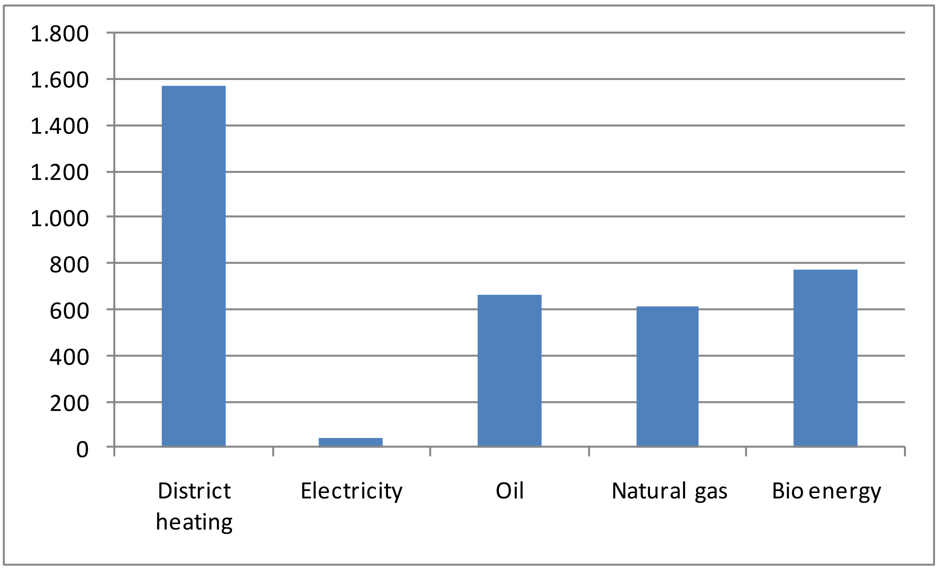

Figure 16: Heat consumption by energy source (TJ final energy), Municipality of Randers 2007 (Energi Randers 2009 data). Heat consumed in industries is not included.

Most of the district heat is generated at the combined heat and power plant Randersværket, which uses a combination of coal and various forms of biomass. It is worth noting that since 2007 the fuel use has shifted to considerably more biomass and less coal. This is reflected in the figure below as data for 2009 are used for Energi Randers. In addition to the individual heating, of the district heating portion, over 70% now comes from biomass. Therefore the total heating (individual and district) in Randers is nearly 55% derived from bio-energy.

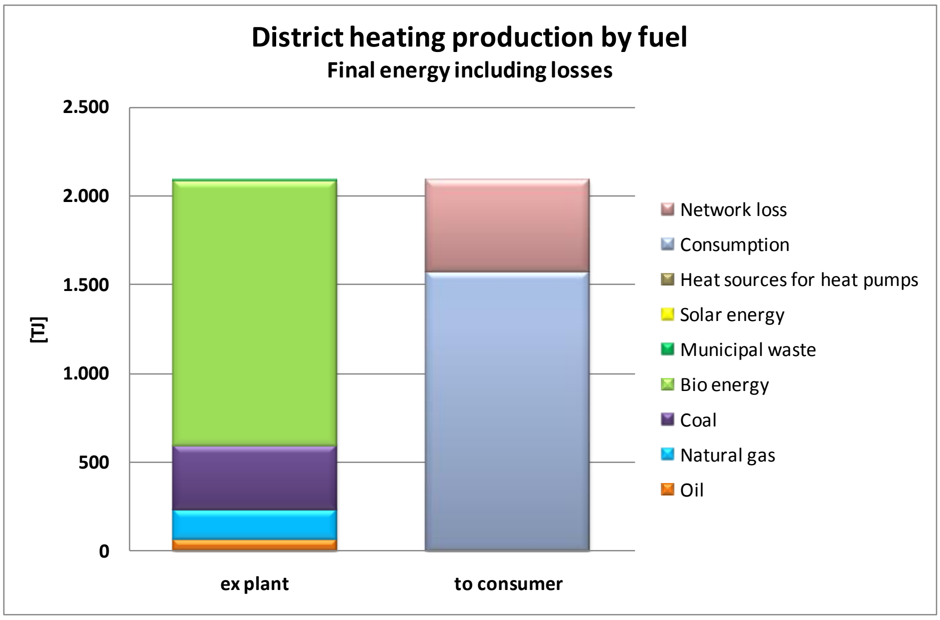

Figure 17: District heating generation and consumption by energy source, Municipality of Randers 2007 (Energi Randers 2009 data). Consumption includes heat used as process energy in industries.

District heating plants in Randers

The remaining district heating plants in Randers are mainly smaller natural gas fired CHP plants. The district heating plants in Randers include:

	Coal (TJ)	Gas oil (TJ)	Natural Gas (TJ)	Biogas (TJ)	Straw (TJ)	Wood Chips (TJ)	Wood and biomass waste (TJ)	Gross Fuel (TJ)
Energi Randers Produktion A/S* (2009)	597						2450	3047
Gassum-Hvidsten Kraftvarmeværk			47.3					47.3
Gjerlev Varmeværk		1.1			23.1			24.2
Havndal Fjernvarme A.m.b.a.		0.7			32.3			33.0
Langå Varmeværk			148.1					148.1
Mejlby Fjernvarmecentral			21.8					21.8
Mellerup Kraftvarme			44.9					44.9
Overgaard Biogasanlæg				43.8				43.8
Randers Central Renseanlæg			42.6	26.1				68.7
Uggelhuse-Langkastrup			32.2					32.2
Værum-Ørum Kraftvarmeværk			39.6					39.6
Total	**597**	**1.8**	**376.5**	**69.9**	**55.4**	**0**	**2450**	**3550.5**

Table 9: Fuels used in district heating plants in Randers in 2007. * For Energi Randers the fuel use is for 2009. It is worth mentioning that the largest supplier, Randers Produktion, has increasingly switched over to greater biomass usage, and less coal. This trend is anticipated to continue throughout the next few years as the plant aims to utilise 100% biomass. It is also worth noting that a significant portion of the 'wood and biomass waste' for Randers is in fact wood chips and to a lesser extent wood pellets. Overgaard biogasanlæg and Randers Renseanlæg have biogas facilities and produce power but no heat according to the available data.

4.3 Summary

The table on the following page summarises the energy situation in the 3 municipalities and compares them with the energy situation in Denmark. Use of municipal waste is not included in the table.

The total gross energy use in the 3 municipalities is 2.4% of the Danish total gross energy consumption. The 3 municipalities have a much higher share of bioenergy use (28-35%) than that of the national average for Denmark (9.5%). The main reason is that there is a very high share of biomass use in both individual and district heating systems. Furthermore, Syddjurs has the large industrial manufacturer Novopan, which uses biomass for the production of process heat and power.

Indicator	Norddjurs	Syddjurs	Randers	Three municipalities	Denmark	Municipalities share
Gross energy (PJ)	5.4	5.7	9.7	20.8	863.5	2.4 %
Final energy (PJ)	4.6	5.5	8.3	18.4	685.2	2.7 %
Total biomass (PJ)	1.5	1.9	3.4	6.8	82.2	8.3 %
Total biomass (% of gross energy)	28	33	35	-	9.5	-
Straw (PJ)	0.74	0.31	0.15	1.2	18.3	6.6 %
Wood (PJ)	0.77	1.62	3.17	5.6	60.0	9.3 %
Biogas (PJ)	0	0.005	0.07	0.075	3.9	1.9 %
District heating production (PJ)	1.21	0.64	2.09	3.9	121.5	3.2 %
District heating production from biomass (PJ)	0.66	0.49	1.49	2.6	19.7	13.4 %
Individual heating (PJ)	1.17	1.50	2.05	4.7	115	4.1 %
Individual heating from bio-mass (PJ)	0.64	0.75	0.77	2.2	N/A	-
Other biomass (PJ)	0	0.71	0	0.7	N/A	-

Table 10: Summary of energy use in the 3 municipalities compared with the Danish consumption in 2007 (*data for Energi Randers from 2009). Biomass does not include municipal waste.

5 Political and Economic framework conditions for biomass usage

5.1 EU goals and biomass usage

EU Goals

The primary driver for renewable energy use within the EU is the renewable energy directive, which establishes the mandatory target of at least a 20% share of energy from renewable sources in overall Community energy consumption by 2020, and that by 2020 at least 10% of transport fuel in each member state must be from renewable sources (green electricity, hydrogen, and biofuels all qualify, with second generation biofuels counting double) (EU, 2009).

In addition, the EU has also announced that it is willing to achieve even more ambitious targets, as prior to the COP 15, in Copenhagen in December of 2009, the EU put forward an offer to reduce greenhouse gas emissions by 30% in 2020 and up to 95% in 2050, provided an international agreement could be reached at the conference. While this did not come to fruition, it does indicate the political will within the EU to further reduce GHG emissions.

EU biomass usage

Use of biomass for energy in Europe

On a whole the EU as of 2007 was at 7.8% renewables, with nearly 70% coming from biomass and waste, representing over 4.000 PJ. Given increases in overall energy demand resulting in a 2020 EU gross inland consumption of 82,400 PJ, to reach the 20% target the EU therefore requires an additional 10,600 PJ of renewable energy by 2020 (in gross consumption terms).[6]

Since the EU directive focuses on final consumption according to a particular calculation, it is difficult to accurately predict how much biomass is required to achieve this objective. It depends to a large extent on how the biomass is utilised. For example, biomass used for cogeneration counts roughly twice as much as biomass for electricity generation in condensing plants. It is therefore likely that the majority of biomass will be used to produce either heat and power, or pure heat.

However, given that over the next 10 years there will be used approx. 10,600 PJ more renewable energy, and within this timeframe the most feasible options for large-scale renewable energy production are biomass and wind, it is possible to develop potential scenarios for future EU biomass usage. A realistic scenario for achieving the EU renewable target could be:

- Renewables such as hydro, solar, wave, and geothermal constitute 20% of this required renewable energy

[6] 2020 EU gross inland consumption of 82.400 PJ is based on DG Tren's 2008 figures (DG Tren, 2008).

- 20% comes from wind, (this corresponds to approximately 196 GW of new capacity, and is approx. 15 to 20 GW more than the European Wind Energy Association (EWEA) forecasts).[7]
- Biomass and waste cover the rest, equivalent to 6,300 PJ, or roughly 420 million tonnes of additional biomass.

Combined with the aforementioned 2007 EU consumption of biomass and waste of 4,000 PJ, an estimate for the annual gross energy from biomass and waste in 2020 is 10,300 PJ, roughly 690 million tonnes of biomass.

In comparison, coal consumption in the EU27 in 2005 was 13,400 PJ, equivalent to around 890 million tonnes of biomass. This indicates that if the objective is to be achieved, over the next 10 years there would need to be a very significant substitution of coal with biomass in large power plants.

The Renewables Directive requires all EU countries to submit national action plans for RE by June 30th, 2010. These plans will shed further light on how each country plans to reach their individual goals for RE, and thereby will provide a clearer picture of whether the above assumptions are reasonable.

In any event, there is no doubt that if the EU is to meet its target of 20% RE in 2020, the use of biomass will increase significantly over the next 10 years.

5.2 Danish goals and biomass usage

Danish Goals

Integration of more renewable energy in the years ahead is a political priority, and Denmark as well as the EU has adopted targets for the share of renewable energy in 2012 and 2020. In 2020, 30% of Danish energy supply is to be renewable energy - a substantial share of total energy production. This challenge will be even greater in the long term, when fossil fuels are to be phased out entirely of Danish energy production. The Danish government has committed to setting/suggesting a timeframe for when Denmark can become independent of fossil fuels, as well as a strategy for how this aim can be achieved.

Danish Biomass Usage

Use of biomass in Denmark

The Danish use of biomass for energy is shown in the table on the following page (from “Energistatistik 2008”). The use of solid biomass was 79 PJ. Furthermore, waste (30 PJ) and biogas (4 PJ) was used.

It is worth noting that wood waste has its own category, whereas some other sources include a large majority of this as wood chips, and thus have total wood chip utilisation of roughly 14 PJ (HedeDanmark, 2009).

[7] EWEA forecasts total installed capacity of 230 GW by 2020 (EWEA, 2010).

TJ	Straw	Wood chips	Wood pellets	Fire-wood	Wood waste	Total
Central el and heat prod.	4,002	3,040	6,215	0	1,093	14,350
Decentralised CHP	3,103	1,905	0	0	470	5,478
District heating plants	3,417	4,407	1,985	0	457	10,266
CHP from Industrial Process	0	549	0	0	135	684
Heat from Industrial Process	0	0	0	0	454	454
Agriculture and Forestry	1,937	27	0	0	0	1,964
Industrial Processes	0	1,081	945	0	3,319	5,345
Private and Public Service	0	148	919	0	0	1,067
One family houses	2,905	81	8,245	27,198	0	38,429
Total	**15,364**	**11,238**	**18,309**	**27,198**	**5,928**	**78,037**
(Of which is import)	0	3,371	15,928	2,176	0	21,475

Table 11: Biomass use in Denmark 2008 (Energistatistik 2008)

The table reveals that in 2008, 18 PJ (roughly 1 mil. tonnes) of wood pellets were used in Denmark. Of this about half was used for heating in households and about half was used for power and district heating production. The Avedøre Power Plant alone used 5.95 PJ of wood pellets (Grønt regnskab 2008) or about one third of the Danish consumption of wood pellets.

The use of biomass and especially of wood pellets is expected to increase over the coming years in Denmark. In its yearly report on Danish energy trends from 2009 (basisfremskrivningen), The Danish Energy Agency expects renewable energy to grow over the coming years. The use of solid biomass will increase to about 165 PJ in 2025. A large part of this increase is due to an increase in the use of wood pellets.

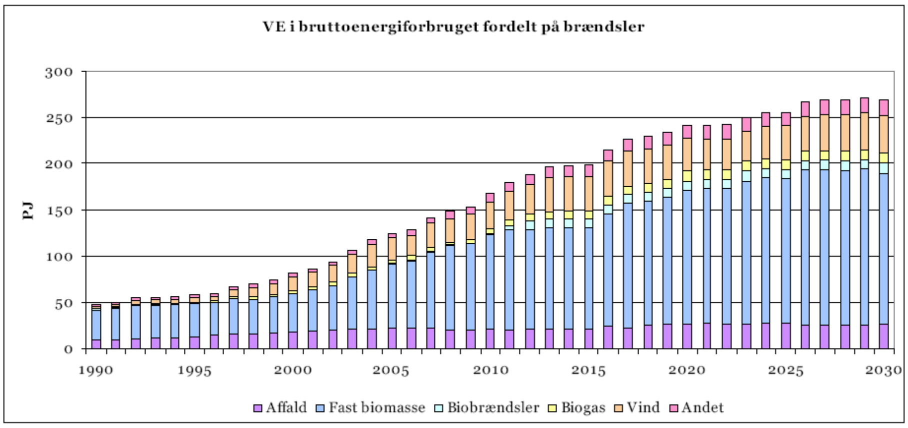

Figure 18: Renewable energy in the yearly report on Danish energy trends from 2009 from the Danish Energy Agency (basisfremskrivningen).

The figure below on the following page shows the expected increase in the use of renewable energy from 2009 to 2020 in the yearly report on Danish energy trends from 2009 from the Danish Energy Agency.

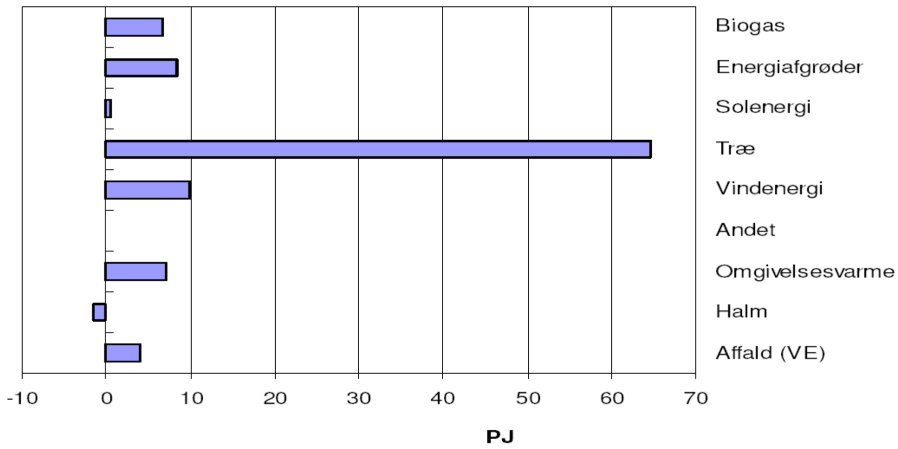

Figure 19: Danish increase of the use of renewable energy from 2009 to 2020 in the yearly report on Danish energy trends from 2009 from the Danish Energy Agency. Biogas, energy crops (energiafgrøder), solar (solenergi), wood (træ), wind (vindenergi), other (andet), heat load for heat pumps (omgivelsesvarme) , straw (halm), and garbage (affald).(DEA, 2009b).

The reason that the use of wood is expected to increase dramatically compared with the other resources is that several of the central power plants are expected to shift from coal to wood pellets within the period. A possible explanation for an expected decrease in straw use could be due to the fact that at least one of the central power plants is expected to replace their straw usage with wood chips or wood pellets

5.3 Climate and Energy Plans for the 3 municipalities

The 3 municipalities are also all working to reduce greenhouse gas emissions and increase the use of renewable energy.

Municipality of Syddjurs and Norddjurs

The municipalities of Norddjurs and Syddjurs have been co-operating in the field of climate energy and in the initiative called Djurs Energiland.[8] The collaboration started in 2007, and in 2008 a think-tank for ideas and initiatives dubbed Energirådet was created. In 2009, an energy and climate action plan was drawn up.

On the basis of statistics from 2007, the action plan presents a vision for a possible energy future with radically lower emissions of CO_2. The action plan encompasses 9 concrete initiatives with focus on energy savings, increased use of renewable energy and restructuring of the transport sector.

The action plan among other things includes the following collaborative visions (Norddjurs og Syddjurs Kommnuer, 2009):

[8] http://www.djursenergiland.dk/index.htm

- 20% reduction in heat consumption
- 75% reduction in oil consumption for heating
- Establishment of 2 new biogas plants
- 40 MW sea wind turbines

In terms of CO_2 emissions, the plan estimates a reduction in Norddjurs from a 2007 value of 270,000 tonnes (7.0 tonnes per person) to 150,000 tonnes by 2025. If displaced CO_2 from electricity exports is subtracted, this will result in 2025 emissions of roughly 90,000 tonnes (approx. 2.3 tonnes per person).

Meanwhile, in Syddjurs, 2007 CO_2 emissions were just under 310,000 tonnes (7.5 tonnes per person), and are estimated to be 180,000 tonnes in 2025, equal to 4.5 tonnes per person and a reduction of roughly 40%.

Municipality of Randers

In 2009, the Municipality of Randers published a plan describing its measures for mitigating climate change in 'Climate Action Plan 2030'.[9] The plan consists of both short term (2010), and long term targets (2030), for reducing the greenhouse gas emissions in the municipality as a geographical area.

The major long term targets of the municipality are:

- 75% reduction of CO_2 emissions relative to the 1990 level by 2030
- 75% renewable energy in the energy supply by 2030

The plan consists of 54 specific initiatives which are to be launched in the next 5 years. The targets and initiatives in the plan are mainly focused on the following three areas:

- Establishment of new wind turbines on land, and continuous replacement of existing turbines with larger and more efficient ones
- Increased use of renewable energy in the collective heat supply
- Establishment of new wood- and wetlands, and securing roughly 250 hectares from crop rotation.

Furthermore, the plan lays the ground work for a heat plan, and a plan for biogas. The plan is currently in hearing at the moment, and afterwards it will have to be approved politically.

In 2007, the 92,984 inhabitants and the municipality as a geographical area emitted approximately 530,800 tonnes of CO_2, corresponding to ca. 6 tons of CO2 per capita. With the vision put forward in the action plan, the average emission per capita is estimated to be 2.4 tonnes of CO_2.

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[9] 'Climate Action 2030' can be found at, http://www.randers.dk/site.aspx?MenuID=3&Langref=1&Area=&topID=&ArticleID=19092&expandID=12&moduleID=

5.4 Danish energy incentives and regulations

Meeting these national targets requires economic and tax incentives, and in Denmark there are a number of different taxes and subsidies in place for both the heating and electricity sectors. Understanding the rationale for their implementation, how they work in practice, and thereby how they effect fuel choice decisions, is particularly relevant for actors within the heat and power sector.

There are a number of different taxes and subsidies that are relevant for the heat and power sector, including:

- Energy taxes
- CO_2 taxes
- CO_2 quotas
- Electricity subsidies
- Sulphur and Nitrogen Oxide taxes
- Waste taxes

The most relevant taxes and subsidies for this study are the energy and CO_2 taxes, as well as CO_2 quotas and electricity subsidies, and as such each will be described below.

Energy and CO_2 taxes

Generally speaking, energy taxes for heat are placed directly on the fuel, whereas for electricity it is normally placed on the end-user and not in the production stages. The main reason for the difference in how heat and electricity is taxed is due to the fact that heat is more of a local good (i.e. it is used relatively close to where it is produced), whereas electricity is a good that is traded internationally across borders and regions. As such, the allocation of electricity taxes on the end-user, as opposed to the producer, helps to maintain the competitive balance with neighbouring countries.

The table below sets out the heat related energy and CO_2 taxes applicable for 2010. The CO_2 tax has been raised from 90 DKK/tonne to 150 DKK/tonne and is given in DKK/GJ for each fuel. It is worth noting that biomass is exempt from these taxes and this is the main reason why biomass usage in the Danish heating sector is so interesting.

Fuel	Energy tax (DKK/GJ)	CO_2 tax (DKK/GJ)
Coal	57.3	14.8
Natural gas	57.3	8.9
Fuel Oil	57.7	12.2
Gas Oil	57.3	11.5

Table 12: Applicable taxes for 2010. The fee payable is the portion of the fuel attributed to heat generation. For industrial uses other than comfort heating and air conditioning lower taxes are applied. Heavy industry which is covered by the quota system are exempt from taxes (other than the minimum EU taxes).

For pure heat the taxation is relatively simple. For combined heat and power however, it is more complex, as it is only the portion of the fuel that is utilised in heat generation that is taxable, and electricity is exempt from taxation at the production level.

Previously there were different ways of determining how the taxes should be allocated between electricity and heat, both for central and decentralised plants, however this changed as of January 1st, 2010. Now the same rules apply for both centralised and decentralised plants, and the allocation of heat and electricity is done via either the so called 'E' or 'V' formulas:

- E formula: 1 – (electricity production / 0.65)
- V formula: Heat production / 1.25

Each year the plant can decide which of the two formulas should be utilised. Typically plants with high electrical efficiency will make use of the E-formula, while decentralized systems with low electrical efficiency will utilise the V-formula.

CO_2 quota system

Within the EU a CO_2 quota system has been in place since 2005. The quota system covers large energy production units and industries representing roughly 50% of European CO_2 emissions. The first few years were a trial period, and the first real period runs from 2008 – 2012. Each year, all entities covered by the quota system must have emission allowances equal to the total amount of CO_2 emitted.

For energy production, all plants over 20 MW thermal are covered by the quota system, and allowances (also known as permits or quotas) can be acquired via purchase on the market, or from the state via the applicable allocation mechanism (free quotas or auctioning).

The price of CO_2 allowances are currently around 100 DKK/tonne, but the Danish Energy Agency estimates that it will gradually rise to 238 DKK/tonne in 2025. For coal and natural gas this amounts to approx. 22.6 and 13.6 DKK/GJ respectively.

Electricity subsidies

There are electricity subsidies for natural gas-fired decentralised heat and power plants as well as electricity production from renewable sources. The rationale for this is a desire to encourage the usage of more environmentally friendly fuels in electricity production. In the absence of such subsidies, and due to the abovementioned exemption of biomass from heat taxes, there would be a significant incentive to solely use biomass for heating.

For natural gas-fired decentralised CHP units under 25 MW_e there is a subsidy of 80 DKK/MWh (22.2 DKK/GJ) up to a maximum production of 8,000 MWh. In addition, through to 2019, existing plants over 5 MW_e receive a production based subsidy, while existing plants under 5 MW_e have the option to continue to get a subsidy via the ‘three step tariff’, or the same subsidy that the larger plants receive.

For electricity produced via biomass, the electricity supplement for all CHP plants is 150 DKK/MWh (41.7 DKK/GJ) over and above the electricity market price. Meanwhile, electricity produced from biogas receives a fixed 745 DKK/MWh (206.9 DKK/GJ).[10]

Heat Supply Act – Restriction regarding fuel choice

In Denmark replacement of the heat production in the district heating plants is regulated by the Heat Supply Act (”Bekendtgørelse om godkendelse af projekter for kollektive varmeforsyningsanlæg”). The act sets out restrictions for municipalities’ approval of new district heating plants.

Following the restrictions of this Act, the municipalities must not approve a biomass heat plant (non taxed fuels) in an area that is currently fired with fossil fuels (taxed fuels). This means that only biomass fired CHP plants can displace the production of existing natural gas-fired CHP plants.

However, a biomass fired boiler can be approved if it is built to cover an increased heat demand and the boiler is dimensioned solely to cover this increased heat demand.

Danish energy incentives and regulations – Illustrative example

The following section provides an example of how these various taxes and subsidies operate in relation to an actual combined heat and power plant, namely the Randers CHP plant.

The figure on the following page presents the Danish Energy Agency’s forecasted fuel costs for delivery at the plant gate. The prices are in 2008 DKK/GJ, and do not include taxes.

The figure clearly reveals that in the absence of taxes and subsidies, the most attractive fuel choice for energy providers will continue to be coal, which only sees a gradual price increase over the next 20 years. Meanwhile the price of natural gas is anticipated to increase greatly, while wood pellets, wood chips, and straw all see more gradual increases. Energy crops are anticipated to see a slight decline (in real prices) based on the assumption that advances in energy crop cultivation will more then compensate for increase in fuel input prices.

[10] Depending on whether the electricity is produced via biogas alone, or in combination with another fuel, electricity producers can also chose a to receive the market price for electricity, plus a supplement of 405 DKK/MWh (112.5 DKK/GJ).

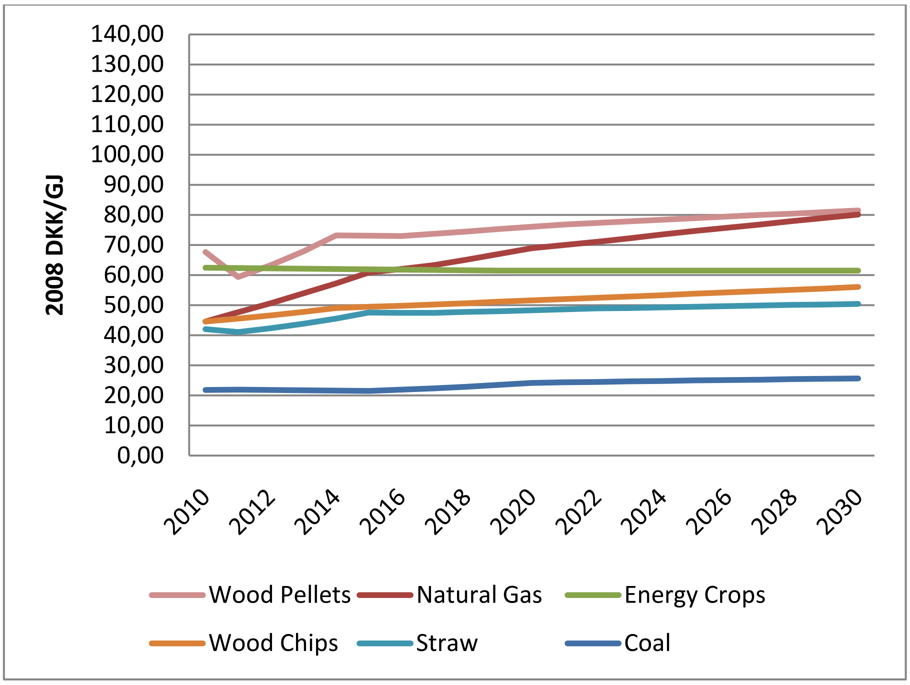


Figure 20: Danish Energy Association forecasted fuel prices, at the plant gate, exclusive VAT.

The figure does not take into account current taxes on fossil fuels, the value of CO_2 quotas needed to cover their emissions, nor subsidies for electricity produced via biomass. When these factors are introduced for the Randers kraftvarmeværk, the cost picture for input fuels looks quite different:

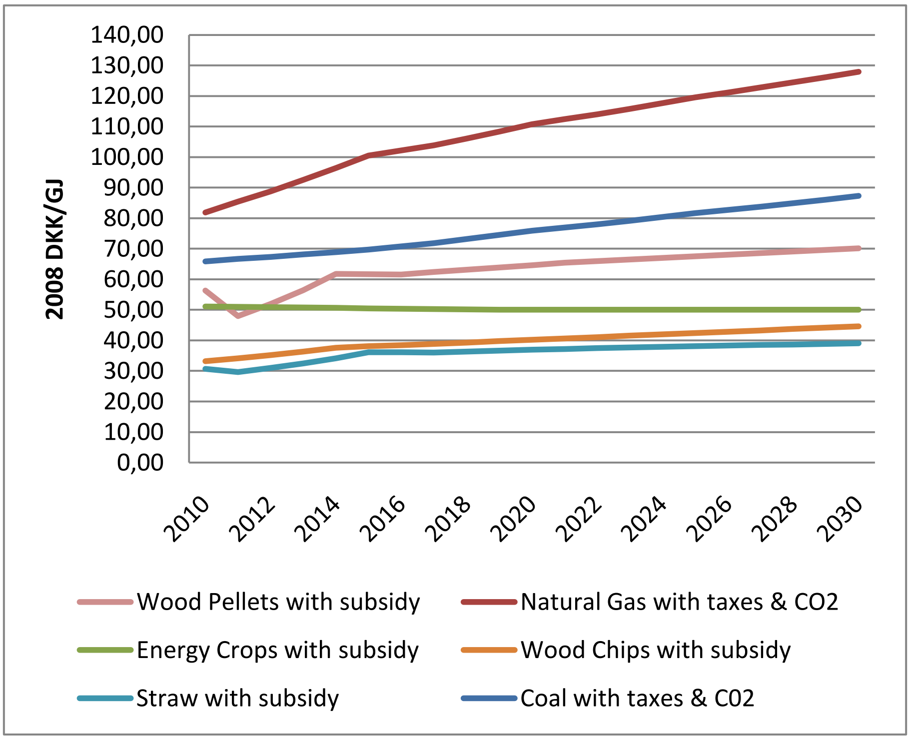


Figure 21: Danish Energy Agency (DEA) forecasted fuel prices for combined heat and power production, at the plant gate, exclusive VAT at Randers kraftvarmeværk, including subsidies and energy taxes in 2008 DKK/GJ.

Calculations in the figure are based on an electrical efficiency of 27% and a heat efficiency of 59%. Coal and natural gas taxes are based on those presented in Table 6, namely 72.1 and 66.1 DKK/GJ respectively. Utilising the V formula and a 59% heat efficiency, this corresponds to a fuel tax of 34.0 and 31.2 DKK/GJ respectively for coal and natural gas. CO_2 quota prices are based on DEA forecasts, and CO_2 contents of 95 and 57 kg/GJ for coal and natural gas. With an electrical efficiency of 27%, electricity subsidies for biomass of 41.7 DKK/GJ correspond to a subsidy of 11.4 DKK/GJ. Sulphur and NO_x taxes are not included.

This figure reveals that a combination of a decrease in biomass subsidies, CO_2 prices, and the price of fossil fuels would have to take place before it would be more cost-effective for Randers kraftvarmeværk to utilise fossil fuels as opposed to biomass. Put another way, the price of biomass would have to increase substantially before heating companies would turn to fossil based fuels. Given that the Danish government is committed to reducing CO_2 emissions, if the biomass and fossil fuels did begin to converge, it is quite likely that new taxes would be implemented to make fossil fuel utilisation in the heating sector less attractive.

6 Relevant Technological Options

Having presented the political and economic framework for biomass usage, the following chapter gives a comparison of the costs of different heat production technologies. Both technologies for individual heating and district heating are compared.

Heat production technologies for district heating

The following technologies are compared:

- Existing natural gas CHP
- Existing biomass boiler (wood chips)
- Existing coal CHP (Randers)
- Existing biomass CHP (wood chips) (Randers)
- New natural gas CHP
- New biomass CHP (wood chips)
- New biomass boiler (wood chips)
- New biogas CHP
- New geothermal plant
- New solar heating including new solar heating with seasonal storage
- New heat pump

For the biomass technologies it has been chosen to only show costs for wood chip-fired technologies. The costs are similar to technologies using straw. Other renewable energy technologies such as geothermal energy and solar heating have been included to show the difference between biomass and these technology options.

The table below shows the assumptions on efficiencies and investment costs for the analysed technologies.

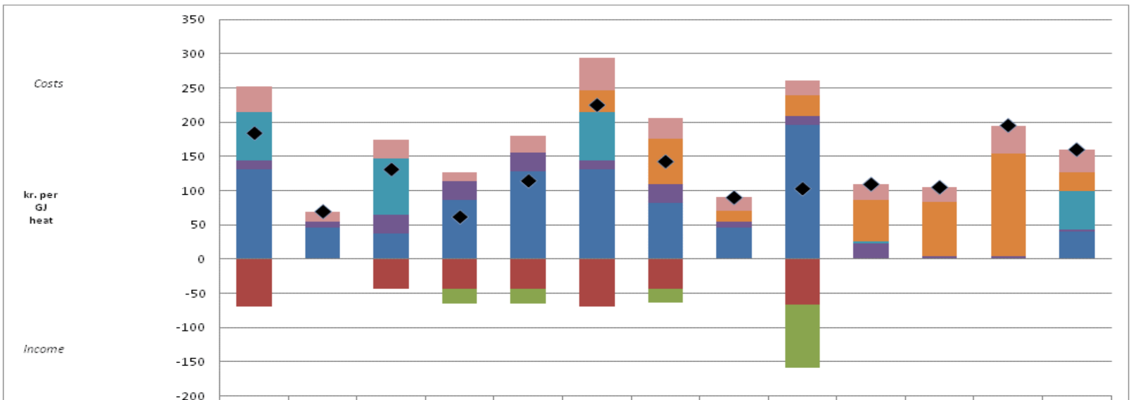
Technology	Existing natural gas CHP	Existing wood chips boiler	Existing coal CHP (Randers)	Existing wood chips CHP (Randers)	New natural gas CHP	New wood chips CHP
Electrical Efficiency	40%	0%	29%	29%	40%	30%
Total Efficiency	90%	108%	86%	86%	90%	90%
Investment (DKK/MW heat), solar (DKK/GJ inv)	-	-	-	-	6,000,000	12,500,000
Investment (DKK/MW_{el})	-	No el. capacity	-	-	7,500,000	25,000,000

Technology	New wood chips boiler	New biogas CHP	New Geo-thermal plant	New solar heating	New solar heating with sea-sonal	Heat Pumps (electric)
Electrical Efficiency	0%	39%	0%	0%	0%	0%
Total Efficiency	108%	90%	100%	100%	100%	300%
Investment (DKK/MW heat), solar (DKK/GJ inv)	3,000,000	5,735,294	15,000,000	907	1,722	5,025.000
Investment (DKK/MW_{el})	No el. capacity	7,500,000	No el. Ca-pacity	No el. Capacity	No el. Capacity	No el. capacity

Table 13: Assumptions on efficiencies and investment costs for the analysed technologies.

The analysis is based on general technology data from the technology catalogue of the Danish Energy Agency from 2005 and the project Heat Plan for Greater Copenhagen. Assumptions on fuel price, CO_2 price and power price are based on the assumptions of the Danish Energy Agency. Prices for 2015 are used. It is assumed that power production can be sold at the average Nord Pool price in 2015. For biogas a production cost of 100 DKK/GJ for delivery at the CHP plant has been assumed, which includes capital, operation and maintenance costs. The capital cost is assumed to be the same as a new natural gas CHP, and the current electricity subsidy of 0.745 DKK for biogas has been utilised.

Costs for heat losses in the district heating network are included (21% of the heat produced) but investment costs for the district heating network are not included. Establishment of the district heating network is thus regarded as sunk costs. The figure below summarises the economic analysis of costs for the heating companies including taxes. The figure shows heat production costs in DKK/GJ at the consumer. Capital costs are distributed over the lifetime of the



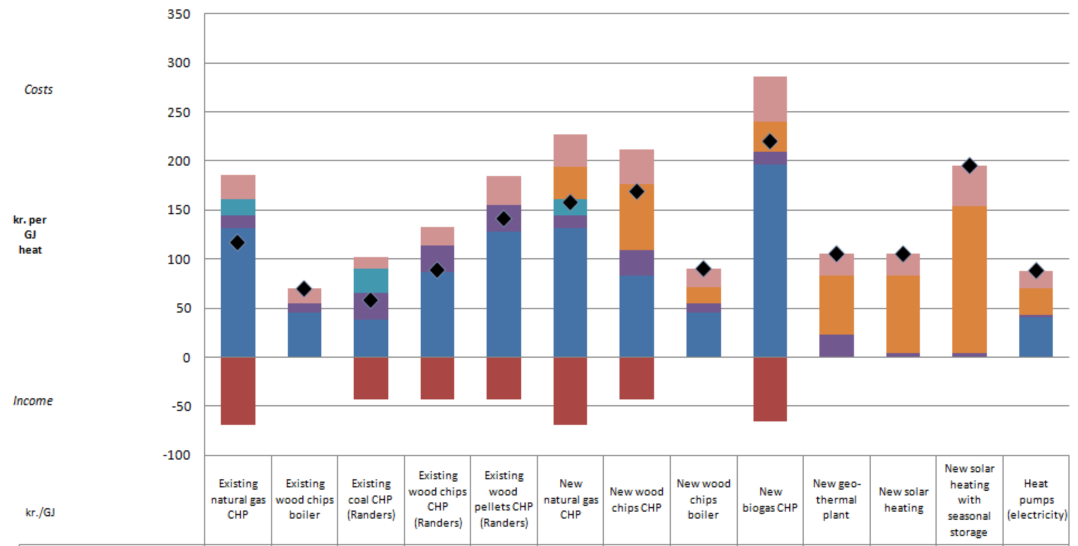
kr./GJ	Existing natural gas CHP	Existing wood chips boiler	Existing coal CHP (Randers)	Existing wood chips CHP (Randers)	Existing wood pellets CHP (Randers)	New natural gas CHP	New wood chips CHP	New wood chips boiler	New biogas CHP	New geo-thermal plant	New solar heating	New solar heating with seasonal storage	Heat pumps (electricity)
Costs distribution loss	39	15	28	13	24	47	30	19	22	23	22	41	34
Capital costs	0	0	0	0	0	32	67	16	31	61	79	150	27
CO2-og energy taxes, CO2 quota	70	0	83	0	0	70	0	0	0	3	0	0	57
Operation and maintenance	12	9	27	27	27	12	27	9	13	23	4	4	2
Electricity subsidies	0	0	0	-21	-21	0	-21	0	-92	0	0	0	0
Electricity sales	-69	0	-44	-44	-44	-69	-43	0	-66	0	0	0	0
Fuel	132	46	38	87	128	132	83	46	196	0	0	0	40
◆ Total heat cost	184	70	131	62	114	225	143	90	103	110	105	195	160

*Figure 22: The figure summarises the economic analysis of costs for the heating companies including taxes. The figure shows heat production costs in DKK/GJ at the consumer. The total heat production cost (sum of income and costs) is marked with a **black dot**.*

technical installations. An interest rate of 6% has been used.

From the figure it can be seen that existing biomass CHP and biomass boilers as well as new biomass boilers have low heat production costs compared to other technologies. The main reason for this is that biomass has no taxes and CO_2 costs. Furthermore, wood chips are relatively cheap as a fuel. The town of Randers and most of the district heating areas in Djursland use biomass technologies and therefore have low heat production costs compared to other district heating areas. Coal has higher costs which is one reason why Randers Kraftvarmeværk has shifted from coal to biomass. Natural gas fired plants have high costs compared to biomass and coal and therefore there can be potential savings in shifting to other technologies. However, the plants are obliged to use CHP technology and not heat-only boilers if they want to change to biomass. From the figure it can also be seen that biomass CHP has fairly high heat production costs because of the high investment and O&M costs. Other renewable energy technologies, biogas, geothermal and solar heating could also be interesting. However, there is still a high uncertainty about the geothermal potential and investment costs and solar heating can only be used as a supplement if it is not combined with a seasonal storage at a higher cost.

The figure below shows the socioeconomic heat production costs (DKK/GJ). The analysis is a simple socioeconomic analysis where the difference from the economic analysis showed above is that taxes and subsidies are excluded.



kr./GJ	Existing natural gas CHP	Existing wood chips boiler	Existing coal CHP (Randers)	Existing wood chips CHP (Randers)	Existing wood pellets CHP (Randers)	New natural gas CHP	New wood chips CHP	New wood chips boiler	New biogas CHP	New geo-thermal plant	New solar heating	New solar heating with seasonal storage	Heat pumps (electricity)
Costs distribution loss	25	15	12	19	30	33	35	19	46	22	22	41	19
Capital costs	0	0	0	0	0	32	67	16	31	61	79	150	27
CO2-og energy taxes, CO2 quota	17	0	25	0	0	17	0	0	0	0	0	0	0
Operation and maintenance	12	9	27	27	27	12	27	9	13	23	4	4	2
Electricity subsidies	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity sales	-69	0	-44	-44	-44	-69	-43	0	-66	0	0	0	0
Fuel	132	46	38	87	128	132	83	46	196	0	0	0	40
Total heat cost	117	70	58	89	141	158	169	90	220	105	105	195	88

*Figure 23: The socio economic heat production costs (DKK/GJ). The total heat production cost (sum of income and costs) is marked with a **black dot**.*

From a socio-economic point of view the biomass technologies are still competitive, though they have relatively higher costs when not including taxes and subsidies.

6.1 Individual heat production technologies

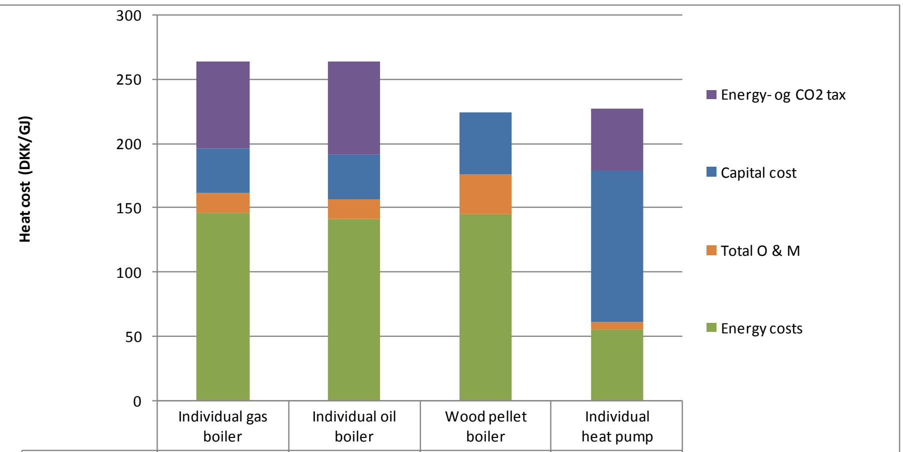
Four technologies for individual heating have been compared, i.e. natural gas boilers, oil boilers, wood pellet boilers and heat pumps (water-water).

In the economic analysis the assumptions on investment costs, lifetimes and efficiencies outlined in Table 14 have been applied. All heat production technologies are assumed to be dimensioned for a house with a heat consumption of 65 GJ/year (18 MWh/year).

Technology	Natural Gas Boiler	Oil Boiler	Wood Pellet Boiler	Heat Pump
Investment (DKK)	26.000	26.000	36.000	88.000
Lifetime (years)	20	20	20	20
Efficiency	97%	92%	90%	350%

Table 14: Assumptions on investment costs, lifetimes and efficiencies.

With the applied fuel and electricity prices for 2015 the wood pellet boiler and the heat pump have the lowest heat production costs for the consumer, about 225 DKK/GJ. From a socio-economic point of view (without taxes) the wood pellet boiler has the highest costs and the costs for the heat pump is lower than for oil and gas boilers. Compared to the district heating technologies the costs are much higher for the individual technologies. However, this does not include the costs for connecting to the district heating network.



	Individual gas boiler	Individual oil boiler	Wood pellet boiler	Individual heat pump
Energy- og CO2 tax	68	72		49
Capital cost	35	35	48	118
Total O & M	15	15	31	6
Energy costs	146	141	145	55

Figure 24: Heat production costs for gas boiler, oil boiler, wood pellet boiler and heat pump for heating of a small residential building with a yearly heat consumption of 65 GJ.

6.2 District heating vs. individual heating

The competition between district heating and individual heat production is highly dependent on the costs of connecting to the district heating network. The connection costs depend on the size of the buildings and the heat density of the area. Experience from the project “Heat Plan for Greater Copenhagen” shows that for office buildings and larger residential buildings it is fair to use an investment cost of 550-750 DKK/GJ yearly heat consumption or a capital cost of 40-55 DKK/GJ (30 year lifetime of district heating connection, 6% interest rate). For smaller residential buildings the investment costs are 1400 DKK.

The costs cover the total connection costs to the district heating network. The local network costs are the most significant. The costs include costs for supplying the heat within the house itself (heat exchangers etc.). Thus, it is more interesting to convert larger residential and office buildings to district heating. For smaller residential buildings the economy is more uncertain.

Comparing the costs of existing biomass fired plants of 60-70 DKK/GJ with the costs of individual technologies of 225-260 DKK/GJ and taking into account the costs for connecting to the district heating network it seems like there would be an economic value of converting individual customers to district heating. However, the costs for connecting to the grid are estimated for quite densely populated areas and an analysis of the local conditions will need to be made in order to estimate the local connection costs.

7 SSCM methodology

Sustainable Supply Chain Management (SSCM) is a concept that has many definitions and the methodologies used to approach this are numerous. We have taken inspiration from the appendix of the tender and adjusted this to comply with our specific needs to answer the following question:

What are the possibilities of increased use of biomass for energy production in the three municipalities, and what consequences are associated with the utilisation each of the selected resources described through our case studies?

7.1 The supply chain matrix

For each of the resource case studies an overview of the supply chain is illustrated through a matrix. Each step of the supply chain from the primal material production in on end to heat and electricity deployment in the other end is analysed with regard to three key aspects:

- Economic aspects
- Environmental aspects
- Social aspects

Economic aspects can be those related to production costs, transport and logistics costs, market prices etc. Environmental aspects can be environmental violation caused by emissions or land use priorities and abatement of fossil fuels, etc. Social aspects can be those related to labour conditions, ethical issues related to land use and feed stock crops and organisation of supply chains, etc.

After creating an overview of these key aspects, the aim is to identify the main existing or potential barriers for utilizing each specific resource within the three municipalities. This is done by integrating the three key aspects and selecting the most critical barriers within each part of the supply chain.

Finally, the possible enablers for the identified barriers are highlighted and their possible economic benefits are discussed.

In each case study, the most critical barriers towards utilisation are analysed with the aim of discussing the potential of aiming at this particular resource compared to other possibilities. The purpose of the matrix is to create an overview of the supply chain for each resource case study and thereby be able to select the most critical barriers for the utilisation of these for further analyses. The purpose is therefore *not* to analyse each aspect of each part of the supply chain thoroughly, but instead to identify the most interesting barriers and potential enablers that can be utilised to overcome these barriers.

7.2 Selection of case studies

The three case studies described in this report were selected in dialog with CBMI and the three municipalities to ensure that the analyses are relevant for their needs. The three cases are:

1. Biogas for CHP production
2. Local biomass for CHP and heat production
3. International biomass for CHP production

Biogas for CHP production

Extending the existing biogas production is on obvious possibility for the three municipalities to increase energy production from biomass. The case study will focus on two types of biogas production:

1) Biogas from slurry - Biogas production based on pig slurry or cow slurry from local farms in the area.
2) Biogas from energy crops - Biogas production from energy crops is a relatively new field. Prior to undertaking the analysis the most relevant energy crops were discussed with relevant actors and by looking at existing studies of the potential. Possibilities included corn, beet, maize, straw, hemp, different types of grasses, oilseed, radish, rapeseed, willow, and others. Based on these initial investigations, biogas from maize was selected to be most interesting within the Danish context.

Local biomass for CHP and heat production

The analyses of locally produced biomass for CHP and heat production will focus on two possible tracks for the agriculture and the forest industry to contribute to the energy production.

a) **Straw and energy crops for CHP and local heat production**
The main challenges for the farmers to maintain or increase their straw delivery to the energy production are analysed. In addition, the possibilities for the farmers to replace their current production of straw (as a by-product) with the production of energy crops will be analysed. After consulting with various relevant actors, the main focus will be on willow.

b) **Local wood resources for CHP production**
The local forest industry's current situation, and their ability to deliver wood for energy production, will be analysed along with the possibilities of increasing local production of wood chips for CHP and local heat production.

International biomass for CHP production

A market for international trade with certain types of biomass resources has been established. The case study will analyse the potential for increased import of wood pellets and wood chips from other countries. By focusing on the existing use of imported biomass at Randers Kraftvarmeværk, which imports both wood chips and wood pellets from abroad, it will be analysed whether continuing or expanding the import of wood pellets and wood chips to the three municipalities is a sustainable solution in order to reach the local climate and energy targets.

8 SSCM analysis of biogas for CHP production

In this chapter the supply chain comprising of slurry and energy crop-based biogas production in co-operative biogas plants for combined heat and power is analysed. To draw up and analyse the supply chain for slurry/animal manure and energy crops for biogas and combustion in CHP plants is relatively complex, and it should therefore be noted that the supply chain can be described and analysed in various ways. We have chosen to include the biogas plant planning in the forthcoming analysis due to its relevance in the Danish context, where the establishment of plants and biogas production has been stagnant in the last couple of years (as is reflected in the figure below). The Danish Energy Agency has estimated the total Danish (theoretical) biogas potential to be 40 PJ from biomass residue, mainly slurry (26 PJ), while the current production in 2009 is estimated at 4 PJ (Brancheforeningen for Biogas & Energinet.dk, 2009).

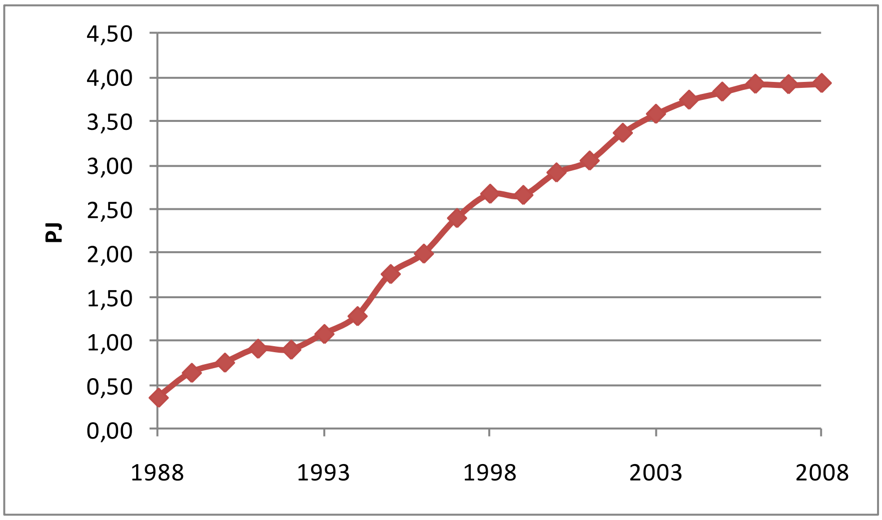


Figure 25 – Biogas production in Denmark 1988-2008 (Danish Energy Agency, 2009).

The chapter describes the biogas supply chain in terms of economic, environmental and social aspects. Furthermore, quantifiable indicators will be put forward for every part of the supply chain. Finally, key targets and enablers for the supply chain are presented and the main existing or potential barriers, possible enablers and economic benefits are summarised.

8.1 Current use and biogas potential

In the following section the current use of biogas and natural gas in the municipalities of Randers, Norddjurs and Syddjurs is estimated. Afterwards the potential for displacing the natural gas used in CHP with biogas is analysed.

It should be noted that biogas, in addition to displacing natural gas for CHP, can potentially be used for:

- Transport purposes via an upgrade to natural gas quality biogas
- Household gas furnaces distributed via gas pipes to individual houses
- Generation of electricity and heat via fuel cells in the future

8.1.1 Current use of natural gas and biogas from slurry and energy crops

According to the Danish Biogas Association (Brancheforeningen for Biogas) and Energinet.dk (2009), biogas is primarily meant to displace natural gas in the future energy supply. Furthermore, the Danish Energy Agency emphasises that the most effective use and the highest socioeconomic value is obtained by using biogas in local CHP plants where it displaces natural gas (Danish Energy Agency, 2009). The explanation for this is that biogas can replace natural gas with only minor additional costs, while there are substantial upgrade and compression costs if it is to be used in transport to replace liquid fuels.

The amount of natural gas consumption in CHP plants in the municipalities appears in the table below. For CHP, there is currently 365 TJ and 12 TJ used in Randers and Syddjurs respectively, while there is not any consumption of natural gas in Norddjurs.

Municipality	Natural gas for CHP (TJ)	Total natural gas use (TJ)
Norddjurs	0	0
Syddjurs	12	12
Randers	365	992
Total	**377**	**1004**

Table 15: Total natural gas consumption and use for CHP in the municipalities of Randers, Norddjurs and Syddjurs (PlanEnergi, 2008/2009).

It should be noted that the total primary natural gas consumption in Randers is estimated to be 992 TJ. Other than CHP, the majority of natural gas is used in small furnaces in the household sector (374 TJ). The total consumption of natural gas in Syddjurs is the 12 TJ utilised in CHP.

8.1.2 Slurry potential for production of biogas

The table below presents the estimated primary energy potential from slurry (PlanEnergi, 2008/2009). According to PlanEnergi (2008/2009) there is currently not any slurry being used for energy production in Randers and Norddjurs, while 5 TJ is being used in Syddjurs for the production of heat alone.

Municipality	Slurry potential (TJ)
Norddjurs	286
Syddjurs	252
Randers	300
Total	**838**

Table 16 – Primary energy potential from slurry in the municipalities of Randers, Norddjurs and Syddjurs (PlanEnergi 2008/2009).

There have also been other studies conducted regarding the potential from slurry in the municipalities, including Kristensen & Jørgensen (2008). They estimate the potential from slurry to be approximately 8 mil. m^3 methane in Randers, 7.7 mil. m^3 in Norddjurs and 6.8 mil. m^3 in Syddjurs corresponding to an energy content[11] of:

- 276 TJ in Norddjurs
- 244 TJ in Syddjurs
- 316 TJ in Randers

As such, the estimated slurry potential put forward by PlanEnergi (2008/2009) and the one by Kristensen & Jørgensen (2008) are very similar.

Overall it is evident that the slurry potential in the three municipalities is significant, but one also has to approach these figures with some caution. It is probably not realistic to utilise such a high share of the slurry for biogas production due to lack of interest from the farmers and/or due to the fact that all livestock farms are not feasible to include in biogas production because of scattered locations, small slurry productions, uncertain futures for the farms due to structural development, etc.

Secondly, at the time being is it necessary to supplement the slurry with organic waste or energy crops for production of biogas due to the fact that it increases gas yield thereby improving the economy of the biogas plant. Thus, the energy potential is at this point only theoretical. Ideally, organic waste would also bed used because this offers a ”cheap” way to re-cycle waste.

Thirdly, HMN Naturgas I/S have estimated the untapped biogas potential in the municipality of Randers to be 10 mil. m^3 natural gas equivalents, corresponding to 359 TJ[12] (Randers Kommune, 2010). The potential estimated by HMN Naturgas I/S is therefore slightly higher than that of Kristensen & Jørgensen (2008).

Finally it should be noted that the future slurry production is dependent on a number of other factors e.g. the structural development in the agriculture, export of livestock, etc.

[11] Given a calorific value of 35.9 MJ/Nm^3 methane (Miljøstyrelsen, 2010).

[12] Given a calorific value of 39.48 GJ/1000 ^{3} for natural gas (Danish Energy Agency, 2009).

8.1.3 Energy crop potential for production of biogas

Theoretically the potential for energy crops in the municipalities is huge, however it is highly dependent on how the production area is actually allocated in practice.

According to PlanEnergi (2008/2009), the total primary energy potential from bio-oil and energy crops in the municipalities is 1,055 TJ in Norddjurs, 896 TJ in Syddjurs, and 1,302 TJ in Randers. Meanwhile the estimated primary energy consumption from bio-oil and energy crops is only 6 TJ from Norddjurs. According to the PlanEnergi (2008) this is bio-oil used in industrial plants.

As the assumptions and calculations for PlanEnergi's current consumption and potential of bio-oil and energy crop figures were unavailable, the data from Kristensen & Jørgensen (2008) has been utilised.

Kristensen & Jørgensen (2008) assume it is possible to use 15% of the area currently cultivated with corn for fodder and food in the municipalities. The assumption is drawn on the basis of a gross export of corn in Denmark between 10% and 20% from 2001-2005. Due to the gross export it is estimated that a 15% reduction would not compromise the role of the agriculture as a fodder and food producer. Naturally, this assumption can be discussed in regards to sustainability from a regional and global perspective.

The table below displays the total farmland area currently cultivated with corn for fodder and food in the three municipalities, as well as a table representing 15% of this as an illustration.

Municipality	Area with corn (hectares)	15% of area with corn (hectares)
Norddjurs	27,800	4,170
Syddjurs	22,000	3,300
Randers	33,100	4,965
Total	**82,900**	**12,435**

Table 17: Area cultivated with corn for fodder and food in the municipalities of Randers, Norddjurs and Syddjurs (Kristensen & Jørgensen, 2008).

The table below displays the yield in tonnes of dry matter and biogas potential. As an illustration of the potential, it is assumed that maize is grown on 15% of the total area cultivated with corn for fodder and food in the municipalities.

The potential is highly dependent on the farmers' incentive to produce energy crops and competition with alternative crops. Thus, the local farmers' interest in different energy crops should be examined, for instance via demonstration projects.

Municipality	Maize potential (tonnes dry matter)	Biogas potential (1,000 m^3)
Norddjurs	50,040	30,827
Syddjurs	39,600	24,396
Randers	59,580	36,704
Total	**149,220**	**91,927**

Table 18: Methane potential from maize if 15% of the area currently cultivated with corn for fodder and food in the municipalities of Norddjurs, Syddjurs and Randers is used for biogas. Assuming, a yield of 12 tonnes of dry matter per hectare, a dry matter content in maize silage of 33%, a biogas potential of 185 m^3 tonnes of maize silage (PlanEnergi, 2010)

The following primary energy potential can be estimated from the biogas potential in the table above with a lower burning value of 23 GJ/1000 m^3 methane (Danish Energy Agency, 2009),

- 709 TJ in Norddjurs
- 561 TJ in Syddjurs
- 844 TJ in Randers

An alternative and more suitable method to the one above could be to estimate the needed amount and area of energy crops to obtain a certain feasible biogas production locally.

8.1.4 Potential utilisation of biogas in CHP

The total primary energy potential from biogas production based on slurry and maize, as described above, and the use of natural gas for CHP in the municipalities is summarised in the table below.

Municipality	Biogas potential from slurry (TJ)	Biogas potential from maize (TJ)	Total biogas potential (TJ)	Natural gas for CHP (TJ)
Norddjurs	286	709	995	0
Syddjurs	252	561	813	12
Randers	300	844	1,144	365
Total	**838**	**2144**	**2953**	**377**

Table 19: Total primary energy potential from biogas production based on slurry and maize and the use of natural gas for CHP in the municipalities.

As displayed in the table, the estimated biogas potential in Randers is more than three times greater than the natural gas consumption, while the theoretical biogas potential in Syddjurs is 67 times greater than the natural gas consumption. Finally, there is not any natural gas use in Norddjurs, and as such any potential biogas production would have to be utilised elsewhere.

Even though the highest socioeconomic value of biogas is obtained by displacing natural gas in CHP plants, a local obstacle can arise in that it may be difficult to access the heat market or utilise the produced heat, which is of course crucial for sustaining the operating economy of biogas plants. The heat market can for example be rather inaccessible if the heat is already produced via renewable energy, or simply because the demand for heat is too low.

In an attempt to overcome this obstacle, the Danish Government and the Danish People's Party in the early part of summer 2009 agreed on a subsidy-based parity for the sale of biogas to CHP plants and the natural gas grid respectively. According to Energinet.dk (2009) this opens up the possibility for a future in which biogas is transported and managed via the natural gas system; thus enabling efficient integration of significant greater volumes than today. As of yet, the subsidy-based parity has not been implemented via legislation.

In the figure below, the areas that are not supplied with natural gas appear in orange.

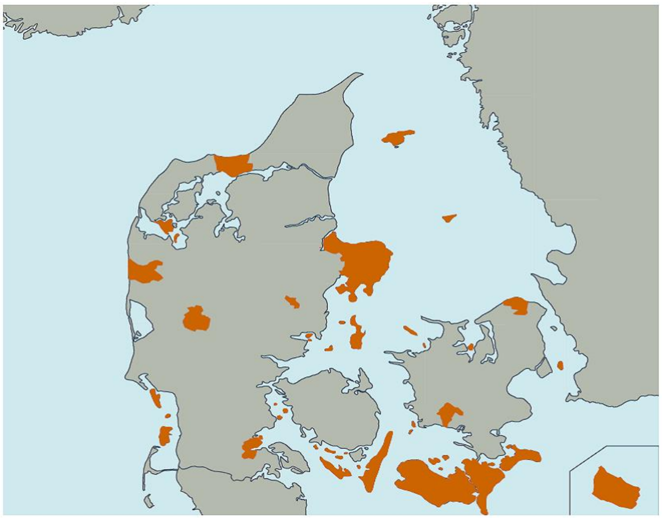


Figure 26 - Natural gas supply in Denmark. The orange areas are not supplied with natural gas (Dong Energy et al, 2007).

Norddjurs and Syddjurs

It is evident from the figure that most if not all of the area within the municipalities of Norddjurs and Syddjurs are not supplied with natural gas. Therefore the opportunity for the upgrading of, and transport via the natural gas grid, in Norddjurs and Syddjurs would have to involve an extension of the existing grid. This is similar to the biogas project in the Andi area, where the biogas is to be transported to the town of Hornslet.

Randers

As the current natural gas consumption for CHP in Randers is approximately 20% higher than the estimated biogas potential from slurry, technically speaking, this biogas production would be able to displace natural gas in Randers.

8.2 SSCM matrix

An overview of the entire SSCM matrix for slurry and energy crop based biogas production for CHP is presented on the following page.

Case 1: SSCM analysis for slurry and energy crops for biogas cooperative plants and CHP

	Economic Aspects	Environmental Aspects	Social Aspects	Main Existing or Potential Barriers	Possible Enablers	Possible Economic Benefits
Slurry Production	Production size % Optimisation of input	Redistribution of nutrients, reduced use of inorganic fertilizer & GHGs	Obnoxious smell & Know-how	Production size	Vertical supply chain, Slurry separators & Long-term contracts	Increased livestock production, reduced use of inorganic fertilizer & higher concentration of nutrients
Production of energy crops	Production costs Alternative use	Fossil fuel use & Use of pesticides	Know-how & R&D&D	Production costs, Alternative use & R&D&D	R&D&D, Vertical supply chain & Long-term contracts	Crop rotation & Business diversification
Transport of feedstock	Capital costs & Operating costs	Fossil fuel use	Traffic % Noise	Traffic, Noise & Distance	Reduced transport & Reduced costs	Reduced Transport, Reduced Capital & Operational costs
Biogas production	Capital costs, Operating costs, Gas output & Authorities processing	Redistribution of nutrients & GHGs	Local acceptance, Political interest, Reduced smell & Security of supply	Establishment process, Financing, Local resistance & Lack of organic material	Access to financing Use of energy crops & supple process	Industry development & Jobs
Heat and electricity production	Fuel Input prices, Availability of Heat Market & CO2 prices	Abatement of fossil fuels	Local political interest & Demand of "green energy"	Availability of heat market	Heat market, Vertical supply chain, Modification of the heat supply act & up- and downgrading etc.	Sale of heat

8.2.1 Slurry production

The first stage of the supply chain is the production of slurry. Slurry is a waste product from livestock, poultry and mink farming and therefore the costs of production are associated with these forms of animal production. As a waste product from livestock and poultry farming, slurry is handled in different ways.

It can be treated at the individual pigsty/cowshed (separation at source) by dividing urine and faeces thereby reducing water waste, at the farm level (pre-separation) with different kinds of separation technologies, termed low or high-tech separation, at the biogas plant - or even both. At the moment only separation at source and the so-called low-tech separation is used in Denmark.

Today the vast majority of the slurry is distributed on farmland without separation, and for the foreseeable future this is also likely to be the case.

Slurry is separated for a number of reasons, amongst others to increase the concentration of nutrients and the share of dry matter by reducing the water content, thus improving the slurry for biogas production. The slurry product can also be optimised through the ordinary day-to-day running of the farm.

Economic, Environmental and Social aspects

Slurry Separation

Normally slurry consists of 90-95% water, so separating slurry can offer some economic benefits for the farmers in regards to optimising slurry handling. For instance, separation leads to a product with a higher concentration of nutrients. By reducing the volume this potentially reduces the costs of transport. In addition, this may allow for increased transportation distances.

Furthermore, as long as the separated liquid slurry is so clean that it does not need to be handled as animal slurry, in some cases new investments for increased storage capacity can be saved. Depending on the specific separation technology, the spread of infectious diseases from one farm to another can also be minimised. (Landbrugsinfo, 2008).

The incentive for farmers to deliver and/or treat their slurry is mainly due to the current legislation making it possible for the farmers to increase their livestock production without necessarily increasing the farmland area. The reduced land area requirements depend on the specific circumstances.

The costs associated with separation are typically paid by the individual farmer. The costs vary from case to case and from how it is calculated. Generally it is considered quite expensive and considerable economics of scale favour larger operations. As such, an economic assessment regarding whether separation should be undertaken, and if so, in what form, is recommend. For example, some farmers may want to utilise a portable separation facility used by a number of farmers thereby spreading out the costs (Birkmose, 2006).

Separation of slurry also reduces odours and emissions significantly, for example ammonia (NH_3), methane (CH_4) and laughing gas (N_2O). Reduced odour can potentially lead to increased social acceptance of the farms and biogas plants from people living close by. Meanwhile reduced emissions of methane and laughing gas limit the greenhouse gases' potential impacts on the climate system.

Lastly, separating the slurry can enable redistribution of potential surplus of phosphorus to another area/farm with a deficiency. (Birkmose, 2006).

A relevant indicator for slurry production delivered for production of biogas is the amount of slurry used in tons of dry matter/solid overall, and if possible the percentage solid from each farmer, which could thus enable measurement of the local optimisation of slurry handling.

According to the Danish Biogas Association and Energinet.dk's research and development strategy (2009), there is still need for optimisation of the content of dry matter in the slurry for biogas production in Denmark. There is also a need for increased knowledge about gas potentials via different separation technologies. Furthermore a new Danish study concludes that there are still some challenges with the low-tech separation regarding operation and costs (Dansk Landbrugsrådgivning, 2010). Reducing the costs of separation will most likely increase the amount of slurry separated, and thereby optimise the slurry handling, possibly enabling the benefits described above. However, it should be noted that a future diffusion of slurry separation is very uncertain.

If the farmers supplying slurry are a part of a co-operative biogas company (vertically integrated) there should already be an incentive for optimisation of the slurry handling. If not, then long-term contracts between the individual farmers and the company could possibly enable additional optimised slurry handling. It is worth noting that optimisation of slurry was also a very important issue raised by biogas stakeholders at a May 31st workshop held in Ebeltoft, Denmark.

Quantifiable Indicators

Quantifiable Indicators for the production of slurry could be the amount of slurry produced, the amount used for biogas production, the amount of slurry separated, the costs of separation, and if possible the dry matter content of the slurry.

8.2.2 Production of energy crops

In principle, energy crops differ from other crops such as food crops and cash crops due to the fact that they are produced with the primary purpose of energy production.

Energy crops can be used for production of biogas in two forms: fresh or as silage. Furthermore, one normally distinguishes between annual and perennial crops, but more or less all crops can be used if they do not contain too much lignin. (PlanEnergi & Århus Universitet, 2009).

At the time being it is necessary to supplement slurry with another type of organic matter for production of biogas. Traditionally organic waste, from e.g. the food industry, slaughterhouse waste, has been used because of its high content of dry matter and fat, thus enabling a higher biogas output. Traditionally this waste has been provided free of charge, and in some cases the biogas plants have been paid to take it (PlanEnergi & Djurs Landboforening et al, 2006). Without organic supplement to the slurry, the biogas output will not be high enough to ensure a profitable production.

Today the above-mentioned type of organic waste is almost fully exploited in Denmark and a certain amount of waste is already imported. Therefore the potential for utilisation of energy crops has received increased attention in recent years (PlanEnergi & Århus Universitet, 2009).

According to Niels Ejnar Rytter, a farmer participating in the aforementioned May 31st workshop, agriculture is generally willing and able to produce large amounts of biomass for energy production if it is economically sustainable. This means that the production of energy crops must be financially competitive with alternative land uses and/or provide other advantages for the farmer.

Production of energy crops on agricultural land in Denmark is generally not considered to be economically viable at this time (Jørgensen, 2010). This therefore explains the lack of energy crop production in the three municipalities. However, as will be touched on in subsequent chapters, the value of energy crops is likely to increase in upcoming years, and as a result this may become more viable in the future.

A number of annual and perennial ‘energy crops’ has been discussed and studied for the use in biogas production e.g. maize, beet, corn, straw, Jerusalem artichoke, hemp, different types of grass, oilseed radish, rapeseed, willow as well as different crop combinations for example maize/grass or maize/rye. A general realisation is that perennial crops have less negative impact on the on the environment compared to annual energy crops. (Larsen, 2009; PlanEnergi & Djurs Landboforening et al, 2006; Tybirk, 2010). E. g. perennial crops have a lower need for fertilizer and pesticides (Uellendahl et al, 2008).

Locally in the municipality of Syddjurs, the biogas company Djurs Bioenergi focuses on maize for biogas production. Maize for production of biogas has also received attention nationally from the Danish Energy Agency (Taftdrup, 2010). Additionally, according to Søren Ugilt Larsen from the Danish agricultural consultancy, Dansk Landbrugsrådgivning, there is a lot of experience to be gained via the experience in production of maize for biogas production in Germany. This is mainly due to the fact that maize is an essential energy crop for biogas production in Germany - maize accounts for 85% of the area with crops for biogas production (Larsen, 2010).

Furthermore, maize is relatively easy to handle in the production of biogas, easy to ensile (store and preserve), and has a high yield (Jørgensen, 2010). Thus, the following analysis will focus solely on whole-crop maize for biogas production.

Procurement of maize

Maize is grown in short rotations on as warm farmland as possible. The crop is either harvested annually, or every second year, depending on the type of maize.

Production of maize consists of the following rotation: ploughing, harrowing, sowing, rolling, fertilizing, spraying of herbicide, sowing and chopping (PlanEnergi et al, 2006). The maize is stored on the agricultural field and preserved for up to 10-12 months with dry matter losses of only a few percent (Thyø et al, 2007).

Economic, Environmental and Social aspects

Maize Production Costs

Economic estimates for the production cost of maize are highly dependent on input costs, for example labour demand. For the biogas projects on Djursland and Kronjylland, costs are budgeted as 0.45 DKK/kg dry matter for maize delivered to the biogas plant, or 0.25 DKK/kg dry matter for maize collected at the field within 5 kilometres of the biogas plant (PlanEnergi et al, 2006). According to study cited above, the most important economic factors are chopping and transport to plant, sowing, ploughing, harrowing, spraying of herbicide and subsidy.

Other sources suggest a price of ensiled maize of 0.25 DKK/kg or 0.240 – 0.265 DKK/kg depending on who undertakes the transportation costs (PlanEnergi, 2010 & Biokraft, 2010).

Due to the economy in producing energy crops including maize in Denmark, the experience with the production and use in biogas plants is very limited. Therefore procurement of new and specialised types of energy crops for biogas production is suggested as a focus area in Danish Biogas Association's and Energinet.dk's research and development strategy (2009).

A Danish study has found that lignocellulosic perennial crops can yield significantly more methane; improve the ratio of energy output/input and make the production of biogas from energy crops more sustainable if they are pre-treated by wet oxidation. Currently this is however very capital intensive. The investment costs are estimated to between 7% and 14% of the biomass supply costs (Uellendahl et al, 2008). According to the same source as cited above, the pretreatment itself, excluding the investment cost, is 122 €/ha.

Farmer Perspective

From a farmer's point of view Danish, studies estimate that with a settlement price of 0.45 DKK/kg maize dry matter, spring barley is 8-270 DKK/ha more profitable (PlanEnergi et al, 2006 & Djurs Bioenergi, 2006).

As indicated above, the greatest barrier for energy crop production, including maize, is the economy i.e. the production costs. The production of energy crops is generally not competitive with alternative uses of farmland such as food production. Therefore the possibilities with respect to choice of energy crop for the individual farmer are highly dependent on the specific circumstances and advantages for the farmers.

For example some farmers may see an advantage in growing maize because the agricultural contractor performs most of the work, thus enabling the farmer to concentrate on the livestock farming. Furthermore, it could be a potential enabler for the livestock farmer who is already producing fodder to then designate another 10% for maize and sell the fodder of poor quality to the biogas plant. (PlanEnergi et al, 2006). Maize can be used to diversify their business through various possibilities for sale, i.e. food, fodder and for production of energy. Furthermore, if the same farmers who supply slurry and maize own the biogas plant, they have further control of the resources used.

Environmental & Social Aspects

A significant environmental aspect when producing maize is that it has a greater negative impact on the environment than a lot of other energy crops, especially perennial crops, due to the relatively frequent need for herbicides. On the other hand maize has very good energy output/input ratio.

In terms of social aspects the general moral/ethical issue concerning the use of farmland area for energy production purposes instead of producing food is relevant and should be factored into the decision making process.

Quantifiable Indicators

Aspects within the production of maize that can be quantified are the costs of production and acquisition, the price of acquisition, and production costs of competitive crops for biogas production. In addition, future indicators will be the amount of hectares used for energy crop production, the produced amount of maize for biogas production, yield in dry matter, the gas yield/ha, and the costs of pre-treatment.

8.2.3 Transport of feedstock

Slurry transportation from the individual farms to the biogas plants is normally done by tank truck. The tank truck arrives with the degassed matter and is unloaded into the farmer's slurry tank. The truck then collects fresh slurry and transports it to the biogas plant. Typically the individual farmers are responsible for spreading the degassed matter on their fields (Landbrugets Rådgivningscenter, 2000).

Economic, Environmental and Social aspects

According to Landbrugets Rådgivningscenter (2000) the total transportation costs are estimated to be 19 DKK/m^3 slurry. Meanwhile another study estimates a fixed operation cost of 6 DKK/ton and a variable cost of 0.625 DKK/ton/km. Transportation has a substantial impact on the economy for the individual farmers, as well as the total economy of the collective biogas plant. Therefore minimising transport is an important aspect in every biogas project.

Beyond the economic aspect, the amount of transportation is also important with respect to the environmental impacts. These include the emissions of GHGs and particles, as well as the related issue of noise. This is a significant social issue as well due to the fact that people are generally bothered by a lot of heavy road transport.

Quantifiable Indicators

Quantifiable indicators for the transport of feedstock are operation costs and variable costs, and/or the total costs of transportation. Another important indicator could be the emission of CO_2-eq/km/year or CO_2-eq/km per ton or m^3 feedstock.

8.2.4 Biogas production

At the biogas plant, manure and energy crops are gathered in a pre-tank and led into the reactor tank, where biogas is produced in an anaerobic environment via biological breakdown of the organic matter. It is mainly the content of carbon in the organic material that is converted into biogas, while the nutrients are left over in the degassed matter. Biogas typically consists of roughly 65-70% methane (CH_4), 30-35% carbon dioxide (CO_2), and a small amount of water vapour and other gasses, e.g. hydrogen sulphide (H_2S) and hydrogen (H_2). The next step involves the degassed organic material moving into a buffer/stock tank and eventually used as a fertiliser in agriculture. Meanwhile the biogas is generally used for heat and electricity production.

The potential to regulate biogas production and store biogas has not been fully explored, however in comparison to natural gas there is generally less flexibility. The production can be increased when needed by adding organic material, but there is a biological limit to how fast the production can be regulated. Experience shows that a typical biogas plant is able to regulate the production approximately +/- 15% within a day by adjusting the feed pumps, but the limit depends on the organic matter used to “boost” production”. More research and demonstration is needed on this subject. Biogas plants have a gas storage capacity corresponding to between a few hours, to a day's production. Therefore the supply can normally match the demand variations within a day. Due to its volume, increasing biogas storage capacity is considered to be very cost intensive (Danish Energy Agency & Energinet.dk, 2010, PlanEnergi & Århus Universitet, 2009).

Economic, Environmental and Social aspects

Biogas production is a multifunctional technology, which integrates agricultural and environmental benefits as well as benefits related to energy outcome and waste management.

Important economic aspects of biogas production and establishment of biogas plants are the specific investment costs and access to capital, tax write-offs, operational costs[13], operation hours, biogas output, exemption from heat taxes and the electricity subsidy.

Biogas Initiatives

With the Agreement on Green Growth in 2009, it was decided to strengthen the role of the agricultural sector as a supplier of green energy. The goal is that up to 50% of Danish livestock manure can be used for energy in 2020. To achieve this goal, several new initiatives will be implemented. One example is a starter pool of DKK 85 million annually for the establishment of new common biogas plants from 2010-2012. Herein a plant grant worth up to 20% of the investment can be provided, while the remaining funds will be provided by a 60% municipal guaranteed loan and 20% own financing. The initiatives also include a starter pool of DKK 15 million annually for organic biogas plants from 2010-2012, where a plant grant worth up to 20% of the investments can be awarded. In 2012 the status of the development of biogas plants will be assessed.

Another initiative consists of amendments to the Planning Act obliging the municipalities to include localisation of biogas plants in municipal planning. In addition, equalisation of grants for selling biogas to cogeneration plants and the natural gas net is included in the initiatives (Regeringen & Dansk Folkeparti, 2009). Lastly, it should be noted that if a biogas project is of a municipal nature, the municipality is allowed to help a potential investor by providing a loan guaranteed by the municipality.

Due to the ongoing financial crisis, uncertainty in biogas projects, and unsuccessful biogas projects in the past, it can be very difficult for farmers and other biogas entrepreneurs to take out a loan from the banks to initiate a project. As such it will be interesting to see what impact the above initiatives have in this respect.

Environmental Aspects

Biogas production implies several environmental benefits due to a reduction of potential negative effects on the environment.

Degassing of slurry has a beneficial effect on the nitrogen cycle. This is due to the fact that degassed slurry, rather than raw slurry, enables proper dosage and easier intake of nutrients for the plants. Hereby the washing out of nitrogen is potentially reduced and thus is of benefit to the local water environment.

[13] Due to the technical diversity of biogas plants, it is however very difficult to generalise about the operational costs.

Furthermore, degassed slurry is a better fertiliser than raw slurry (Landbrugsinfo, 2002).

Biogas production also enables redistribution of the nutrients of the slurry from cattle and pigs. Typically, slurry from pigs contains too much phosphorus while slurry from cattle does not contain enough phosphorus. A mixing of the two different types of slurry in the production of biogas enables a redistributing of phosphorus. This is of benefit to the farmers and can potentially lead to a reduced need of inorganic fertilizer and thereby the resulting cost savings. In addition, inorganic fertilizer is an energy intensive product and therefore less use of it will reduce the emissions of GHGs. (PlanEnergi & Århus Universitet, 2009).

Lastly, degassing of slurry almost eliminates the smell when the slurry is subsequently spread on the fields (PlanEnergi & Århus Universitet, 2009). This aspect in particular, combined with the other above mentioned environmental benefits, can potentially lead to an increased local acceptance of biogas plants.

Social Aspects

With regard to social aspects, the planning and establishment of biogas plants is often a complex and time-consuming process. This is due to the fact that the realisation of biogas projects requires several approvals by the authorities in compliance with the Planning Act, the Environment Protection Act, the Nature Protection Act, the Heat Supply Act, the Animal By-Product Regulation and the Building Act. Particularly local objections regarding the localisation contribute to delaying the authorities processing. Therefore, a challenge for the municipalities is to shorten the authorities processing by making it more supple (Jørgensen et al, 2005).

To ensure holistic planning and a supple process, the municipalities could in advance handle the district plan proposals and the strategic environmental assessments. The possibility to receive prior approvals could also be considered. Furthermore the planning of biogas plants could be a part of a strategic planning process in line with the recommendations of KL and Danish Energy Agency.

Demands regarding the particulars of a biogas project can be made by authorities via the authorisation process. As such the process can dictate which plant types are developed. Hence, a challenge for the municipalities is to make appropriate demands on the projects.

It is crucial to achieve local acceptance in and via the biogas planning and establishment process. Without local acceptance, it is rarely possible to localise future biogas plants and thus realise potential biogas projects. In fact, biogas projects often fail as a result of local resistance (Jørgensen et al, 2005. Therefore, the lack of local acceptance can be defined as a key barrier. When a biogas project meets local resistance, it is often due to concerns regarding smell and increased traffic within the local area (Jørgensen et al, 2005). Often the concern regarding smell is exaggerated. Due to the fact that municipal councils find it uncomfortable to make unpopular decisions, it is particularly during the public hearings on district plan proposals regarding localisation that the realisation of biogas plants can be delayed or obstructed by objections from local residents.

The negative reputation of biogas plants has largely emerged due to public attention on poorly designed and poorly working biogas plants. Modern biogas plants are designed such that smell can be greatly minimised, if not almost eliminated altogether. In overcoming prejudices, it is important to make an effort to communicate this key fact. For instance, study trips to existing, well-functioning biogas plants can be arranged for interested, local residents. To achieve local acceptance, it is necessary to inform and involve local residents early on in the planning and establishment process. Dialogue and participation is important in all stages of the process and must be emphasised and secured by the municipality.

Finally, an important socio-economic aspect of biogas production (and heat and electricity production) is its potential ability to improve the national security of supply.

Key Barriers

The above section has outlined some key barriers for realisation of biogas plants, namely: localisation difficulties, a long authorisation process, acquisition of finance, and project economy (Jørgensen et al 2005). These barriers can also be identified in the case of Kronjysk Biogas Co-operative illustrated on the following page.

Quantifiable Indicators

Aspects within the production of biogas that can be quantified are the production costs/m^3 biogas or GJ, the amount of biogas produced (TJ), the duration from pre-project to having an operational plant, protests can be quantified through the number of objections and hearing statements, and access to financing can be quantified in DKK or €.

Kronjysk Biogas Co-operative

In 2003 a group of 30-40 keen farmers in the greater Randers area initiated the Kronjysk Biogas Co-operative with the intention of establishing a biogas plant. After approximately 7 years of work, the project has now ceased, but the farmers have gained a lot of experience from the process.

Why establish a biogas plant?

According to farmer and chairman of the co-operative, Anders Christian Wegger, the farmers' incentive was the possibility to increase their livestock production by treating their slurry at the biogas plant.

The co-operative's experiences

One of the main experiences from the co-operative's point of view is the importance of openness and inclusion of the public. The co-operative held public meetings and organised a trip to a biogas plant, which according to chairman was fruitful, although the attendance was low.

Furthermore the co-operative learned the importance of:

- Distance between the potential biogas plant and neighbours is a must due to complaints and fear of obnoxious odours, noise, etc.
- A nearby heat market for purchase of the heat
- Suitable traffic conditions to minimise the inconvenience for the local community
- Cooperation with the local CHP plant
- The municipality designating an area suitable for the plant and implementing it in the district plan
- The municipality providing a loan and collateral

More information about Kronjysk Biogas Co-operative can be found at, http://www.purhusnet.dk/Debatter/biogas/biogas.html

Source: Anders Christian Wegger, Workshop, 6/31-10, Ebeltoft.

8.2.5 Heat and Electricity production

Biogas for combined heat and power production is generally used in a gas engine/generator and a boiler producing heat and power (CHP plant).

Prior to using the biogas at the CHP plant, it needs to be cleansed from hydrogen sulphide. Thereafter it is transported to a local CHP plant or distributed in pipes to an external plant (Danish Energy Agency & Energinet.dk, 2010).

The electricity efficiency of such a CHP plant is approximately 35-44% and the total efficiency is around 80-85% (Danish Energy Agency & Energinet.dk, 2010). However, a significant amount of the heat is often used for process heat/own-consumption at the biogas plant, for example in heating of the biomass. The electricity is sold and fed into the electricity grid.

Economic, Environmental and Social aspects

Economic Aspects

Naturally, the availability of a heat market in the form of a district heating system and sufficient heat demand is of importance. The availability of a heat market is currently an existing barrier nationally. A possible enabler is expansion of the district heating and natural gas grids, thereby likely improving potentials for income from heat sale.

Important economic aspects of heat and electricity production also comprise the electricity subsidy, the exemption from CO_2 tax, and the exemption from fuel taxes for heat production.

With the Energy Policy Agreement (21st February of 2008) for the years 2008-2011 it was decided that new as well as existing biogas plants will be subject to a fixed electricity price of 745 DKK per MWh, or a fixed-price premium of 405 DKK per MWh if biogas is used along with natural gas. It was also decided that the fixed electricity price and price premium are to be adjusted by 60% of the increases in the net price index (Regeringen et al, 2008).

The value of the biogas replacing natural gas in a combined heat and power plant corresponds to the total value of the fixed-price premium of 405 DKK per MWh_{el} (approx 44 DKK/GJ_{input}), the exemption from CO_2 tax (approx 9 DKK/GJ), the exemption from heat tax (approx 19 DKK/GJ), and the replaced natural gas (approx 70 DKK/GJ). Thus, the total value of biogas replacing natural gas corresponds to 141 DKK/GJ (Tafdrup, 2009).

The heat price is settled between the biogas plant and the local CHP/utility company based on the production costs regulated by the Heat Supply Act's price conditions. Furthermore, the Heat Supply Act regulates which fuels can be used where.

In accordance with the Heat Supply Act (chapter 4), the disposal of heat is regulated as non-profit and therefore the biogas company's possible earnings from sale of heat are limited (LBK nr. 347 af 17/05/2005). The purpose of this regulation is to protect the consumers against the natural monopoly of the utility companies. However it is also reducing the biogas company's opportunity to profit, and thereby potentially decreasing the incentive for investors to establish of biogas plants. Modifications of the regulation have been discussed and could possibly enable an increased incentive.

The Danish District Heating Association has been working on a standard contract for sale of heat produced from biogas which is aimed at minimising and avoiding some of the frequently occurring problematic issues. This work has put on hold as it awaits the current legislative work on biogas subsidies (Danish District Heating Association, 2010). Standard contracts could likely lead to fewer issues in the contractual agreements between the biogas company and the CHP plant.

Environmental and Social Aspects

A significant environmental aspect of heat and electricity production based on biogas is the replacing of natural gas and thus contributing to a more CO_2 neutral energy supply.

The substitution of natural gas with biogas can also be regarded as a social aspect due to local interest in achieving political energy and climate targets. In addition, this substitution improves security of supply and reduces dependence on what is likely to be growing amounts of foreign supplied natural gas.

Quantifiable Indicators

Quantifiable indicators for the heat and electricity production are the input cost of biogas, the amount of electricity and heat produced e.g. in MWh and TJ, the efficiency of the CHP plant, the amount of GHGs displaced (tonnes CO_2eq or CO_2eq/GJ), subsidies and tax exemptions, and the available heat market assessed in amounts of energy (MWh).

8.3 Summary of main Existing or Potential Barriers, Possible Enablers and Economic Benefits

Feedstock

A possible enabler and economic benefit in the first part of the supply chain is optimisation of the slurry for biogas production, thereby increasing the gas yield in the biogas production per ton of slurry. This can in some cases be done in the day-to-day running of the farm by reducing water spillage.

Locally it can be a barrier if livestock farms are too small or too scattered to be feasibly included in a co-operative biogas production system.

Energy crop production

In regard to the production of energy crops, including maize, in the second part of the supply chain, the main existing barrier is the production costs and competition with other land use. Furthermore the experience with energy crops for biogas production is quite limited in Denmark. A possible economic benefit is that maize may be used by the farmers to diversify their business from only food and fodder, towards energy, with possibilities of long term price agreements or even common ownership.

Transport

In the third part of the supply chain, transportation of feedstock, the main exiting barrier is the fixed and variable costs of transport. Transportation has a substantial impact on the economy for the individual farmers as well as the total economy of the co-operative biogas plant. A possible enabler is the reduction of transport distances travelled and its costs. Reducing the distance travelled can be done via careful geographic planning of biogas plant locations, or in some cases by decentralising the biogas production into several plants to be situated directly on the largest farms. In the second case the gas will probably have to be transported over a longer distance to the CHP plant instead of transporting the slurry to the biogas plant. Another enabler might be to separate the slurry and only transport the more solid part. However, the cost of separation might be higher than the saved cost of transport. Another incentive for separation is for the farmer to be able to increase their livestock production under current environmental legislation.

Production of biogas

With regard to the actual establishment of biogas plants, the main barriers consist of financing (access to venture capital), a long authorisation process, the project economy, and access to a local heat market. Currently, it can be difficult to take out a loan from the banks due to the ongoing financial crisis, uncertainty in biogas projects and unsuccessful biogas projects in the past. A possible enabler could be loans guaranteed by the municipalities, perhaps with partial re-guarantees from the State.

For the time being, it is a complex and time-consuming process to get a construction permit for a biogas plant. Particularly the localisation of biogas plants can be a barrier due to local resistance. It is important that biogas plants are able to acquire constructions permits in land-zones close to the slurry production and a distance from residential neighbours.

A possible enabler regarding constructions permits could be a development of a more smooth planning process. In achieving local acceptance it is important to have dialogue and participation. In addition, the establishment of Biogassekretariatet in February 2010 comprises an enabler regarding localisation and local acceptance.

The project economy comprises a main barrier due to high investment costs (service of debt) and operational and transportation related costs. A possible enabler in this respect could be reduced transport costs.

Sale of biogas

Currently, lack of access to a local heat market with the possibility of long-term agreement for heat sale at reasonable prices can be a major barrier. A possible enabler could be more flexible biogas production thus allowing it to closer resemble heat demand patterns. Another enabler would be conditions that made it more attractive for the local heat plants to produce their heat using biogas. Stability in the incentive framework (taxes and subsidies) is important here. Another possibility is injection of biogas into the natural gas network either by upgrading the biogas (costly) or by redefining the gas specifications in local gas-networks to biogas quality. The preparation of a standard contract for sale of heat produced via biogas should also provide more clarity and stability for biogas plant owners.

9 Straw for use in CHP

The most prevalent contribution from agriculture to the Danish energy production today is straw. In this chapter the supply chain for local production of biomass straw is analysed.

9.1 Introduction

Straw is originally a residue from the production of commercial crops, primarily cereal grain. However, because of its contribution to energy production, straw is considered a high value product today and can no longer be seen as merely a residue. To some extent it can be argued that the costs of cultivation and harvest are shared with the grain production, which gives straw the advantage of lower primary production costs compared to other resources such as energy crops. The straw itself is only 'paying' for the marginal costs of collecting, transport and storage.

Straw from winter wheat and spring barley accounts for roughly 75% of the annual straw harvest (Landbrugsinfo, 2009). The straw quality and amount of straw that can be gathered in strongly depends on the weather conditions during growing and harvest seasons.

9.2 Current use of straw and potential for increased use and production

According to Danmarks Statistik and Landbrugsinfo.dk (2009), the total production of straw in Denmark in the years 2004-2008 amounted to 5.4 million tonnes a year. 33% of the straw was used for animal food and bedding and 26% were burned for energy purposes. That leaves a surplus on roughly 41% of the straw not being collected. (Landbrugsinfo, 2009). The figure below illustrates the dispersion of straw being used for different purposes over the last decade.

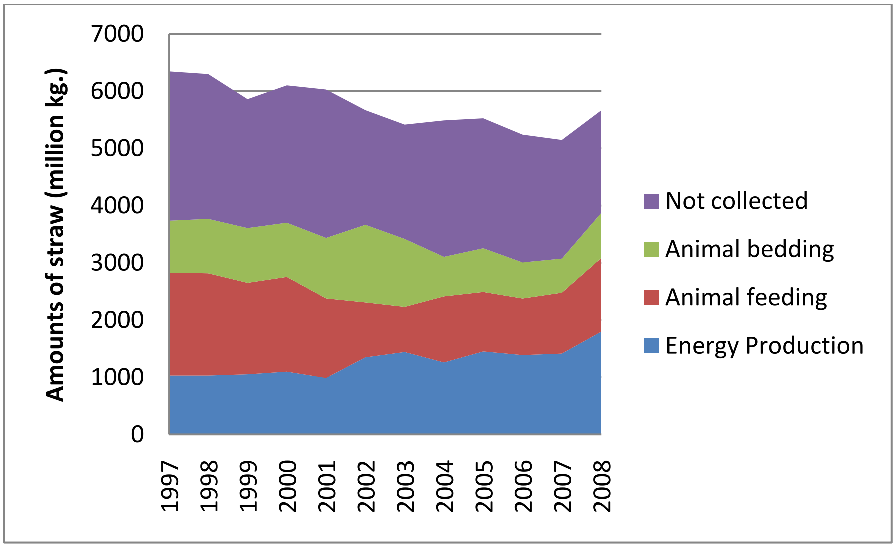


Figure 27: Usage of straw for different purposes 1997-2008 (Danmarks Statistik, 2010).

Looking solely at Region Midtjylland in the year 2008, the picture is much similar except for a higher amount of the straw being collected and used for animal feeding and bedding. This could indicate a higher concentration of livestock farms in this region compared to the national average. Straw used for animal purposes has slightly decreased over the last decade and is expected to either decrease, or stay at the level it is today (Landbrugsinfo, 2009).

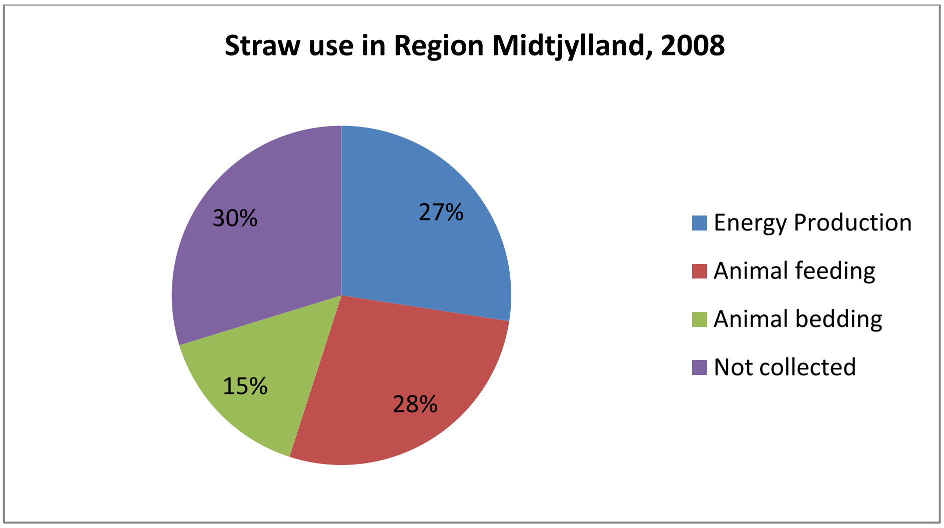


Figure 28: Use of straw for different purposes in Region Midtjylland in 2008 (Danmarks Statistik, 2010).

How big a share of the uncollected straw that could be available for energy production depends on several conditions. First of all it is important to note that not all straw can be gathered in. Approximately 10% of the straw is technically not possible to gather in (The Centre for Biomass technology, 1998).

The table below shows the current production and use of straw for each of the three municipalities, based on recent figures from Conterra.

Tonnes/year	Total straw production	Energy production	Animal feeding and bedding	Not collected/ unavailable
Norddjurs	114,611	31,961	25,477	57,173
Syddjurs	140,583	41,399	26,288	72,896
Randers	86,729	22,329	18,670	45,730
Total				**175,799**
-10%	34,192			141,607

Table 20: Production and use of straw for different purposes in the three municipalities (Conterra, 2010).

The figures show that roughly half of the straw produced in the three municipalities is currently used for either energy production or for animal purposes. The remaining 50% of the straw produced in the last column is ‘not collected’ or ‘not available’. Looking at the share of ‘not collected’ straw from the entire region Midtjylland this only amounts to 30%, which leaves two possible explanations for this rather significant difference:

- There is a possibility that Randers, Norddjurs and Syddjurs utilise a smaller share of their straw production than the remaining municipalities in the region and thereby differs from the average.
- Alternatively, it is possible that the figures from Conterra and Denmark's statistic are simply not comparable due to different years of measurements, different methods, etc.

As can be seen from the figure, there appears to be a surplus of available straw totalling 175,799 tonnes/year for the three municipalities. Subtracting 10% from the total straw production as uncollected straw from the municipalities, a surplus of 141.607 tonnes is available. With a calorific value of 14.5 GJ/tonne this equals 2.05 PJ.

Plough back of straw

However, plough back of straw can influence the amount of straw for energy purposes. Plough back of straw can affect the fertility of the soil positively. Furthermore, the carbon content of the soil is included in the Danish national CO_2 balance in relation to Kyoto Protocol article 3.4.

In the report 'Landbrug og Klima, Ministry of Food, agriculture & Fisheries, 2008' the effect of removing straw instead of ploughing it back is discussed. The long-term effect (20 years) is evaluated to be 210 kg CO_2 per tonne of straw removed. The CO_2 effect of replacing coal with straw is approx. 1350 kg, and the effect of replacing natural gas is approx. 850 kg. Thus the negative effect from reducing the carbon content in the top soil is 15% - 25% of the positive effect from replacing fossil fuels.

In Denmark the sectors outside the EU-ETS, including Agriculture, are meeting requirements of a 20% CO_2 reduction. Gathering in large amounts of straw might affect the agricultures CO_2 balance negatively while benefitting the overall national balance far more.

With this reservation in mind, there is a potential for reaching a larger share of straw used for energy production within the three municipalities. It is however, the market possibilities in terms of marketing conditions and sales prices that determine the farmers' motivation to increase the collection of straw or to optimise their straw production.

9.3 Supply chain for energy production from straw

The matrix on the following page shows the primary steps of the supply chain for straw. Even though straw cannot be seen as merely a residue from grain production, it will be treated as such in the supply chain analysis. As such, the planting and fertilising processes are only covered where they have an effect on the yield of straw.

Case 2a: SSCM analysis of Straw for CHP and local heating

	Economic Aspects	Environmental Aspects	Social Aspects	Main Existing or Potential Barriers	Possible Enablers	Possible Economic Benefits
Production and collection of straw	Yield per ha. Unused potential	Plough back GHG lifecycle Nutrient balance	Displacement of food production Competitive use for animal purposes	Market possibilities (no heat market)	Long-term contracts Expand market	Minimisation of supply risk Cost certainty
Transport to power plant	Transport costs	Fossil fuel use GHG emissions	Daily heavy truck transport through towns and landscape	Daily heavy truck transport Share of total costs	Use of local resources Vertical expansion Compress straw	Lower transport costs
Handling and storage	Limited storage space Handling costs	-	-	Limited storages	Compress bales	Reduced storage costs
Heat and electricity production	Straw prices Competition with wood Corrosion and slag	Fossil fuel displacement CO2 reduction Ash	-	Corrosion and slag problems	Fuel diversification Local dialog	Security of Supply Lower Fuel Costs
Heat and electricity deployment	Lack of heat markets	-	-	No market for heat Competition with individual heating Fuel choice restriction	Expanding existing district heating areas Displace coal Find new markets	Cheaper heat prices

9.3.1 Primary Material production

The yield of straw depends on the species of grain. Some grain species create more straw than others. Thus it should be possible for farmers to enhance their straw production by concentrating on grain species with a high yield of straw. For example barley and triticale create more straw per 100 kg grain than traditional species such as spring barley and winter wheat (Landbrugsinfo, 2009).

Another factor with influence on the straw yield is the use of fertiliser. Recent experiments have proved that the amount of straw produced from winter wheat is reduced with increased use of fertiliser. The results of the experiment are however considered uncertain due to local cultivation differences (Landbrugsinfo, 2009).

When used for heat and CHP production, straw is delivered in bales. Big bales are the only types of bales that are accepted by the district heating and CHP plants. The big bales have an average weight of 525 kg.

9.3.2 Transport to power plant

Looking at different studies that estimate the transport costs for straw, they come out with quite similar results. According to the Danish Energy Agency, Dong Energy (Boldt 2009) and Fødevareøkonomisk Institut (Graversen & Gylling, 2002), the price for transport of straw is roughly 6 DKK/GJ (for the first 10 km on truck) corresponding to 87 DKK/ton.[14]

According to Danish energy Agency the price after the first 10 km increases with 1 øre/10 km/kg corresponding to 0.7 DKK/GJ/10 km. With a straw price of 37.8 DKK/GJ (DEA), the transport costs are roughly 16.5% of the total delivery price.

The average farm to plant distance is roughly 50 km in Eastern Denmark and 30 km in Western Denmark. The distance is determined by the amount of straw required from the plant. For large CHP plants that use large amounts of straw the distance can be up to 75 km. The transport of straw to smaller heat plants is more often being carried out by the farmer himself than it is the case with larger CHP plants (Boldt, 2009).

The heavy truck transport of straw from field to power plant leads to CO_2 emissions. A rule of thumb is that the emission is roughly 1 kilo CO_2 per kilometre run (DONG Energy & Vattenfall, 2007 and The Centre for Biomass Technology, 1998).

[14] Given a calorific value of 14.5 GJ/ton (Energistatistik 2008)

9.3.3 Handling and storage

Straw is more difficult to handle and store than most other types of biomass as it has a high volume relative to the energy content. Fødevareøkonomisk Institut has estimated the costs for storage of straw to be 71 DKK/tonne - given a weight of 525 kg/bale and a storage capacity of 350 ton (Graversen & Gylling, 2002).

9.3.4 Heat and Electricity production

Straw is a complex fuel to use in CHP plants because the high burning temperature needed to produce electricity leads to various troubles with the ash, corrosion of the boiler, formation of slag and fusion of straw ash and bedding material. Co-firing with coal can solve some of these problems, which is why a solely straw-fired CHP plant is not common. Another opportunity is to establish a separate steam boiler in connection with the straw-fired CHP plant, thus the CHP plant can lower the temperature and thereby avoid some of these problems. Straw-fired heat plants are however quite common as heat alone can be produced at lower temperatures and thus reduce the abovementioned problems.

The production costs are highly dependent on the price of the raw material. Using the price forecasts from the Danish Energy Agency (2010), the market price of straw was estimated to 37.8 DKK/GJ by delivery to a decentralised plant in 2010. The price is expected to increase to 43.3 DKK/GJ in 2015 and 44.1 DKK/GJ in 2020. However, looking at the statistics for actual sales prices for delivered straw for the district heating companies in the 1st quarter of 2009, the average price is 33.06 DKK/GJ.

9.3.5 Heat and electricity discharge/deployment

Heat and CHP production from straw can displace coal or natural gas fired production and thereby lead to a reduction in CO_2 emissions.

As illustrated in chapter 3, a large share of the district heat plants in the three municipalities is already biomass-fired. As such, there exists only limited potential to displace coal or natural gas in these specific municipalities. Coal at the Grenå Kraftvarmeværk and natural gas in the city of Randers could be displaced by biomass.

However, the restrictions on fuel choice for new plants as described in chapter 4 make it somewhat difficult to replace fossil fuel production with biomass. Following the restrictions of this Act, the municipalities can only approve a biomass fired CHP plant to displace the production of existing natural gas fired plants. As small decentralized plants are having difficulties achieving good economy in CHP production this is not likely to take place. In addition to this, straw-fired plants are seldom solely straw-fired due to slag and corrosion problems with high temperature combustion, as described above.

9.4 Main existing barriers for increased use of straw for CHP production

There is a large potential for collecting more straw from the grain fields of the three municipalities. However, the greatest barrier regarding increased utilisation of straw seems to be a limited sales market within the municipalities. Only limited potential exists to displace fossil fuel production in existing CHP plants or to expand the district heating grid.

Other barriers are problems with corrosion in relation to decentralised CHP production and handling issues. Other biomass resources like wood chips might be more expensive, but are easier to handle, store and burn than straw.

Key targets and enablers for straw for local CHP or heat production

If the target is to use more straw in the existing energy production of the three municipalities, the only obvious enablers are an extension of the existing district heating grid where possible, or to displace coal in centralised CHP plants. As the central CHP plants are owned by private investors, cooperation and dialogue is the only enabler for the municipalities to affect this process.

If the target is to produce more straw not only for the three municipalities but also for export to other municipalities, the resource availability is extensive. Roughly 50% of the straw that is currently produced is not collected. This potential can be further increased by shifting to grains with a higher yield of straw.

10 Energy crops for CHP production (willow)

This chapter will introduce an alternative to the traditional contribution from agriculture to the energy production that is based on straw. The growing of energy crops could be a new business area for the agricultural sector to contribute and interact with the energy sector in order to reach climate targets.

10.1 Introduction

Several species of energy crops could be considered for this purpose. Willow, corn and different types of grasses are the species of focus in the current debate. Recent studies recommended aiming at a mix of different types of crops instead of concentrating on one single crop. However this analysis will focus solely on willow for energy production as this is so far the best known energy crop as regards research and experiences.

10.2 Current use of energy crops and potential for increased use and production

Little experience has been gathered in Denmark with the production of energy crops for CHP production. Most experiments have been related to willow plantations, but only few in the three municipalities.

Previous co-operation attempt

The local wood-processing industry Novopan Træindustri in the Municipality of Syddjurs produces particle board from wood chips and other waste wood from forestry and sawmills. In 2003 Novopan tried to establish a co-operation with the local farmers involving the production of willow chips. This project failed as a result of lack of interest among the farmers, a change in the terms for agricultural subsidies, and disagreements between Novopan and the farmers related to the price of the willow chips. At the time, Novopan calculated that they would need at least a 500 ha. of willow plantation to cover 5% of their wood chip consumption. (Novopan, 2010).

Potential for energy crops on farmland

With respect to the potential for growing energy crops on farmland, the overriding issue is the question of land use. It is important to recognise that the question of land use for energy production is not a national problem, as the consequences are global. As has been explained in chapter 4, the demand for biomass on a European and global level is increasing rapidly as a result of political energy and climate targets. The energy sector, the transport sector and the industrial sector are expected to use an increasingly higher share of biomass over the coming decades. Replacing grain production with energy crops can therefore in the long run mean displacement of food production and valuable nature reserves in other countries.

As such, it is extremely difficult to estimate the exact potential for the production of willow chips in the three municipalities. The potential depends on political and ethical considerations related to land use, supply and demand for similar biomass, and the evolution of costs related to willow chip production.

Looking at the physical potential alone it would be possible to replace a very high share of the grain production with willow trees, perhaps limited solely by the amount of grain and straw that are required for animal purposes. The current grain production area of the three municipalities amounts to 82,842 ha. With an assumed dry matter of willow chips 12 tonnes per hectare (Kristensen & Jørgensen, 2008), this equates to 9,874,104 tonnes of dry matter.

Different actors have estimated the possible potential for production of energy crops. The Danish wood trading company, HedeDanmark, and the Danish private forestry association, Skovdyrkerne, in 2009 estimated the future potential for Danish production of wood chips, willow chips and gardening waste. For willow chips they estimate a future of 13-17 PJ with the establishment of 6,000 hectares of willow plantation. (Thygesen & Hilbert, 2009)

Kristensen & Jørgensen (2009) have made scenarios for Region Midtjylland with a 15% replacement of the grain production fields with energy crops. The 15% is chosen because Denmark exports between 10 and 20% of the national grain production every year. Therefore, according to Kristensen & Jørgensen, the 15% reduction of the grain production will not compromise the national production of food or animal feed. This argument is however in conflict with the recommendation of this report to look at the land use and food production issues in a global perspective.

10.3 Supply chain for production of willow chips

The matrix on the following page shows the primary steps in the supply chain for energy produced from willow chips and gives an overview of the most important barriers and enablers related to each step in the chain.

Willow as an energy fuel is economically vulnerable relative to residue biomasses such as straw and forest wood chips because the entire production costs from planting and cultivation to harvest and transport must be covered by the sale of the willow wood chips, which are considered to be a ‘low value product’ (The Centre for Biomass Technology, 2002).

On farmland willow trees are grown in short rotations. They are harvested every 3-4 years when the willow shoots are about 6 metres high. The willows can grow for at least 20-25 years without any reductions in the plant yield before new trees have to be planted. (The Centre for Biomass Technology, 2002)

The calorific value of willow chips can vary depending on various drying processes. Willow chips have a rather high moisture content of roughly 50-55% (The centre for Biomass Technology, 2002 and Thygesen & Hilbert, 2009). Therefore we have assumed a calorific value of 8 GJ/tonne by delivery in this report. The calorific value per tonnes dry matter (0 % water) is 18 GJ/tonne. The Danish Energy Agency uses a calorific value for willow chips of 14.4

Case 2b: SSCM analysis of Willow for CHP

	Economic Aspects	Environmental Aspects	Social Aspects	Main Existing or Potential Barriers	Possible Enablers	Possible Economic Benefits
Field preparation and planting	Labour costs Farm equipment Input costs Subsidy Large investment costs	Global displacement of nature resources Land use Nitrogen absorbtion Heavy metals from ash	Displacement of food production.. Local resistance	High Investment Costs Competing demand Competition with food production Public resistance	Long-term contracts Correlation with environmental policy Guarantees for sale Cooperation with CHP co.	Minimisation of supply risk Cost certainty
Weed control and fertilise	Labour costs Fertilizer costs	Loss of biodiversity Nutritive balance	-	Loss of biodiversity and nutritive balance	Drying in forest Return ash Nursing trees	-
Harvest, chipping and transport	Harvest and chipping machinery Drying Transport costs	Loss of biodiversity Nutritive balance Fossil fuel use	Local resistance	High investment cost in machinery High moisture content	Cost sharing farmer/ plant Use of local resources?	Lower risk for farmer
Handling and Storage	Limited storage possibilities	Improved nutrient balance via forest storage	-	Long time storage not possible	Use of local resources? Guaranteed sale price	Lower risk for farmers
Heat and electricity production	Fuel input prices & availability CO2 prices	Displacement of fossil fuels Ash, etc CO2 reductions	-	Fuel input prices High moisture content	Long-term contracts	-
Heat and electricity deployment	Lack of heat markets	-	-	No market for sale Restricted fuel choice Competition with individual heating	Strategic planning Free fuel choice Displace coal	Lower heat prices

GJ/tonne, but doesn't explain the assumptions behind this figure[15] (Danish Energy Agency, 2010).

10.3.1 Field preparation and planting

Economic aspects

The costs of investment in the establishment of a willow plantation depend on variable conditions such as: soil type, willow specie, number of shoots per hectare, field size, etc. The main part of the investment is the planting and harvesting machinery. The lifetime of a willow plantation is 20-22 years. Some studies estimate the costs of establishing a willow plantation to be in the region of 7,500 -8,000 DKK/hectare for areas larger than 2 hectares. For areas below 2 hectares an extra fare of 500 DKK/ can be added. (Vestjysk Landboforening, 2009 and Dansk Bioenergi, 2003). Using the calculation tool on www.landbrugsinfo.dk the costs are estimated to be lower; 5500 DKK/ha.

To ensure a rational utilisation of the machines and to keep the costs of planting, maintenance and harvesting at an acceptable level, the area of the plantation should be at least 5-10 hectares (Dansk Bioenergi, 2003). This is consistent with what John Jessen from Assens Fjernvarme is telling in relation to their cooperation with local farmers on willow production. Assens Fjernvarme does not enter an agreement with farmers with a production on less than 5-10 hectares (John Jessen, 14/6 2010). The average field sizes in the three municipalities are more than 50 hectares (in Region Midtjylland the average field size is 54 hectares). However, small or narrow hedges and passages will not be suitable for willow plantation.

The contribution margin per hectare varies depending on the assumptions behind the calculations. In the calculation tool on www.landbrugsinfo.dk, a contribution margin of 1596 DKK/ha is reached by assuming a lifetime of 22 years, harvest every 3 years, a fixed sales price of 42 DK/GJ and a yield of 12 tonnes dry matter a year. The governments 'Grøn Vækst' strategy proposes an investment subsidy of 3200 DKK/ha. for planting willow in the years 2010 – 2012, which raises the contribution margin to 4796 DKK/ha.

Yield

The yield of willow depends on the type of soil it is planted in; however there is currently not much material on the yield from growing willow on Danish soil. Generally speaking the yield is higher when planted in soils with a good water supply, such as clay soil. Different studies estimate the expected yield of willow production to be roughly 150 GJ/ha[16] given a calorific value of 16 GJ/tonne dry matter (Jørgensen et al., 2008). However, the amount of dry matter per hectare when calculated is crucial for the results. Most studies uses a dry matter of 10-12 tonnes/ha on clay soil. A yield of minimum 8 tonnes of dry matter per hec-

[15] It can be inferred that this 14.4 GJ/tonne figure assumes a certain amount of drying.

[16] Given a calorific value of 16 GJ/t dry matter. According to an article in Dansk Bioenergi the yield is 145-170 GJ/ha (Dansk Bioenergi, 2003).

tare will be realistic on most types of soil (www.landbrugsinfo.dk). With a calorific value of 18 GJ/t 100% dry willow chips, a yield of 144 GJ/ha is reached.

Environmental aspects

Willow plantation can be established for both the purpose of energy production and environmental protection. As the willow trees absorb nitrogen from the soil while growing they help solve problems with nitrogen erosion from the agriculture to the water environment.

On the other hand, practises with spreading the ash from the burned willow chips on the soil to restore the nutrient balance can create problems with high concentrations of heavy metals that are accumulated in the ash. In addition, local and national nature and biodiversity can be threatened by planting energy crops on set-aside fields.

Social aspects

Another environmental and social aspect of willow plantations is their visual effect on the landscape. Willow trees are tall and can dominate the view of the landscape for a very long period (as willow plantations have a lifetime of roughly 20-25 years). To avoid local resistance as it has been seen in connection to the establishment of large wind turbines it is therefore crucial to ensure a considered physical planning process prior to the establishment of willow plantations (Fødevareministeriet, 2008b).

Lastly, there are serious social and ethical considerations related to replacing a large share of the grain production with energy crops. In a global context the increased demand for land for biomass production can lead to displacement of nature preservatives such as rain forest areas, particularly in developing countries.

10.3.2 Weed control and fertilising

Weed control is a vital part of the initial phase of the willow growing as the willow shoots are very vulnerable to weed attacks in the establishing phase. Later, when the trees are starting to grow they have a strong resistance towards weeds. The estimated costs for weed control and fertilising is roughly a little more than 1000 DKK/ha. (www.landbrugsinfo.dk).

The use of pesticides in willow plantations are considerably lower than for the growing of traditional crops like grain. The index for pesticide use ('behandlingsindex') is regulated in "Pesticidplan 2004-2009" where the aim is to reduce the average use of pesticides from agriculture from and index value of 2.3 in 2006 to a value of 1.7 in 2009 (Miljøministeriet and Fødevareministeriet, 2003). Willow has a pesticide index of 0.3 - 0.7 and is thereby much lower than the aim for the average pesticide use in the agriculture. In 2006, winter wheat had a pesticide index of 2.5, while spring barley was 1.84. (Fødevareministeriet, 2008a)

10.3.3 Harvest and transport

Harvesting

As described above, willow is harvested every 3-4 years when the shoots are about 6 metres high. The harvesting takes place in the winter and the following spring new shoots will grow from the roots and be ready to harvest after another 3-4 years. (The Centre for Biomass Technology, 2002)

Two different types of methods are used for harvesting. In the first, the wood is directly chipped during the harvesting process in the field and is delivered to the plant with a water content of 45-55%. In the alternative method the whole trunks of willow are collected and are not chipped until the water content has dropped to roughly 25-35%.

In a natural forest balance, the nutrients that a tree absorbs through its lifetime are released to the soil again by defoliation and when the tree dies. By harvesting the willow and removing it, the nutrients and other organic material that the trees have absorbed are also removed from the soil and over time the nutrient balance will be spoiled. However, by cutting down the trees and leaving them to dry in the forest at the place of felling, certain defoliation will take place and thus partly compensate for the nutrient loss of the soil. Another method of re-establishing the nutrient and organic balance is to return the ash from the burning of the wood to the forest. However, this practice involves the risk of spreading too high concentrations of heavy metals to the soil. (The Centre for Biomass Technology, 2002)

Transport

The transport costs for willow chips are estimated by Graversen & Gylling (2002) to be 93 DKK/tonne given a density of 147 kg/m^3 and a truck load of 11.8 tonnes/load.

The CO_2 emissions from truck transport are highly dependent on the local conditions (roads), the type of truck and empty-truck-driving. Assuming a truck with a load of 20 tonnes and a fuel economy of 3 km/l, the CO_2 emissions of the transport can be estimated to be 87 g/tonne/km. Given a calorific value of 9.5 GJ/t, the CO_2 emission can also be described as 9.2 g/GJ for the transport of 1 km.

10.3.4 Handling and storage

Willow is lighter than other wood products because it contains less dry matter. This affects the storage possibilities due to larger volumes to be handled in storage compared to alternative fuels. Another aspect is that willow is difficult to store over long periods of time. Willow shoots contain a large share of bark and nutrients and when stored in piles a fast temperature development takes place leading to a considerable loss of dry matter. This problem can be minimised either by using larger chips, or by storing them under an airtight sealing.

10.3.5 Heat and electricity production

Heat and electricity production costs are highly dependent on the price of the raw material. In the 1st quarter of 2009 the average sales price for forest wood chips delivered to the district heating companies were 44.5 DKK/GJ. As willow chips and wood chips have comparable calorific values[17] it is fair to assume that the sales prices are similar. (The centre for Biomass Technology, 2002)

The high moisture content (around 50 %) of willow chips makes it less attractive for the majority of existing the CHP plants to use because the existing plants are built to combust fuels with a higher dry matter, such as wood pellets. (The Centre for Biomass Technology, 2002).

10.3.6 Heat and electricity deployment

Heat and CHP production from straw can displace coal or natural gas fired production and thereby lead to a reduction in CO_2 emissions. Under the current regulations for fuel shift as described in chapter 4, it is however only allowed to replace a taxed fuel such as coal or natural gas with a non-taxed fuel such as straw by establishing a CHP plant. Since small decentralised biomass-fired plants have difficulties making good economy in CHP production the only real option is displacement of coal in centralised CHP plants such as Grenå Kraftvarmeværk.

10.4 Main existing barriers for increased use of willow chips for CHP production

As was the case with straw for energy production, one of the main barriers for an increased use of willow chips is uncertainty of the sales price. With little possibility of displacement of fossil fuels within the three municipalities, the production of willow chips might have to be designed for export to other municipalities.

As mentioned previously, the establishment of willow plantations is expensive due to the high investment costs related to planting and harvesting equipment. Investment subsidies are available, which leaves the harvesting machinery to be the highest investment for the farmers.

Environmental issues such as loss of biodiversity and risks of large concentrations of heavy metals by the spreading of ash have yet to be solved.

The social and ethical concerns also have to be mentioned in relation to the growing of energy crops. Locally and nationally, nature and biodiversity can be threatened by planting energy crops on set-aside fields. In a global context the increased demand for land for biomass production can lead to displacement of

[17] Willow chips contain more water than forest chips and thus have a lower calorific value. In this report it is assumed that willow chips have a calorific value of 8 GJ/t and forest chips 9.5 GJ/t. However, the calorific value depends on the water content, so *dried* willow chips and dried forest chips likely have similar calorific values.

nature preservatives such as rain forest areas, particularly in developing countries.

Key targets and enablers for willow for local CHP or heat production

A possible enabler to overcome the investment costs for the farmers is to establish cooperation between the farmers and the energy producers. The energy producers can minimise the risk for the farmers by sharing the machinery costs and/or providing a sales guarantee for the willow produced, as has been demonstrated in the Assens-case described below.

The Assens Case

Assens Fjernvarme is concerned about the rise in prices of biomass and the security of supply of wood chips for their CHP production. They have therefore entered into a co-operation with local farmers for the production of willow chips. Currently they have entered contracts for 300 hectares but the aim is to reach 500 hectares.

Assens Fjernvarme has entered 21 year contracts with the farmers. Assens Fjernvarme pays for the planting and harvesting and the farmers are only responsible for the daily maintenance of the plantations. The machinery for planting and harvesting is rented.

The farmers are guaranteed sale of their product and the contracts include fixed sales prices. The farmer receives 4165 DKK/ha/year by delivering 12 tonnes of dry matter per ha/year. This corresponds to 21 DKK/GJ. If the dry matter is less than 12 tonnes/ha the payment gets proportionally lower.

John Jessen from Assens Fjernvarme estimates that the price of the willow chips will be around 40 DKK/GJ. Today he pays 44-45 DKK/GJ for forest wood chips. However, the willow trees cannot be harvested within the first three years, so the exact comparison price is still uncertain.

(John Jessen, 14/6 2010)

A possible way for the municipalities to gain more experience in relation to the economic, environmental and social barriers associated with willow production could be to establish a pilot project in cooperation with farmers and energy producers similar to the Assens case above.

11 Forest wood chips for CHP production

Wood chips from forestry differ from willow chips as they are a residue product and not a crop grown solely for energy purposes. This chapter describes the supply chain for wood chips from local Danish forests.

11.1 Introduction

As mentioned above, wood chips are a residue product from the forest industry. This means that the primary product (typically sawmill timber) pays for the tree growth and forest maintenance. Hence, the sale of wood chips need only cover the costs of chipping, storage and transport.

11.2 Current use of wood chips & potential for increased use and production

It is estimated that 85-90% of the Danish wood chip consumption is covered by national resources and the last 10-15% is imported (Thygesen & Hilbert, 2009, HedeDanmark, 2009). Forest wood chips produced in Denmark are typically made from waste wood from the forest industry (thinning, etc).

Forest Committee

In June of 2010 the Danish government commissioned a national Forest Committee ('Skovpolitisk Udvalg') to map and analyse the possibilities of achieving different targets for Danish forestry. The committee has three main targets:

- Maintain and develop possibilities for public access to the forest
- Maintain and develop the forest's potential to deliver wood for energy production to reach the climate and energy targets
- Promote sustainable forestry on a global, European, Nordic and national level.

The committee is to deliver their recommendations to the Minister of the Environment at the beginning of January, 2011.

Mapping the exact biomass potential within the municipalities is being carried out by Conterra in another work package of the Enercoast project. Unfortunately this report will be finalised before the results of the Conterra work are complete.

Danish forest area

According to the National Forest Statistics (Danmarks Skovstatistik), the national forest areas amount to roughly 579,563 ha in 2009, however it doesn't include smaller forests under ½ hectares. The same statistics estimates the forest area in Central Region Denmark to be 202,730 hectares. The National forest statistics are not based on actual measurements but are the results of test samples that have been scaled up. (Skov & Landskab, 2010)

Uffe Jørgensen uses the AIS statistics also under Danmarks Statistik and estimates the regions forest area to be 188,000 hectares (Jørgensen et al 2008). Both figures do not include the unknown potential for gardening waste.

Breaking these figures down for the municipalities shows that the three municipalities focused on in this report are close to the Danish average. According to Danmarks Statistik, in 2000 the total forest area within the three municipalities amounted to 30,190 hectares (Danmarks Statistik, 2010). Looking at the municipality level, Randers Municipality has a smaller forest area than those in Norddjurs and Syddjurs:

	Forest land (ha)
Norddjurs	11,470
Syddjurs	12,629
Randers	6,091
Total	**30,190**

Table 21: Forest land in the three municipalities in 2000 (Danmarks Statistik, 2010)

It has earlier been estimated by the Research Center for Forest and Landscape (Forskningscenter for Skov og Landskab) that the yield of biomass for energy from the forests are 1.5 tonnes of dry matter per hectare per year (Kristensen & Jørgensen, 2008). For the three municipalities that amounts to 45,285 tonnes of dry matter a year. Converted into energy this gives a current potential of 0.8 PJ, given a calorific value of 18 GJ/tonne dry matter.

Increased potential for wood chips

Various scenarios have been made for the increased potential for wood chips from local forests. In one end The Danish Energy Agency estimates that the wood resourced from the Danish forests is already fully utilised. The Forest industry however estimates that it is possible to double the outcome from the forests. On this background Uffe Jørgensen has chosen to assume a potential 50% increase in the utilisation of wood from the forests for energy production. Half of this is expected to be used for wood chip production and half of it for firewood. (Kristensen & Jørgensen, 2008)

In the scenarios made by Uffe Jørgensen, the yield of 1.5 tonnes dry matter per hectare is increased to 2.25 tonnes dry matter per hectare. As such, the 188,000 hectares of forest land in Central Region Denmark amounts to 6.7 PJ energy from wood chips, given a calorific value of 16 GJ/tonnes of dry matter.[18] With a calorific value of 18 GJ/tonne the energy potential is 7.6 PJ for the whole region. The table below shows the wood chip potential for each municipality with a yield of 1.5 tonnes dry matter and 2.25 tonnes of dry matter.

[18] The upper calorific value for wood with a water content of 0 % is 18 GJ7t. Uffe Jørgensen uses 16 GJ/t in his calculations as he has counted in the evaporation.

Technology	Forest land (ha)	Energy potential with 1.5 t. dry matter (PJ)	Energy potential with 2.25 t. dry matter (PJ)
Norddjurs	11,470	0.3	0.5
Syddjurs	12,629	0.3	0.5
Randers	6,091	0.2	0.2
Total	**30,190**	**0.8**	**1.2**

Table 22: Energy potential from forest biomass with a yield of 1.5 and 2.25 tonnes of dry matter per hectare given a calorific value of 18 GJ/t.

11.3 Supply chain for energy production from forest wood chips

The supply chain for wood chips resembles in many ways the one for willow chips, though the planting process is left out and the harvesting methods differ from that of willow trees.

The moisture content in wood chips is slightly less than for willow chips, at roughly 42% (Thygesen & Hilbert 2009). This means that the calorific value at delivery used in this report is 9.5 GJ/t. The calorific value for dry wood chips (0% water) is 18 GJ/t.

11.3.1 Foresting

Domestically produced wood chips are primarily a residue product from other forest industries. The wood used for wood chips typically comes from thinning of forests, harvesting dying or damaged trees, foliage, and harvesting of nurse trees. Nurse trees are fast growing trees planted in between the primary tree species to protect against frost, weeds, etc.

Being a residue product there has so far only been estimated a yield of 1.5 tonnes of dry matter per hectare (compared to willow chips that are estimated to deliver a yield of 8-12 tonnes of dry matter per hectare).

As described in the case of willow chips, by harvesting the tree and removing it, the nutrient balance is disturbed. As was the case with willow plantations, the nutrient loss can partly be compensated by cutting down the trees and leaving them to dry in the forest at the place of felling.

Case 2c: SSCM analysis of locally produced Wood Chips for CHP

	Economic Aspects	Environmental Aspects	Social Aspects	Main Existing or Potential Barriers	Possible Enablers	Possible Economic Benefits
Foresting	Forest machinery Input costs	Nutrient balance Land use Control with sustainability	Control with labour conditions Public/NGO resistance	Competition with import biomass Competing interests Competition with firewood	Long-term contracts Supply diversification	Minimisation of supply risk Cost certainty
Transport	Transport costs & logistics	Fossil fuel use GHG emissions	Transport through urban areas	GHG emissions Logisitics	Use of local resources	Reduced costs
Handling and storage	Limited storage Handling costs	Improved nutrient balance via forest storage	-	Limited storage facilities	Storage in forest	Reduced costs
Heat and electricity production	Fuel input prices & availability CO2 prices	Displacement of fossil fuels Plant emissions Ash, etc	-	Fuel input prices & availability	Long-term contracts	-
Heat and electricity discharge/ deployment	Lack of heat markets	-	-	No market for sale Restricted fuel choice Competition with individual heating	Strategic planning Free fuel choice	Lower heat prices

11.3.2 Chipping and Transport

The wood can either be chipped directly in the forest as it is felled or it can be delivered as whole trunks at the CHP plant and be chipped there. With direct chipping, the wood is felled, collected and chipped by the same machine.

Local forest wood is transported by truck. The transport costs for local forest wood chips are estimated to roughly 35-50 DKK/t (Boldt, 2009).

The CO_2 emissions from truck transport of wood chips from local forests are assumed to be similar to those of willow chips. Thus again assuming a truck with a load of 20 tonnes and a fuel efficiency of 3 km/l, the CO_2 emissions of the transport can be estimated to be 87 g/tonne/km. Given a calorific value of 8 GJ/t, the CO_2 emission can also be described as 10.9 g/GJ per 1 km of transport.

11.3.3 Handling and storage

Leaving the wood to dry in the forest where it was felled solves two problems. First of all the nutrient balance is somewhat restored by the defoliage that takes place when the wood is lying in the forest. Secondly, storage costs can be minimised by using the forest as 'storage'.

11.3.4 Heat and electricity production

The production costs are highly dependent on the price of the raw material. In the 1st quarter of 2009 the average sales price for forest wood chips delivered to the district heating companies was 44.5 DKK/GJ.

The biggest competitors to locally produced wood chips are firewood for private stoves, and imported wood chips. Despite the additional transport costs, imported wood chips are currently competitive price-wise with domestic chips. A more detailed analysis of imported biomass is carried out in the next chapter.

11.3.5 Heat and electricity deployment

Heat and CHP production from straw can displace coal or natural gas-fired production and thereby lead to a reduction in CO_2 emissions. As was the case for both straw and willow chips, there exists very little potential within the three municipalities to displace fossil-fired CHP production. Therefore, there may be a bigger potential for export of wood chips to other municipalise for displacement of fossil fuels.

11.4 Main existing barriers for increased use of wood chips for CHP production

Apart from the previously mentioned uncertainty regarding the local market price for wood chips, the main barrier for increased local wood chip production are the uncertainties related to the potential yield from existing forests. In addition, Danish forest areas are small and scattered compared to other countries that produce wood chips, and as such it may be less economical. Another uncertainty is the resource potential from the so called 'gardening waste' from private gardens and municipal green areas.

Key targets and enablers for forest wood chips for local CHP or heat production

Of possible enablers to overcome the uncertainty of the resource potential, thorough mapping of the resources and potentials for both forests and gardening waste in the specific three municipalities should be analysed.

12 SSCM analysis for international biomass for CHP

The third business case example investigated is that of international biomass for use in a large combined heat and power facility. Randersværket in the municipality of Randers provides an excellent concrete case as it imports large amounts of biomass from abroad, both in the form of wood chips and wood pellets.

12.1 Randers kraftvarmeværk

First put into operation in 1982, the Randers kraftvarmeværk is located on the River Guden in Randers, Denmark's 6th largest city with a population of roughly 60,000. Since its inception Randers kraftvarmeværk has produced the majority of the central heating in the area, as the local heating stations have only been called on to produce additional heat in short periods during the winters. A heat accumulator was added to the plant in 1991, which for example allows heat produced during the night to be utilised during the morning (Verdo, 2010a).

Technical aspects

In terms of the technical aspects, the plant is equipped with two Ålborg boilers with a common steam turbine system. The steam data are 110 Bar and 520°C. The plant can supply 50 MW of electricity and up to 116 MJ/s of heat. The total efficiency of the plant is approximately 85%. Under full load conditions the plant is capable of burning 1200 tons of wood chips and roughly 500 tons of alternative biomass per day, or 600 tons of coal. The wood chips are transported to the grate via a shaft, and the alternative biomass is typically blown in (depending on the type of biomass). There are many options for adjusting the air intake and this is one of the reasons that the plant can fire so many different fuels, and up to 100% biomass.

Fuel usage

The plant has traditionally relied on coal as its main fuel input, with nearly 100% coming from coal as recently as 2002. However, recent modifications have increased the flexibility of the plant, allowing it to utilise a growing proportion of biomass. This is reflected in the plant's 2008 annual green audit, which reveals that the percentage of fuel input met by coal has decreased from 83.0% in 2004, to 59.6% in 2008. Biomass inputs have increased from 16.5% to 40.0% during the same years, and were over 66,000 tons in 2008 (Energi Randers Produktion, 2009). Today the plant is capable of utilising 85-90% biomass, and the transformation to a power plant capable of firing 100% biomass is expected to be completed by 2011 (Miljømagasinet, 2009).

The current biomass utilisation is comprised of roughly 60% wood chips, and 40% from wood pellets and alternative biomass, including: olive stones, shea nuts, sunflower hulls and wood residues. These alternative biomass forms typically come from Denmark, the Baltic States, and Southern Europe (Verdo, 2010b).

In the future it is anticipated that wood chips will count for 60-80% of the biomass usage, with wood pellets and alternative biomass sources accounting for the remaining 20-40%. Verdo anticipates that the wood pellet portion will become less significant as it is not foreseen to be economically competitive with wood chips and/or the alternative biomass sources (Verdo, 2010b).

In terms of storage capacity, the Randers kraftvarmeværk has space for:

- Roughly 4,000 tonnes of wood chips, representing approximately 4 days usage under full load conditions
- Roughly 20,000 tonnes of other biomass, representing approximately 2 months usage under full load conditions
- Roughly 10,000 tonnes of coal, representing the anticipated yearly coal usage, however this capacity is not fully utilised (Verdo, 2010b).

The lack of storage capacity for wood chips, the primary input, is a challenge and thus requires a constant inflow of ships arriving at the correct time. An example of this occurs during the winter season, when severe ice in the Baltics can disrupt supplies. Randers kraftvarmeværk currently addresses this problem in part by utilising an external site for storage of whole logs for later chipping (Verdo, 2010b).

12.2 SSCM matrix

As was done for the case of biogas for CHP production, a SSCM matrix was applied to the case of international biomass for use in the Randers kraftvarmeværk. A version of this matrix that presents the sustainable supply chain flow of both wood chips and wood pellets is displayed on the following page.

12.2.1 Wood Chips

Raw material production

The method for producing wood chips in Denmark was described above in section 11.3. In comparison to Danish produced wood chips where the vast majority of the input are very small trees, top ends, and other residues, the Baltic produced wood chips typically come from larger trees, and as a result a significantly larger proportion of the input material is from the trunk. Therefore, all other things being equal, the Baltic produced wood chips have a lower bark content than that of the Danish produced wood chips. In addition to the Baltic wood chip trees being larger, there are also fewer types of tree species utilised. The end result is that Randers kraftvarmeværk has found the Baltic produced wood chips to be more homogenous in nature, have a lower bark content, a lower moisture content, and produce less ash (Corneliusen, 2010)

Case 3: SSCM analysis of International Biomass for CHP

	Economic Aspects	Environmental Aspects	Social Aspects	Main Existing or Potential Barriers	Possible Enablers	Possible Economic Benefits
Primary Material/Input Production	Labour costs Currency risk Input costs	Biodiversity Sustainability GHG lifecycle	Labour Conditions	Competing demand	Long-term contracts Supply diversification Vertical supply chain	Minimisation of supply risk Cost certainty
Transport of raw materials	Costs Availability	Biodiversity Sustainability GHG lifecycle	-	-	-	-
Pellet Production	Capital costs Operational costs Input costs Input availability	Fossil fuel use Plant emissions	-	Input supply disruptions	Long-term contracts Vertical supply chain	Minimisation of supply risk Cost certainty
Wood Chip / Pellet Transport	Ship availability Price fluctuations Currency risk	Fossil fuel use GHG emissions	Local resistance to export of biomass	Supply Disruptions	Long-term contracts	Minimisation of supply risk Cost certainty
Heat and Electricity Production	Fuel input prices & availability CO2 prices	Fossil fuel use Plant emissions Ash, etc	Reliance on imported biomass	Fuel input prices & availability	Increased storage capacity Long-term contracts Hedging Vertical supply chain	Minimisation of supply risk Cost certainty
Heat and Electricity discharge/ deployment	Difficulties in expanding district heating market	-	-	Difficulties in expanding district heating market	-	-

Raw material acquisition

The vast majority of wood chips utilised in Denmark are domestically produced, with only 10-15% of Denmark’s 14-16 PJ of wood chip demand (150,000 – 250,000 tonnes) being met by exports. Many of the power plants that utilise wood chips in Denmark are quite small and/or are located inland, and as such can not take advantage of relatively cheap shipping costs associated with less expensive wood chips from abroad. As such, the high cost of land transport of wood chips results in most plants relying on domestically produced wood chips. In fact, in a survey of plants within the three municipalities, of the 10 wood chip utilising plants that responded to the survey, the vast majority of wood chips came from either within the municipality, or a nearby region (Ea Energianalyse, 2010).

Larger CHP plants that are located on the water can take advantage of the import option, and at the present time Danish produced wood chips (43-47 kr/GJ) are more expensive then wood chips produced and sailed from the Baltics (Ea Energianalyse, 2010, Corneliusen, 2010).

For Randers kraftvarmeværk, the second stage in the wood chip supply chain is the acquisition of the wood chips by the owners of the Randers kraftvarmeværk, Verdo. These wood chips are mainly purchased from Baltic States in the form of long-term contracts. Based on 2008 figures, Randers kraftvarmeværk utilised just over 66,000 tonnes of biomass while using 40% biomass (Energi Randers Produktion, 2009). Given similar energy demand, and current biomass utilisation of 80-85%, this will require approximately 135,000 tonnes of biomass annually. With wood chips making up roughly 60% of total biomass usage, this represents an annual wood chip demand of approximately 80,000 tonnes (likely to grow to roughly 100,000 in the near future) with only very little coming from Denmark.

From the Baltics, Randers purchases both wood chips, and unchipped wood in the forms of trees and foliage 6-60 cm in diameter, and 3 meters in length. This unchipped wood is later chipped at Randers kraftvarmeværk and consists of various tree types, including aspen, birch, beech, oak and maple (Verdo, 2010c).

Economic, Environmental and Social aspects related to raw material production and acquisition

Economic aspects

Factors that will affect the price of wood chips are competing sources of demand, foreign exchange rates, and to a lesser extent local labour costs. According to Boldt (2009), the price of wood chips are most closely related to the price for cellulose for use in paper production, as relatively similar low value tree portions are used for both. As a result, if cellulose for paper production increases in price, the price of wood chips is also likely to increase. To guard against price shocks, purchasers of wood chips can enter into long-term contracts, diversify their supply, and/or purchase suppliers and thereby vertically integrate a portion of the supply chain.

In the case of the Randers kraftvarmeværk, Verdo purchases the majority of their woodchips via CIF (cost, insurance, and freight), euro denominated, long-term contracts (one year or season). These contracts are as precise as possible, and very little is left to spot purchasing as this is seen as risky from both a security of supply, and economic viewpoint. In cases where contracts are entered into with non-euro or Danish crown denominations, currency hedging is usually undertaken (Verdo, 2010b). Throughout this analysis the currency risk between the Danish crown and Euro is deemed to be very minimal as the fluctuations in this rate have been very minor since the euro's launch. This is reflected in the figure below which displays the fact that the crown to euro ratio has remained within an extremely narrow window between 7.434 and 7.468 since the euro's inception in Jan of 1999.

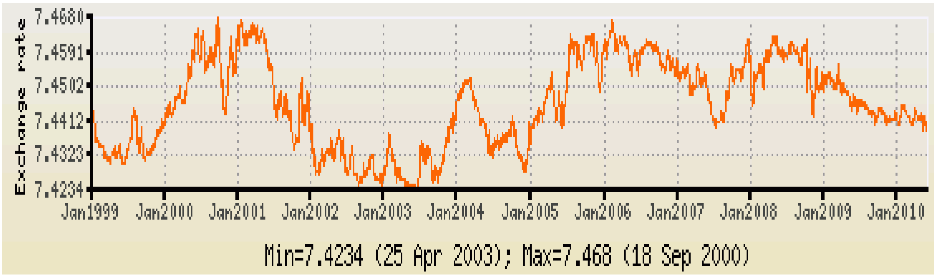


Figure 29: Historic Danish Crown to Euro conversion rates since Jan of 1999 (Titidorancea, 2010).

Environmental aspects

From an environmental perspective, the effects on biodiversity, the sustainability, and GHG lifecycle of the input wood are all of importance. If for example the wood comes from dedicated monoculture forests, this can have adverse affects on biodiversity and may not meet the sustainability requirements for all certification programs. To ensure that the wood chips are produced in an environmentally sustainable manner, the purchaser can acquire their wood chips from a certified forest; examples include the Forest Stewardship Council (FSC), Program for the endorsement of Forest Certification schemes (PEFC), and the Sustainable Forestry Initiative (SFI). In addition, some actors (for example municipal or regional officials) may prefer that wood chips are derived from wood residues, smaller trees, tree tops or branches, as opposed to large entire trees.

With respect to Randers kraftvarmeværk, Verdo has been assured that:

- The logs and wood chips are harvested and supplied in accordance with the related legislation and regulations of the country of origin
- Their deliveries are to be derived from sustainably managed forests
- Certification according to the rules of "Forest Stewardship Council" (FSC) or "Programme for the Endorsement of Forest Certification schemes" (PEFC) or similar schemes, is regarded as proof hereof
- They reserve the right to request evidence of trace ability of the origin of all import woodchip supplies.

- UN Recommendations concerning labour protection and child labour (Nos. R096, R097, R125 and R190) are respected in all parts of the production process.

To ensure that all the above take place, Verdo conducts regular inspection visits to the production sites (Verdo, 2010b).

Quantifiable Indicators

Aspects within raw material production and acquisition that can be quantified are the price of woodchips, the percentage of wood chips that are purchased via long-term contracts, the amount of imported vs. domestically produced chips, and the percentage of wood chips that come from sustainably managed forests.

The nominal prices of wood chips according to the Danish heating companies are represented by the dark green line in Figure 30 below.

As opposed to its fossil fuel counterparts, and to a lesser extent wood pellets, wood chips have remained fairly stable in price since 1997, particularly up to 2007. Since then prices have begun to increase, and as of the 3rd quarter of 2009 wood chips cost about 150-160 DKK/MWh, or 40-45 DKK/GJ. As was noted above, current prices appear to be a tad higher, as they are in the 42-47 DKK/GJ range.

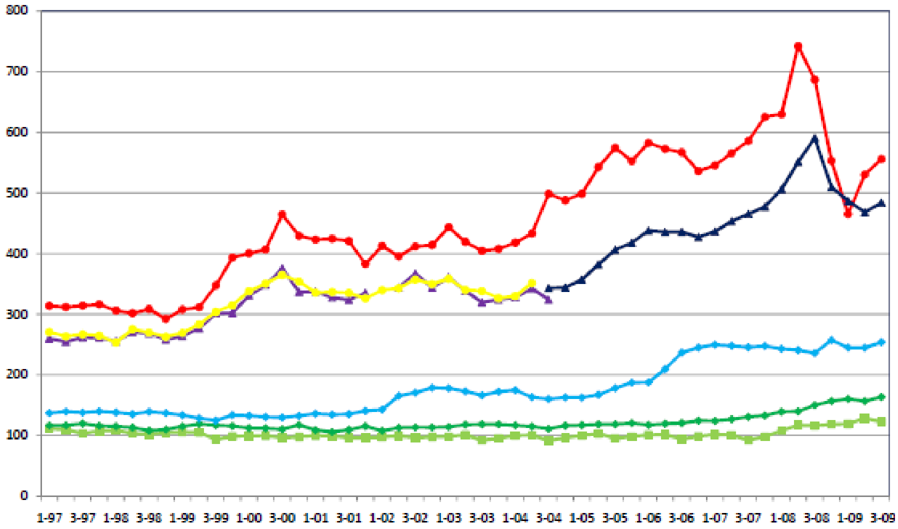


Figure 30: Nominal fuel costs for district heating in DKK/MWh at the plant gate, exclusive VAT, but including other taxes from January of 1997, till the 3rd quarter of 2009. The red line depicts oil, the yellow and dark blue natural gas, the light blue wood pellets, the dark green wood chips, and the light green straw. Fossil based fuels incur a tax of roughly 200 DKK/MWh, while biomass for use in heat production is exempt from such taxes. (Boldt, 2009).

With respect to the percentage of wood chips that are purchased via long-term contracts, according to Verdo this is currently the vast majority. This is also the case for the proportion of wood chips utilised at Randers that come from abroad, however this is very different from the national average, where only 10-15% of wood chips are imported. Lastly, the percentage of Randers wood chips that come from sustainably managed forests is currently deemed to be 100% as they are covered by certification schemes such as the Forest Stewardship Council.

12.2.2 Wood pellets

Raw material production and acquisition

The main raw material input for wood pellets is usually wood waste in the form of sawdust, shavings, or sander dust from sawmilling operations, furniture manufacturing, etc. In addition, clean recycled wood can also be used as an input for wood pellets, however due to its lower lignin content (which binds the pellets during the pelletisation process), an additive such as potato starch, maize, or vegetable oil, generally must be used with recycled wood. (Pellets@tlas, 2009). As wood pellet prices have increased, the pulverising of whole trunks for use in wood pellets has also begun to take place. Some dedicated plantations for energy crops (including the production of wood pellets) have also begun to emerge, as is seen with Willmott forests in Australia. In the case of Randers kraftvarmeværk the majority of the wood pellets come from the Baltics and Russia where wood pellets are generally produced from wood residues (Verdo, 2010b). These raw materials are then either purchased by a wood pellet manufacturer, or utilised by firms that also have a pellet production facility on site.

Economic, Environmental and Social aspects

Economic aspect

The main economic aspect at this stage of the process is the state of the milling, housing, and/or furniture industries. If the demand within these industries is low, then there will be very little wood residue produced, and therefore wood pellet raw material prices will increase. This has been seen on a few occasions over the past few years, for example in Germany and the Baltics in 2008 when the building industry was hard hit and many sawmills sat silent (Bøldt, 2009). It was also seen in North America during the recent American housing crisis which resulted in a reduction in Canadian lumber exports, and thereby a reduction in wood residues from the Canadian saw mills (Bradley, 2010).

Environmental aspect

A potential environmental aspect of the raw material production stage arises if the input does not come from wood residues. If the input comes from dedicated energy plantations, then this wood should be deemed sustainable by one of the forestry cortication organisations outlined above.

Quantifiable Indicators

Quantifiable indicators for the raw material and acquisition stage could include the % of raw materials that come from wood residues, as well as the % of the wood pellet cost that is comprised of the input materials. Currently the vast majority of wood pellets are produced from wood residues, and input materials typically account for 30-45% of the wood pellet cost (Bøldt, 2009).

Transport of raw materials

The next step in the supply chain is the transport of raw materials to the pellet plant. This is typically done via truck and the distance varies depending on the proximity of the sawmill/industry to the pellet manufacturer. Standard fossil fuel usage for transport and the associated CO_2 emissions with this transport are the only relevant aspects of this step in the supply chain.

Pellet production

Production of wood pellets can be broken down into three major processes, grinding, pelletising, and cooling. The figure below illustrates these major processes, and includes an initial drying process as well. This initial drying process is important because if the moisture content of the raw material is too high, then it will impede the pelletisation process.

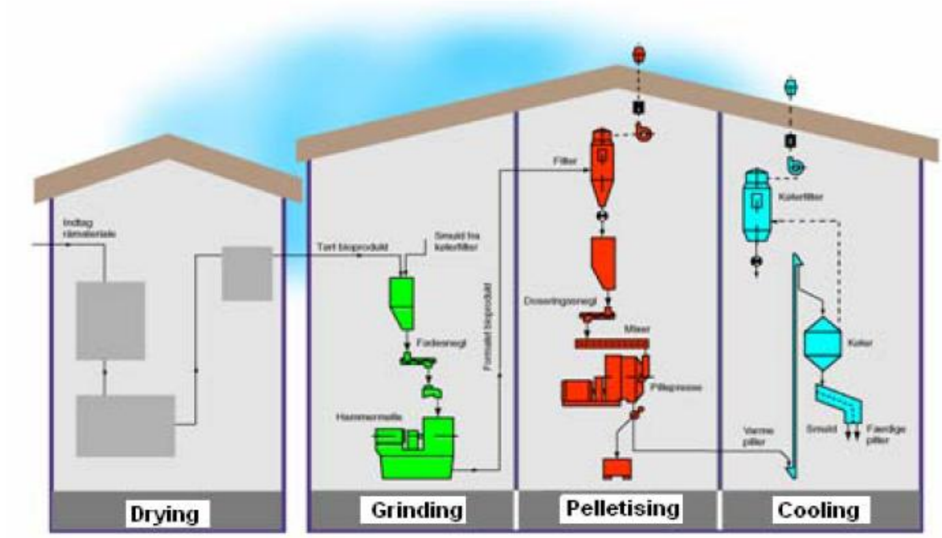


Figure 31: The pelletising process (Pellets@tlas, 2009)

After being dried and cleansed the raw material enters the grinding process where it becomes a homogenous pulverised product. Steam is then supplied to the raw material thereby heating it to roughly 70 ºC, and thereby releasing the lignin in the wood which allows for better binding of the particles. The material is now ready for pelletising into various sized pellets depending on the required specifications. Lastly, the pellets are cooled to just above room temperature, thus increasing the durability of the pellets (Pellets@tlas, 2009).

The finished product is typically one of two main types of wood pellets, bulk pellets for industrial use (for example those used in Randers kraftvarmeværk and some of the other large CHP plants in Denmark such as Dong's Avedøreværket), and those for personal use, which are generally sold in bags of 15 - 25 kg.

Economic, Environmental and Social aspects

Economic aspects

The major economic aspect related to pellet production is the availability of input materials. If these are scarce, then pellet production costs will be higher, and can result in the pellet manufacturer having to purchase whole trees in order to meet customer demands. Other economic aspects are the capital and operational costs related to the factory such as financing, or labour and fuel costs.

Environmental aspects

Environmental aspects related to the production of wood pellets include the fossil and other fuel use in the operations, as well as the associated CO_2 emissions. In addition, if whole trees are purchased for use in production of pellets, then there may be issues with forest certification.

Quantifiable Indicators

Quantifiable indicators for wood pellet production could include the cost of producing the pellets, both in energy terms, and in monetary terms. According to Bøldt, 2009, production and storage of wood pellets represented between 30-50% of the total pellet cost.

12.2.3 Transport of Raw Materials, Wood Chips, or Wood Pellets

The next step in the supply chain is the transport of raw materials to the plant. Wood chips are generally first transported via truck in either chip form, or as whole trees, and then by ship. In the case of Randers, the distance via truck varies, depending on how far the forest is from the Baltic port. The means of transport is generally a standard road truck with trailer, each with a removable bin capable of transporting 40m^3, for a total of 80m^3. These bins are generally left at the forest site for loading (Möller, 2007).

Like wood chips, both bulk and individual residential wood pellets are transported by truck, however more care must be taken that they do not get wet as they can not tolerate a great deal of moisture.

From the Baltic port to Randers kraftvarmeværk wood chips are transported as bulk cargo, wood for energy purposes, while whole trees are sailed on deck. These ships are generally 2,500 – 4,000 tonnes in size (Verdo, 2010c). Bulk wood pellets are also sailed to Verdo on ships of the same size, however do to the fact that they can not tolerate getting wet, wood pellets are transported as dry bulk.

Economic, Environmental and Social aspects of raw material transport

Economic aspects

The most important economic aspect with respect to transport is the availability and price of shipping. Shipping rates and availability can vary greatly depending on demand, and therefore long-term contracts are again a good hedge against price shocks.

The figure below reveals indexes for shipping costs of 4 different sizes (Capesize (typically capable of carrying over 80,000 dead weight tonnes (DWT)), Panamax (50,000 – 80,000 DWT), Supermax, (roughly 50,000 DWT) and Handysize (10,000 – 35,000 DWT), measured over 25 global routes, carrying various dry bulk commodities. The figures are not actual prices, but an index reflecting actual prices for each ship size (therefore the value is not per tonne).

The ship sizes here are larger than those used for shipping wood chips or wood pellets from the Baltics to Denmark (typically 5,000 tonnes or smaller for delivery direct to a CHP plant), and as such the particular index figures are not of significance relevance. However, what is particularly interesting and should be taken from the figure, is that it clearly shows the price volatility within the shipping market.

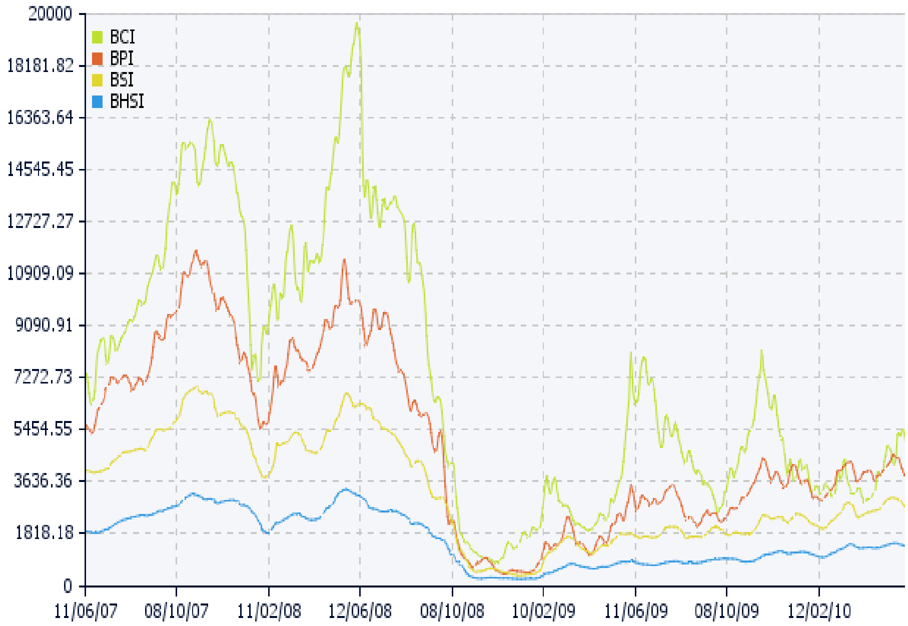


Figure 32 – Price indices for international dry bulk shipping according to size, Baltic Capezie (BCI), Baltic Panamax (BPI), Baltic Supermax (BSI) and Baltic Handysize (BHSI) from June of 2007 till June of 2010 (Navigate, 2010)

It is worth noting that the price deviations, while less extreme for the smaller ships, are still of a significant nature and can therefore greatly affect the total shipping cost. This fact was confirmed by Verdo, which indicated that shipping costs for wood chips represent roughly 25% of the final product cost; however swings in shipping rates can see this percentage vary between 20 and 35% (Verdo, 2010b).

An early study for the Danish Energy Agency estimated wood chip shipping prices from the Baltics to Denmark to be roughly 60 DKK/tonne (6.3 DKK/GJ) and unloading costs to be an additional 25 DKK/tonne (2.6 DKK/GJ), giving a total of 85 DKK/tonne (8.9 DKK/GJ) (Bøldt, 2009). These figures were based on 2003 figures, and as such a reasonable estimate for current prices would likely be in the range of 95-105 DKK/tonne (10 DKK/GJ). Given that Danish wood chips cost in the range of 42-47 DKK/GJ, and Verdo has confirmed that it can acquire wood chips at a lower price than this, and that shipping generally constitutes 25% of the end price, a value of roughly 10 DKK/GJ for transport from the Baltics to Denmark appears reasonable.

Due to the dry bulk nature of wood pellets, in per tonne terms, transport and unloading costs are slightly higher than for wood chips, however due to their higher energy content, the cost per GJ expense is actually lower.

Pellet unloading costs as of 2003 were generally in the range of 25 – 35 DKK/ton (1.5 – 2 DKK/GJ) (Bøldt, 2009).

As was outlined above, in the case of Randers kraftvarmeværk, Verdo generally enters into long-term CIF contracts, and only on occasion utilises FOB (Free on Board) contracts, which essentially involve taking the spot price that day, and thus freight prices are negotiated on trip by trip basis. Only very rarely does Verdo arrange any long-term shipping contracts (Verdo, 2010b).

Another potential option is for the wood chip or wood pellet purchaser to acquire its own shipping capabilities. While not unheard of, this is however rare within the power plant sector and this is not within Verdo's current long-term strategy.

Currency risk is again also an issue here; however this can easily be mitigated via numerous hedging options.

Environmental aspects

From an environmental standpoint, the main issues are the fossil fuels utilised in the transport, and the GHG emissions associated with this usage. The reason for burning wood chips and wood pellets in the first place is to reduce fossil fuel usage and GHG emissions, therefore utilising fossil fuels to facilitate this replacement can be environmentally problematic, depending on the amounts of fuel used and GHGs emitted. Related to this is the amount of energy utilised per tonne of biomass transported. If a large percentage of the energy within the biomass is utilised via transport, then the shipping of biomass will be unlikely to be deemed sustainable. In practice however, wood chips usually replace coal, and coal also has a GHG footprint when transported.

According to a report by the Danish Ministry of the Environment, the international transport of wood pellets to a Danish port on average utilises 282 MJ per tonne of wood chips, which is equivalent to 1.6% of the energy content of the pellets (Miljø- og Energiministeriet, 2000).[19] In terms of CO_2 emissions this corresponds to 1.2 kg CO_2/GJ. For wood chips the amount of energy utilised per tonne is likely to be very similar, however given the lower energy content of wood chips relative to wood pellets (9.5 GJ/ton vs. 17 GJ/ton), this is equivalent to roughly 3.0% of the energy content of wood chips, and 2.2 kg CO_2/GJ. The international transport of coal to Denmark was meanwhile estimated to have an energy usage of 485 MJ per tonne of coal, which given an energy content of 25.15 GJ/tonne, equates to 1.9% of the energy content of the coal, and 1.4 kg CO_2/GJ. When comparing coal to wood chips and wood pellets it is

[19] This transport figure was based on average of all wood pellets shipped to Denmark, and therefore included pellets from Canada as well. Therefore figures for transport from the Baltics would be slightly lower than the average figure.

also worth noting that there is a higher energy usage and GHG release related to the procurement and processing of coal than that associated with the production of wood pellets and wood chips. In addition, there are additional GHG considerations related to methane emissions from coal mining and storage.

As can be seen from the above figures, the amount of energy that goes to transport is relatively little. If however, the goal of a power plant is to become 100% CO_2 neutral, one possibility would be for the plant to purchase CO_2 credits amounting to these transport related emissions.

Social aspects

In terms of social aspects, one of the main barriers may be local resistance to the export of biomass. Local NGOs may for example frown upon a country or region exporting its biomass, particularly if that biomass is in demand locally.

Quantifiable Indicators

Quantifiable indicators related to transport include the Baltic Dry Index (BDI) which charts price fluctuations in the shipping industry, distance the wood chips or pellets travel, and energy use and CO_2 emissions from transport.

12.2.4 Heat and Electricity Production

The final step in the supply chain for wood chips and wood pellets is their utilisation in a power plant to generate heat and electricity. At Randers kraftvarmeværk wood chips are burnt via grate-firing, while wood pellets and other biomass are blown in. The plant has a total efficiency of roughly 85%.

Economic aspects

In terms of utilising wood chips and pellets for heat and power production, the most important economic aspects are the total costs incurred in their procurement, the tax savings associated with biomass usage for heat and electricity, the availability of biomass and other fuel inputs, alternative fuel prices, and the CO_2 price.

On the following page is the previously presented figure outlining the fuel costs for Randers kraftvarmeværk when the various energy and CO_2 taxes and subsidies have been incorporated.

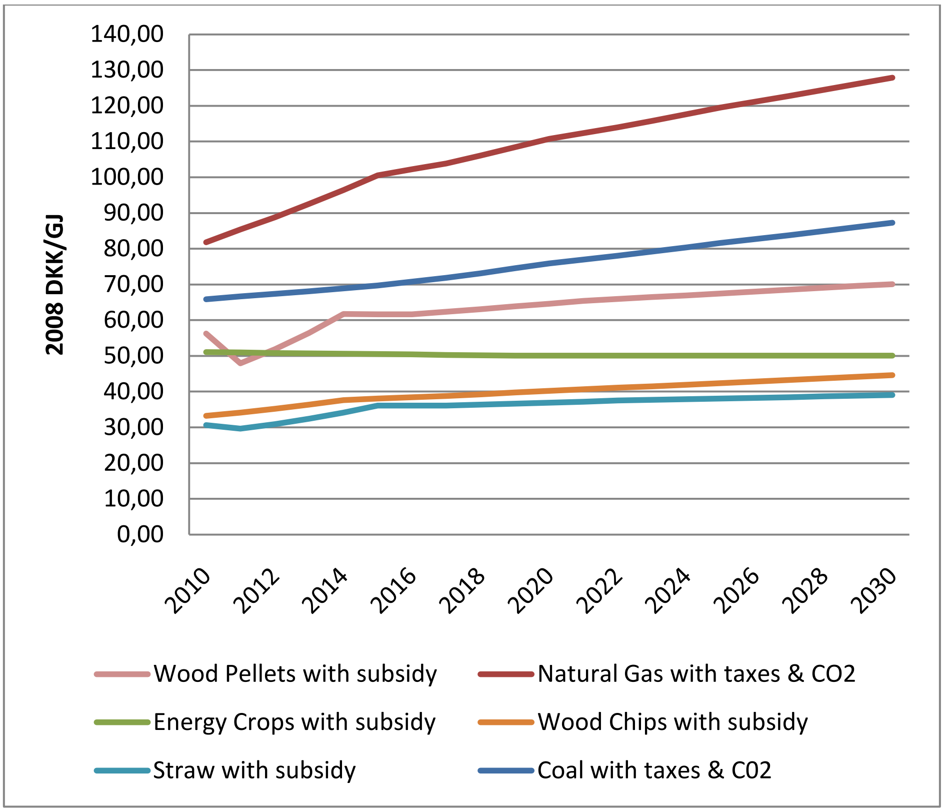


Figure 33: Danish Energy Agency (DEA) forecasted fuel prices for combined heat and power production, at the plant gate, exclusive VAT at Randers kraftvarmeværk in 2008 DKK/GJ. Calculations are based on an electrical efficiency of 27% and a heat efficiency of 59%. Coal and natural gas taxes are based on those presented in table 4, namely 72.1 and 66.1 DKK/GJ respectively. Utilising the V formula and a 59% heat efficiency, this corresponds to a fuel tax of 34.0 and 31.2 DKK/GJ respectively for coal and natural gas. CO_2 quota prices are based on DEA forecasts, and CO_2 contents of 95 and 57 kg/GJ for coal and natural gas. With an electrical efficiency of 27%, electricity subsidies for biomass of 41.7 DKK/GJ correspond to a subsidy of 11.4 DKK/GJ. Sulphur and NO_x taxes are not included.

This figure illustrates why it is that Randers kraftvarmeværk is shifting away from coal, and also why wood chips are preferable to wood pellets. Although wood chips do have some disadvantages relative to wood pellets in large CHP plants (such as increased ash and slag), for Randers kraftvarmeværk these are lessened by the type of technologies in place, and therefore wood chips are a more cost-effective fuel choice under current market and regulatory conditions.

Environmental and social aspects

From an environmental viewpoint, the important aspects are the various emissions from the plant, as well as the handling of the ash, particularly for wood chips, which have a higher ash content than other fuels.

From a social standpoint it should be noted that the reliance on imported biomass may not be considered sustainable. In this regard a number of municipalities have announced plans where the import of biomass was not included.

Quantifiable Indicators

The most relevant quantifiable indicators are the amount of international biomass used, both in fixed terms, and as percentage of total fuel input. Another relevant indicator is the amount of storage capacity for each fuel input at the Randers plant. Fuel input prices, CO_2 quota prices, fossil fuel taxes, and subsidies for biomass for use in heating are also all sub-indicators that will have an affect on how much biomass is utilised.

Another indicator could be the proportion of the region utilising biomass generated heat, particularly if there is potential to expand the district heating network.

12.3 Summary of main Barriers, Possible Enablers and Economic Benefits

Lack of storage space at Randers kraftvarmeværk for the primary input, wood chips, could be seen as a barrier for 100% utilisation of biomass. With only four days storage capacity, supply disruptions may force the plant to utilise other fuel inputs, which may be more expensive, or less optimal. An enabler here would be assistance to Randers kraftvarmeværk in acquiring more storage capacity for wood chips. The economic benefits associated with this would include the minimisation of potential supply disruptions, as well as greater flexibility with respect to supply logistics.

If the municipality would like to rely less on imported biomass, then it will have to facilitate ways in which locally produced biomass can compete with imported biomass. One possibility would be for the municipality to enter into talks with Verdo regarding the establishment of a similar program that has been undertaken with Assens værket, where willow will be grown by local farmers, but the plant is responsible for the harvest and chipping of the materials. This arrangement frees the farmers from investing in expensive machinery, while at the same time gives the plant a local buffer and flexibility in terms of a nearby resource that can be called on when needed.

13 Local Resources and Energy Balance

In order to evaluate the potential for increased use of biomass in the three municipalities the assessed sustainable resources were compared to the current use for energy purposes. The balance is presented in the table below.

Fuel (TJ)	Potential Energy Resource	Current energy use in municipalities	Balance
Straw Today	3,441	1,200	2,241
Straw with 15% willow	2,771	1,200	1,571
15% willow on farmland	1,789	0	1,789
Forest Biomass	815	5,560	-4,745
Biogas from slurry	833	12	821
Total without willow crops	**5,089**	**6,772**	**-1,683**
Total with willow crops	**6,209**	**6,772**	**-563**

Table 23: Potential biomass resources, current utilization, and potential biomass energy balance for the three municipalities. The biogas value is solely for biogas from animal slurry.[20]

It is worth noting the large usage of woody biomass; this is largely due to use at the Randers CHP plant, industrial user Novopan, and usage in individual heating. According to local estimates there are substantial unused resources of especially straw, biogas and energy crops – but also residues from the forest (wood chips). However, due to the large quantities of imported biomass (both from other municipalities and abroad), with Randersværket being the most prominent example of international import, the current use of solid biomass today is considerably greater than the local resource. For straw and slurry based biogas the local use is significantly below the resource potential.

[20] The potential straw resource was calculated as the amount of straw produced today, minus 10% that is deemed uncollectable, minus the amount that is currently used for animal feed and bedding. The calorific value for straw utilised was 14.5 GJ/tonne. In calculating the straw resource the same methodology was used, however 15% was first subtracted from the total straw produced today. The potential energy resource for willow was based on 15% of the current agricultural land for grain being planted with willow (12,426 ha), an anticipated production of 8 tonnes/hectare, and a calorific value of 18GJ/tonne. For biomass from forestry a land size of 30,190 hectares was used, along with a per hectare value of 1.5 tonnes/hectare, and a value of 18GJ/tonne of dry matter. For the biogas calculation, only the potential from animal slurry was incorporated.

References

Andersen (2010): Henrik Andersen, Dansk Fjernvarme. Conference on Biogas, Vejle, 2010.

Biokraft (2010): *Biomasser*. Available at: http://www.biokraft.dk/biomasser.asp

Birkmose, Thorkild (2006): *Biogas og gylle separering – en god kombination*. Dansk Landbrugsrådgivning, Landscentret. Available at: http://www.landbrugsinfo.dk/Planteavl/Goedskning/Husdyrgoedning/Sider/Pjece_Biogas_og_gylleseparering__en_god_.aspx

Björheden (2006): *Drivers behind the development of forest energy in Sweden*. Rolf Björheden. Article in Biomass & Energy, January 10th 2006.

Boldt (2009): *Fremtidige priser på biomasse til energiformål.* Jørgen Boldt, Wazee, notat udarbejdet til Energistyrelsen, 20/1 2009

Bradley, Douglas (2010): *Bio-trade Equity Fund*, presentation at Biomass Trade and Power, Rotterdam, March 11th, 2010.

Brancheforeningen for Biogas, EUDP & Energinet.dk (2009): *Forsknings- og udviklingsstrategi for biogas.* Available at: http://www.ens.dk/da-DK/NyTeknologi/strategier/Bioenergier/Biogas/Documents/biogasstrategi.pdf

Christiansen (2010): *Nulpunktsanalyse for biogasanlæg baseret på husdyrgødning.* Videncenter for Svineproduktion. Michael Groes Christiansen. Available at: http://vsp.lf.dk/Aktuelt/Nyheder/2010/03/~/media/Files/PDF%20-%20Publikationer/Notater/Biogasrapport.ashx

Conterra (2010): Data from Poul Larsen, Conterra.

Corneliusen (2010): Workshop om muligheder ved forøget anvendelse og produktion af biomasse i Syddjurs, Norddjurs og Randers Kommuner. Ebeltoft, Denmark, 31/5 2010.

Danish District Heating Association (2010): *Biogas set igennem forsynings øje.* Presentation made by Henrik Andersen in Vejle, June 2010. Available at http://www.kl.dk/Dokumenter/Artikler/MLM/2010/05/Biogas-2020-Fra-ambitiost-mal-til-lokal-praksis1/

Danish Energy Agency & Energinet.dk (2010): *Technology Data for Energy Plants.* Available at: http://www.ens.dk/Documents/Netboghandel%20-%20publikationer/2010/Technology_data_for_energy_plants.pdf

Danish Energy Agency (2009): *Notat om biogas i energiforsyningen*. Danish Energy Agency, 2009.

Danish Energy Agency (2009b): *'Energistatistik 2008* Danish Energy Agency, 2009.

Danish Energy Agency (2010): *Forudsætninger for samfundsøkonomiske analyser på energiområdet*. Copenhagen, April 2009.

Danmarks Statistik (2010). Available at: www.statistikbanken.dk

Dansk Bioenergi (2003): *Pilen er blevet populær*. Article by Torben Skøtt in Dansk Bioenergi no. 69, June 2003.

Dansk Brændesalg (2010): E-mail correspondence with Tommy Bruus-Jensen from Dansk Brændesalg 19/5 2010.

Dansk Gasteknisk Center (2007). *Naturgasselskabernes oversigtskort – transmissions- og fordelingsnet (stål) pr. 1. maj 2007*. Available at: http://www.dgc.dk/gastransport/Naturgasselskabernes_Oversigtskort.pdf

Dansk Landbrugsrådgivning (2005): *Start af biogasfællesanlæg*.

Dansk Landbrugsrådgivning (2006): *Biogas og gylleseperation – en god kombination*

Dansk Landbrugsrådgivning (2010): *Status over anvendelsen af gylleseparering i Danmark, maj* 2010. Available at: http://www.landbrugsinfo.dk/Tvaerfaglige-emner/Gylleseparering/Sider/pl_10_187.aspx

Djurs Bioenergi (2006): *Energiafgrøder til biogas.* Available at: http://www.djursbioenergi.dk/log/pdf/Energiafgr%F8der_medium.pdf

DONG Energy, MAN Last og Bus, Trafikselskabet Movia and Veolia Transport, DONG Energy *et al* (2007): *Demonstration af naturgasbus - Demonstrationsprojekt i København i perioden december 2006 - februar 2007.* Available at: http://www.dongenergy.com/SiteCollectionDocuments/NEW%20Corporate/PDF/Naturgasbus/naturgasbusHAN126333.pdf

Ea Energianalyse, (2010): *Survey of power plants*. June 15th 2010.

Energi Randers Produktion (2009): *Energi Randers Produktion, 2009 A/S Kraftvarmeværket Kulhomsvej, Grønt regnskab for 2008*.

Energinet.dk, (2009): *System Plan 2009*. Available at http://www.energinet.dk/NR/rdonlyres/23FA3710-E21D-4611-8A9E-92EFDE43D690/0/Systemplan2009GBweb.pdf

Fødevareministeriet (2008a): *Landbrug og klima. Analyse af landbrugets vir-*

kemidler til reduktion af drivhusgasser og de økonomiske konsekvenser. Fødevareministeriet, December 2008.

Fødevareministeriet (2008b): *Jorden – en knap ressource. Fødevareministeriets rapport om samspillet mellem fødevarer, foder og bioenergi*. Fødevareministeriet, January 2008.

Graversen & Gylling (2002): *Energiafgrøder til fastbrændselsformål – produktionsøkonomi, håndteringsomkostninger og leveringsplaner*. Jesper Graversen og Morten Gylling, Fødevareøkonomisk Institut, maj 2002.

HedeDanmark (2009): *Markedet for træflis*. Materiale til Det Energipolitiske Udvalg m.fl. af 23. oktober 2009.

John Jessen (2010): Telefonsamtale med John Jessen fra Assens Fjernvarme den 11. juni 2010.

Jørgensen (2010): Personal communication with Uffe Jørgensen, May 2010
Jørgensen et al (2005): *Start af biogasfællesanlæg – forprojekt, information og myndighedsbehandling*.

Jørgensen *et al* (2005): *Start af biogasfællesanlæg – forprojekt, information og myndighedsbehandling.* Dansk Landbrugsrådgivning. Available at: http://www.cbmi.dk/upload/fckeditor/file/biogasfaellesanlaegvejl.pdf

Jørgensen et al.(2008): *Energi fra biomasse – ressourcer og teknologier vurderet i et regionalt perspektiv*. Uffe Jørgensen, Peter Sørensen, Anders Peter Adamsen og Inge T. Kristensen, Institut for Jordbrugsforskning og Miljø, Århus Universitet, 2008.

Keoleian & Volk (2005): *Renewable Energy from Willow Biomass Crops: Life Cycle Energy, Environmental and Economic Performance*. Gregory A. Keoleian and Timothy A. Volk.

Kristensen & Jørgensen (2008): *Nuværende og potentielt energibidrag fra biomasse i region Midtjyllands kommuner*. Inger T. Kristensen og Uffe Jørgensen, Institut for Jordbrugsforskning og Miljø, Århus Universitet, 2008.

Landbrugets Rådgivningscenter (2000): *Biogasfællesanlæg – et bidrag til et bæredygtigt landbrug.* Available at: http://www.landbrugsinfo.dk/Planteavl/Filer/lp07382BiogasFaelles.pdf

Landbrugets Rådgivningscenter (2002a): *Biogasanlæg - hvordan medvirker de til at lette landbrugets gødningshåndtering og –udnyttelse.* Available at: http://www.landbrugsraadet.dk/getMedia.asp?mb_GUID=F0EF3020-4560-4B4B-8E70-61CCA0B41029.pdf

Landbrugets Rådgivningscenter (2002b): *Økonomi i gylleseparering.* Available at: http://www.landbrugsinfo.dk/Planteavl/Goedskning/Husdyrgoedning/Separering/Sider/1_c.pdf?List={cc47e3ea-656e-4453-84ac-46f07d28d805}&download=true

Landbrugsinfo (2002c): *Kvælstofudnyttelsen af afgasset gylle.* Videncentret for Landbrug. Available at: http://www.landbrugsinfo.dk/Tvaerfaglige-emner/Biogasanlaeg/Sider/Kvaelstofudnyttelsen_af_afgasset_gylle.aspx

Landbrugsinfo (2008): *Hvorfor separere gyllen?* Videncentret for Landbrug. Available at: http://www.landbrugsinfo.dk/Tvaerfaglige-emner/Gylleseparering/Sider/Hvorfor_separere_gyllen.aspx

Landbrugsinfo (2009): Available at: http://www.landbrugsinfo.dk

Larsen, Søren Ugilt (2009): *Energiafgrøder til biogas – muligheder og omkostninger*. Presentation made by Søren Ugilt Larsen in Gjern, December 2009. Available at: http://www.biogasdk.dk/down/semdec09/SUL.pdf

Larsen, Søren Ugilt *et al* (2010): *Tyske erfaringer med majs til biogas.* Agro-Tech. Available at: http://www.landbrugsinfo.dk/Planteavl/Bioenergi/Sider/Bioenergiartikelagrol1108.pdf?List={1b8bb2ed-21e8-4171-a51b-aabce8b751c5}&download=true

LBK nr. 347 af 17/05/2005: *Bekendtgørelse af lov om varmeforsyning.* Klima- og energiministeriet, 2005. Available at: https://www.retsinformation.dk/Forms/R0710.aspx?id=22435

Miljø- og Energiministeriet (2000): *Drivhusgasemission ved tilvejebringelse af fossile brændsler og biomassebaserede brændsler til energiformål*. København, November 2000.

Miljømagasinet (2009): *Energi Randers: Det CO2-neutrale kraftvarmeværk*. Miljømagasinet, Oktober 2009. Available at: http://www.miljomagasinet.dk/documents/00492.pdf

Miljøministeriet & Fødevareministeriet (2003): *Pesticidplan 2004 – 2009 for nedsættelse af pesticidanvendelsen og pesticidbelastningen*. Miljøministeriet and Fødevareministeriet, October 10th 2003.

Miljøstyrelsen (2010): *Basisdokumentation for biogaspotentialet i organisk dagrenovation.* Miljøstyrelsen. Available at: http://www2.mst.dk/common/Udgivramme/Frame.asp?http://www2.mst.dk/udgiv/publikationer/2003/87-7972-590-2/html/bilag03/kap03.htm

Möller & Nielsen (2007): *Analysing transport costs of Danish forest wood chip resources by means of continuous cost surfaces*. Bernd Möller og Per S. Nielsen, Biomass & Energy, 26 march 2007.

Navigate (2010): Avalilable at: http://navigatemag.ru/indices/

Norddjurs og Syddjurs Kommuner (2009): *Handlingsplan for Djurs Energiland*.

Novopan (2010): Telefonsamtale med Novopan, fredag den 11. juni 2010.

Pellets@tlas (2009): *English Handbook for Wood Pellet Combustion*. English translation of Force Technology's 'Træpillehandbogen, 2002', Pellets@tlas, 2009.

PlanEnergi & Djurs Landboforening, *et al* (2006): *Energiafgrøder & biogasanlæg.* Available at: http://www.djursbioenergi.dk/log/pdf/Energiafgr%F8der%20til%20biogas%20hos%20Brdr%20Thorsen%20dec%202005%20-%20jan%202006.pdf

PlanEnergi & Århus Universitet (2009): *Biogas – Grøn energi, proces, anlæg, energiforsyning og miljø.* Available at: http://www.energibyen.dk/fundanemt/files/Biogas_groen_energi.pdf

PlanEnergi (2008): *Baggrundsnotat til udarbejdelse af Energibalance Region Midtjylland*.

PlanEnergi (2008/2009): *Energy balances for the municipalities of Randers, Norddjurs and Syddjurs.*

PlanEnergi (2010): *Notat om biogaspotentiale i Herning Kommune*.

PlanEnergi *et al* (2006): *Demonstration af produktion og dyrkning af energiafgrøder til biogasproduktion.* Available at: http://www.djursbioenergi.dk/log/pdf/Biogasrapport,%20DLR.pdf

Randers Kommune (2009): *Klimaplan 2030, Strategisk energiplan. Forslag*.

Randers Kommune (2010): *Forslag til Klimaplan 2030 – Indsigelser og bemærkninger samt redaktionelle rettelser.* Available at: http://nhsoft.dk/work/Fg21/Jun/EnclosureFile.pdf

Regeringen & Dansk Folkeparti (2009): *Aftale om Grøn Vækst.* Available at: http://www.fm.dk/Publikationer/2009/1735-Aftale%20foraarspakke%202%200%20Vaekst%20klima%20lavere%20skat/Download.aspx

Regeringen, Socialdemokraterne, Dansk Folkeparti, Socialistisk Folkeparti, Det Radikale Venstre & Ny Alliance (2008): *Energipolitisk aftale af 21. februar 2008.* Available at: http://193.88.185.141/Graphics/ENS_Energipolitik/Energiaftalen/energiaftale-21022008_final.pdf

Rytter, Niels Ejnar (2010) : *Workshop om muligheder ved forøget anvendelse og produktion af biomasse i Syddjurs, Norddjurs og Randers Kommuner. Ebeltoft, Denmark*, 31/5 2010.

Syddansk Universitet (2010): *Life Cycle Assessment of Biogas from Separated slurry*.

Tafdrup, Søren (2009): *Grøn Vækst udfordrer eksisterende og nye biogasselskaber.* Presentation in Gjern, December 2009. Available at: http://www.biogasdk.dk/down/semdec09/ST.pdf

Taftrup, Søren (2010): *Økonomi og beslutningsgrundlag.* Presentation made by Søren Taftdrup, Danish Energy Agency, in Vejle, June 2010. Available at: http://www.kl.dk/Dokumenter/Artikler/MLM/2010/05/Biogas-2020-Fra-ambitiost-mal-til-lokal-praksis1/

The Centre for Biomass Technology (1998): *Straw for energy production.*

The Centre for Biomass Technology (2002): *Wood for energy production*.

Thygesen & Hilbert (2009): *Stort potentiale i dansk produceret flis*. Brev til minister og FEPU af 10. december 2009. Carsten With Thygesen, HedeDanmark og Per Hilbert, De Danske Skovdyrkerforeninger.

Thyø et al (2007): *Life Cycle Assessment of Biogas from Maize silage and from Manure – for transport and for heat and power production under displacement of natural gas based heat works and marginal electricty in northern Germany*.

Tititudorancea (2010): Available at: http://www.tititudorancea.com/z/euro_to_dkk_exchange_rates_danish_krone.htm

Tybirk, Knud (2010): *Energiafgrøder og andre biomasse til biogas*. Presentation made by Knud Tybirk, CBMI, in Vejle, June 2010. Available at: http://www.kl.dk/Dokumenter/Artikler/MLM/2010/05/Biogas-2020-Fra-ambitiost-mal-til-lokal-praksis1/

Uellendahl *et al* (2008): *Energy balance and cost-benefit analysis of biogas production from perennial crops pretreated by wet oxidation.* IWA, 2008.

Verdo (2010). Available at: http://www.verdo.dk/Privat/Kompetencer/Varme/Fjernvarmens

Verdo (2010a). Available at: http://www.verdo.dk/Privat/Kompetencer/Varme/Fjernvarmens

Verdo (2010b): Email correspondence with Benny Corneliusen from Verdo, May 21st, 2010

Verdo (2010c): Email correspondence with Benny Corneliusen from Verdo, June 14th, 2010

Vestjysk Landboforening (2009). Available at: http://www.vjl.dk

Videnscentret for Landbrug (2009). *Hvor meget halm er der I overskud?* Article in Landbrugsinfo, 2009. Available at: http://www.landbrugsinfo.dk

Annex 1: Telephone interviews with local district heating plants

As a part of the SSCM analysis, a phone questionnaire regarding the local biomass market was completed during the period 15-28th June, 2010. Representatives from the local plants in the municipalities of Norddjurs, Syddjurs and Randers were asked the following questions:

1) What fuel type is used?
2) What is the amount of fuel used annually?
3) Who are the suppliers?
4) How much of the fuel comes from outside the municipality borders?
5) What is the fuel price?
6) What size of district heating area does the plant supply?
7) Which immediate expansion possibilities exist?
8) When was the plant built and when is a replacement expected?
9) Is a replacement of the plant type (fuel type) planned?

As regards Grenå Kraftvarmeværk, it has not been possible for us to interview representatives from the plant. Instead available data from “Grenå Kraftvarmeværk - Grønt regnskab 2008” has been used.

For the conversions regarding amount of fuel and fuel price, the following values have been used: Straw 14.5 GJ/tonne, wood chips 10 GJ/tonne, wood pellets 17 GJ/tonne, waste 10.5 GJ/tonne, oil 42.7 GJ/tonne, coal 25 GJ/tonne, natural gas 39.6 GJ/m^3, and landfill gas 23 GJ/m^3.

The main conclusions from the phone questionnaire are:

- Regarding the suppliers, HedeDanmark A/S is the main supplier of wood chips (supplemented by local suppliers), while local farmers are the main suppliers of straw. The main supplier of wood pellets is Grenii A/S. HMN Naturgas I/S is the main supplier of natural gas.
- As for the fuel prices, the price of wood chips is 45-47 DKK/GJ, the price of straw is 31-41 DKK/GJ, and the price of wood pellets is 81 DKK/GJ.
- With regard to the possibilities for immediate expansions, there are some minor possibilities for immediate expansions inside the supply areas. The local plants are actively working on connecting more consumers to the grid. Few district heating companies have experience with expansions.
- Finally, the main conclusions regarding the expected replacements of plants and fuel types are that, for the foreseeable future, some of the local plants have to consider replacements and change of fuels. Currently, only few of the plants have actual plans. Those currently using biomass plan to proceed with biomass, while those currently using natural gas tend to consider the possibilities of using biomass or solar heat due to the high prices of natural gas.

The Municipality of Norddjurs (1/3)									
Plant	**Fuel type**	**Amount of fuel**	**Suppliers**	**Percentage of the fuel coming from outside the municipality borders**	**Fuel price**	**District heating area**	**Immediate expansion possibilities**	**The age of the plant + expectations regarding replacement**	**Plans for future fuel types**
Grenå Kraftvarmeværk	Coal, oil, straw, additional bio fuels	1,222,643 GJ/year (64,760 tonnes/year in total (in 2008)). Coal 642,325 GJ/year (25,693 tonnes/year). Oil 20,966 GJ/year (491 tonnes/year). Straw 553,494 GJ/year (38,172 tonnes/year). Additional bio fuels: 5,858 GJ/year (404 tonnes/year).	Unknown	Unknown	Unknown	Unknown	Unknown	The plant was built in 1991.	Unknown
Grenå Forbrændingsanlæg	Waste	231,000 GJ/year (22,000 tonnes/year)	Reno Djurs I/S	50 %	Reno Djurs I/S is charged 16.2 DKK/GJ (170 DKK/tonne waste delivered)	The town of Grenå (30 % of the district heating in the town)	Inside the supply area it is possible to connect a few new consumers to the grid.	The incineration plant was built in 1981. In 2000 the service life of the plant was lengthened. A replacement or a renewal has to take place in 2015.	The waste delivery agreement with Reno Djurs I/S runs until 2015. It has been discussed whether or not the waste will be delivered to the incineration plant in the future. If not, a new fuel type must be chosen, e.g. wood chips or straw.
Voldby Fjernvarmeværk	Wood chips	11,810 GJ/year (1,181 tonnes/year (in 2009))	HedeDanmark A/S (from the area of Eastern Jutland)	Unknown	47 DKK/GJ	The town of Voldby (approx 120 consumers)	Inside the town it is possible to connect a few new consumers to the grid. Outside the town there are no immediate expansion possibilities.	The plant was built in 2002. It will probably be replaced around 2022.	Uncertain

The Municipality of Norddjurs (2/3)									
Plant	**Fuel type**	**Amount of fuel**	**Suppliers**	**Percentage of the fuel coming from outside the municipality borders**	**Fuel price**	**District heating area**	**Immediate expansion possibilities**	**The age of the plant + expectations regarding replacement**	**Plans for future fuel types**
Gjerrild Fjernvarmeværk	Wood chips	21,330 GJ/year (2,133 tonnes/year (in 2009))	HedeDanmark A/S (from the area of Eastern Jutland)	Unknown	47 DKK/GJ	The town of Gjerrild (approx 160 consumers)	Inside the town it is possible to connect a few new consumers to the grid. Outside the town there are no immediate expansion possibilities.	The plant was built around 1997. It will probably be replaced around 2017.	Uncertain
Trustrup-Lyngby Varmeværk a.m.b.a.	Wood chips	45,000 GJ/year (4,500 tonnes/year)	Local suppliers (from the area of Djursland)	Unknown	43 DKK/GJ	The towns of Trustrup and Lyngby (475 consumers in total – corresponding to around 85-88 % of the households in the area)	There are no immediate expansion possibilities outside the supply area, since the nearby towns are too small to make it profitable. Inside the supply area they are constantly working on getting more consumers connected to the grid.	The plant was built in 1997. The boiler will probably be replaced around 2015-17.	Still wood chips
Ørum Fjernvarmeværk	Wood chips	24,960 GJ/year (2,496 tonnes/year (in 2009))	HedeDanmark A/S (from the area of Eastern Jutland)	Unknown	47 DKK/GJ	The town of Ørum (approx 190 consumers)	Inside the town it is possible to connect a few new consumers to the grid. Outside the town there are no immediate expansion possibilities.	The plant was built in 1994. A replacement of the boiler is planned for 2013-14.	Still wood chips
Stenvad Fjernvarmeværk	Wood chips	11,150 GJ/year (1,115 tonnes/year (in 2009))	HedeDanmark A/S (from the area of Eastern Jutland)	Unknown	47 DKK/GJ	The town of Stenvad (approx 100 consumers)	Inside the town it is possible to connect a few new consumers to the grid. Outside the town there are no immediate expansion possibilities.	The plant was built around 1997. It will probably be replaced around 2017.	Uncertain
Ørsted Fjernvarmeværk	Straw (oil as backup)	72,500 GJ/year (5,000 tonnes/year)	Mainly local suppliers (from the municipality of Norddjurs)	Around 6 %	34.5 DKK/GJ (500 DKK /tonne)	The town of Ørsted (650 consumers)	There are no immediate expansion possibilities as there are no nearby towns.	The plant was built in 1988. The boiler was replaced in 2007.	Uncertain

The Municipality of Norddjurs (3/3)									
Plant	**Fuel type**	**Amount of fuel**	**Suppliers**	**Percentage of the fuel coming from outside the municipality borders**	**Fuel price**	**District heating area**	**Immediate expansion possibilities**	**The age of the plant + expectations regarding replacement**	**Plans for future fuel types**
Allingåbro Varmeværk a.m.b.a.	Wood chips	60,000 – 70,000 GJ/year (6,000-7,000 tonnes/year)	Local suppliers (from inside and outside the municipality borders)	Unknown	41.5 DKK/GJ	The town of Allingåbro (625 consumers)	Inside the town it is possible to connect a few new consumers to the grid. Outside the town there are no immediate expansion possibilities.	The plant was originally built in 1962, but was last replaced in 2002. It will not be replaced in a while.	Probably still wood chips
Vivild Fjernvarmeværk	Wood chips	60,000 GJ/year (6,000 tonnes/year)	Local suppliers	Unknown	45 DKK/GJ	The towns of Vivild and Nørager (510 consumers in total)	Inside the towns it is possible to connect more consumers to the grid.	The plant was originally built in 1962. The entire plant was replaced in 2009, while the reserve plant was replaced in 2007.	Uncertain
Glesborg Fjernvarmeværk	Wood chips	21,480 GJ/year (2,148 tonnes/year)	HedeDanmark A/S (from the area of Eastern Jutland)	Unknown	47 DKK/GJ	The town of Glesborg (approx 160 consumers)	Inside the town it is possible to connect a few new consumers to the grid. Outside the town there are no immediate expansion possibilities.	The plant was built in 1994. A replacement of the boiler is planned for 2014.	Still wood chips
Auning Varmeværk	Straw	116,000 GJ/year (8,000 tonnes/year)	Local suppliers (mainly from Djursland)	50 %	35,9 DKK/GJ (520 DDK/tonne)	The town of Auning (1,000 consumers)	Inside the town it is possible to connect a few new consumers to the grid. Outside the town there are no immediate expansion possibilities.	The plant was built in 1992. In 2000 an extra boiler was installed. A replacement will have to take place before 2015-16.	Still straw

The Municipality of Syddjurs (1/3)									
Plant	**Fuel type**	**Amount of fuel**	**Suppliers**	**Percentage of the fuel coming from outside the municipality borders**	**Fuel price**	**District heating area**	**Immediate expansion possibilities**	**The age of the plant + expectations regarding replacement**	**Plans for future fuel types**
Ebeltoft Fjernvarmeværk a.m.b.a.	Wood chips	180,000 – 120,000 GJ/year (18,000-20,000 tonnes/year)	HedeDanmark A/S (mainly from the area of Djursland)	Unknown	47.4 DKK/GJ (Approx 9 million DKK/year)	The town of Ebeltoft (approx 2,000 consumers)	There are always expansion possibilities, but no immediate plans.	The plant was built in 1963. Parts of the plant are being replaced in 2014.	Still wood chips
Balle-Hoed-Glatved Fjernvarmeværk	Wood chips, landfill gas from a nearby landfill	Wood chips: 9,250 GJ/year (925 tonnes/year (in 2009)). Landfill gas: 11,999 GJ/year (521,702 m^3/year (in 2009))	HedeDanmark A/S and Glatved Losseplads (from the area of Eastern Jutland)	Unknown	Wood chips: 47 DKK/GJ. The landfill gas is free (only investment costs regarding the pump)	The towns of Balle, Hoed and Glatved (150 consumers in total)	Inside the towns it is possible to connect a few new consumers to the grid. Outside the towns there are no immediate expansion possibilities.	The plant was built in 1998. It is uncertain when it will be replaced.	Uncertain
Nimtofte Fjernvarmeværk (Brdr. Thorsen Varmeværk I/S)	Straw	50,750 GJ/year (3,500 tonnes/year) increasing to 72,500 GJ/year (5,000 tonnes/year)	Nimtofte Maskinstation (owned by Brdr. Thorsen)	0 %	31-34.5 DKK/GJ (450-500 DKK/tonne)	The towns of Nimtofte and Ramten, and Lybker Golf Resort (approximately 400 consumers increasing to approximately 700 consumers in total)	Currently, they are expanding the grid (increasing the number of consumers from approximately 400 to approximately 700 in total)	The plant was built in 2007. It is uncertain when it will be replaced.	Uncertain
Rønde Fjernvarmeværk	Straw	92,800 GJ/year (6,400 tonnes/year (in 2009))	Local suppliers	Maybe 10 %	Varies from month to month, e.g. 40 DKK/GJ (580 DKK/tonne)	The towns of Rønde and Ugelbølle (1,200 consumers in total)	An expansion including Ubbebølle has just been accomplished (increasing the number of consumers from 869 to 1,200 and rising to approximately 1,400 in total).	The plant was built in 1987. It is uncertain when it is being replaced.	Still straw

The Municipality of Syddjurs (2/3)									
Plant	**Fuel type**	**Amount of fuel**	**Suppliers**	**Percentage of the fuel coming from outside the municipality borders**	**Fuel price**	**District heating area**	**Immediate expansion possibilities**	**The age of the plant + expectations regarding replacement**	**Plans for future fuel types**
Thorsager Fjernvarme-værk a.m.b.a.	Straw	36,250 GJ/year (2,500 tonnes/year)	Local suppliers	Around 10-20 %	37.9 DKK/GJ (550 DKK/tonne)	The town of Thorsager (386 consumers)	Outside the supply area there are no immediate expansion possibilities. Inside the supply area, all oil consumers have been connected to the grid. They are continuously working to connect consumers within the supply area.	The plant was built in 1989. The boiler was replaced in 2007.	Uncertain
Ryomgaard Fjernvarme-værk a.m.b.a.	Straw	72,500 GJ/year (5,000 tonnes/year)	Local suppliers (from the municipalities of Syddjurs and Norddjurs)	Around 50 % from the municipality of Norddjurs	37.9 DKK/GJ (550 DKK/tonne)	The town of Ryomgaard (approx 600 consumers)	They are working on including 250 potential consumers in the town.	The plant was built in 1989. It is expected to be replaced in 2013.	Still straw
Mesballe Varmeværk	Wood pellets	4,794 GJ/year (282 tonnes/year (in 2009))	Greenii A/S	Almost all of it	80.9 DKK/GJ (1,375 DKK/tonne)	The town of Mesballe (approx 35 consumers)	Inside the towns it is possible to connect a few new consumers to the grid. Outside the towns there are no immediate expansion possibilities.	The plant was built in 1998. It is uncertain when it is being replaced.	Uncertain
Pindstrup Varmeværk a.m.b.a.	Surplus heat from Novopan and oil	Surplus heat: 32,400 GJ/year (9,000 MWh/year). Oil: Approx 330,000 liters/year.	Surplus heat: Novopan. Oil: Q8.		Surplus heat: 43.1 DKK/GJ (155 DKK/MWh). Oil: 5-7 DKK/liter.	The town of Pindstrup	Inside the towns it is possible to connect a few new consumers to the grid. Outside the towns there are no immediate expansion possibilities.	The plant was built as an oil-fired plant in 1965. In the 1970s they began to buy surplus heat from Novopan. A replacement is planned for 2010.	Still surplus head, but a change of fuel to wood chips instead of oil is planned.

The Municipality of Syddjurs (3/3)									
Plant	**Fuel type**	**Amount of fuel**	**Suppliers**	**Percentage of the fuel coming from outside the municipality borders**	**Fuel price**	**District heating area**	**Immediate expansion possibilities**	**The age of the plant + expectations regarding replacement**	**Plans for future fuel types**
Rosmus Varmeværk	Wood pellets	5,270 GJ/year (310 tonnes/year (in 2009))	Greenii A/S	Almost all of it	80.9 DKK/GJ (1,375 DKK/tonne)	The town of Rosmus and Rosmos School (approx 35-36 consumers)	Inside the towns it is possible to connect a few new consumers to the grid. Outside the towns there are no immediate expansion possibilities.	The plant was built in 1997. It is uncertain when it is being replaced.	Uncertain
Tirstrup Varmeværk	Wood chips	17,640 GJ/year (1,764 tonnes/year (in 2009))	HedeDanmark A/S (from the area of Eastern Jutland)	Unknown	47 DKK/GJ	The town of Tirstrup (approx 130 consumers)	Inside the towns it is possible to connect a few new consumers to the grid. Outside the towns there are no immediate expansion possibilities.	The plant was built in 1999. It is uncertain when it is being replaced.	Uncertain
Kolind Halmvarmeværk	Straw	Around 58,000 GJ/year (4,000 tonnes/year)	A local agricultural contractor and local suppliers	Unknown	41.4 DKK/GJ (600 DKK/tonne)	The town of Kolind (well over 400 consumers)	Currently they are connecting more consumers to the grid. When the expansion is completed there will be approximately 500 consumers in total.	The oil-fired plant was built in 1964. The straw-fired plant was built in 1989 and is being replaced with a new straw-fired plant in 2010.	Still straw

The Municipality of Randers (1/2)									
Plant	**Fuel type**	**Amount of fuel**	**Suppliers**	**Percentage of the fuel coming from outside the municipality borders**	**Fuel price**	**District heating area**	**Immediate expansion possibilities**	**The age of the plant + expectations regarding replacement**	**Plans for future fuel types**
Langå Varmeværk a.m.b.a.	Natural gas	Unknown	HMN Naturgas I/S and DONG Energy	Unknown	Unknown	The town of Langå (approx 900 consumers)	There are no immediate expansion possibilities, but it depends on the development.	Langå heating plant was built in 1960. Langå combined heat and power plant was built in 1991. It is uncertain when it will be replaced.	Possibly, solar heat will completely or partially replace natural gas
Værum-Ørum Kraftvarmeværk a.m.b.a.	Natural gas	Unknown	Unknown	Unknown	Unknown	The towns of Værum, Jebjerg and Væth (the number of consumers unknown)	Inside the towns it is possible to connect potential consumers to the grid.	Unknown	Uncertain
Mejlby Fjernvarmecentral	Natural gas	23,926 GJ/year (604,198 m^3/year)	HMN Naturgas I/S	Unknown	46.2 DKK/GJ (1.83 DKK/m^3 (exclusive of transmission, storage, distribution and taxes))	The town of Mejlby (approx 192 consumers)	The expansion possibilities are dependent on the local development regarding partitioning.	The plant was built in the 1990s. They currently have a service agreement including a main service in 2011.	Uncertain
Mellerup Kraftvarmeværk a.m.b.a.	Natural gas	31,680 GJ/year (800,000 m^3/year)	HMN Naturgas I/S	Unknown	Unknown	The town of Mellerup (177 consumers)	Inside the town it is possible to connect approximately 40 households to the grid.	The plant was built in 1993. It is uncertain when it will be replaced. In 2012 the debt will be settled making new investments possible.	A change of fuel to wood pellets is considered.

The Municipality of Randers (2/2)									
Plant	**Fuel type**	**Amount of fuel**	**Suppliers**	**Percentage of the fuel coming from outside the municipality borders**	**Fuel price**	**District heating area**	**Immediate expansion possibilities**	**The age of the plant + expectations regarding replacement**	**Plans for future fuel types**
Uggelhuse-Langkastrup Kraftvarme-værk a.m.b.a.	Natural gas	Around 35,640 GJ/year (900,000 m^3/year)	HMN Naturgas I/S	Unknown	Almost 4 million DKK/year ~ 112 DKK/GJ (all included)	The towns of Uggelhuse and Langkastrup (approx 195 consumers)	It is possible to include approximately 50 consumers by forced connection. Because of the high prices on the heat they are losing consumers.	The plant was built around 1995. The motors were replaced in 2007.	They have tried a change of fuel (dead stock) but taxes have made it impossible.
Havndal Fjernvarme-værk a.m.b.a	Straw	33,350 GJ/year (2,300 tonnes/year)	Local suppliers	0 %	31.7 DKK/GJ (460 DKK/tonne)	The town of Havndal (357 consumers)	All parts of the town are connected to the grid. Outside the town there are no immediate expansion possibilities.	The plant was built in 1993. The boiler was replaced in 2008. A replacement is not expected before 2028.	Uncertain
Gjerlev Varmeværk a.m.b.a.	Straw	Around 29,000 GJ/year (2,000 tonnes/year)	Local suppliers	0 %	30.3 DKK/GJ (440 DKK/tonne)	The town of Gjerlev (230 consumers)	Inside the town it is possible to connect approximately 70 households to the grid. Additionally, a pipeline of 5-6 km could be laid including yet another village. However, it requires that an extra boiler is installed.	The plant was built in 1990. A replacement is expected around 2020.	Still biomass
Gassum-Hvidsten Kraftvarme-værk a.m.b.a.	Natural gas	Around 47,520 GJ/year (Around 1,200,000 m3/year)	HMN Naturgas I/S	Unknown	Around 4 million DKK/year ~ 84 DKK/GJ (all included)	The towns of Gassum and Hvidsten (197 consumers)	It is possible to include approximately 30 consumers by forced connection. Because of the high prices on heat they are losing consumers.	The plant was built around 1994. The motors will be replaced before 2014-15.	If it were made possible by the politicians, they would like to make a change of fuel to biogas.