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Eucalyptus Short Rotation Forestry and harvesting methods

11/12/17

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This presentation is in two parts:

1) **A characterisation of eucalyptus short rotation forestry plantations in Ireland**

2) **A financial analysis of eucalyptus short rotation forestry supply chains**

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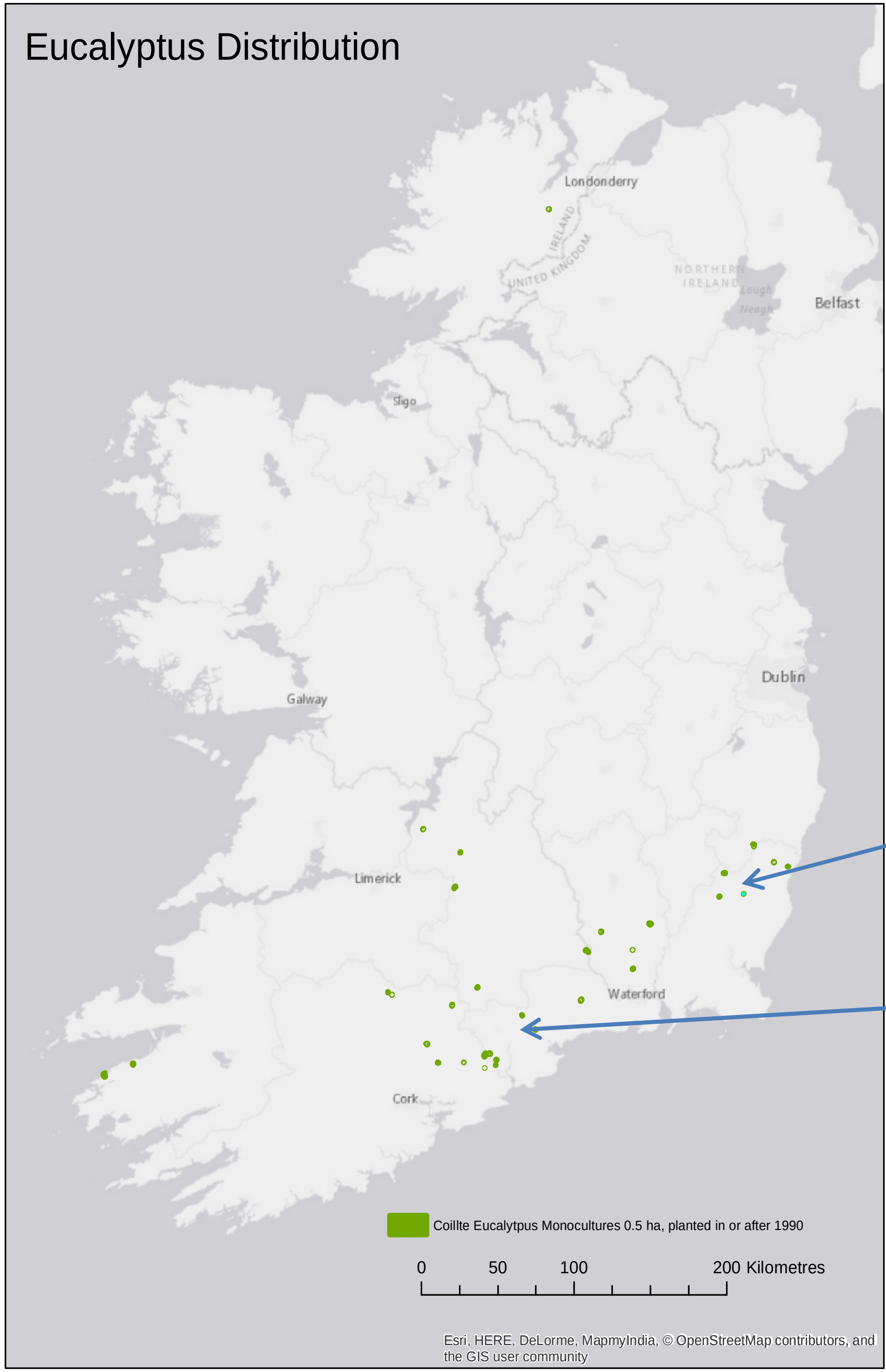
A characterisation of eucalyptus short rotation forestry plantations in Ireland



Planted since 2009

	Coillte	Private	Total
No. Sites	53	0	53
Total Area (ha)	333	0	333
Average Area (ha)	6.3	0.0	
Min area (ha)	0.6	0	
Max area (ha)	25.5	0	

Older Plantations

Kilbora, Co. Wexford. Planted 1992.

Glenshelane, Co. Waterford. Planted 1993.

Fieldwork

- Stratifying
- Assessing the canopy cover (DENSIOMETER)
- Setting out plots for an assessment of survival, stocking and dbh distribution
- Height measurements
- On a number of sample trees, upper stem measurements were taken to develop a local volume equation for each strata (CRITERION)
- Crown projection measurements (DENSIOMETER)
- Identification of soil type and soil nutrient regime (Soil pit + indicator species)

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Destructive sampling on 3 sites

- Trees felled, stem measured in 1 m intervals, partitioned and weighed.
- MC, density, oven dry mass, CV, ash, chemical analysis

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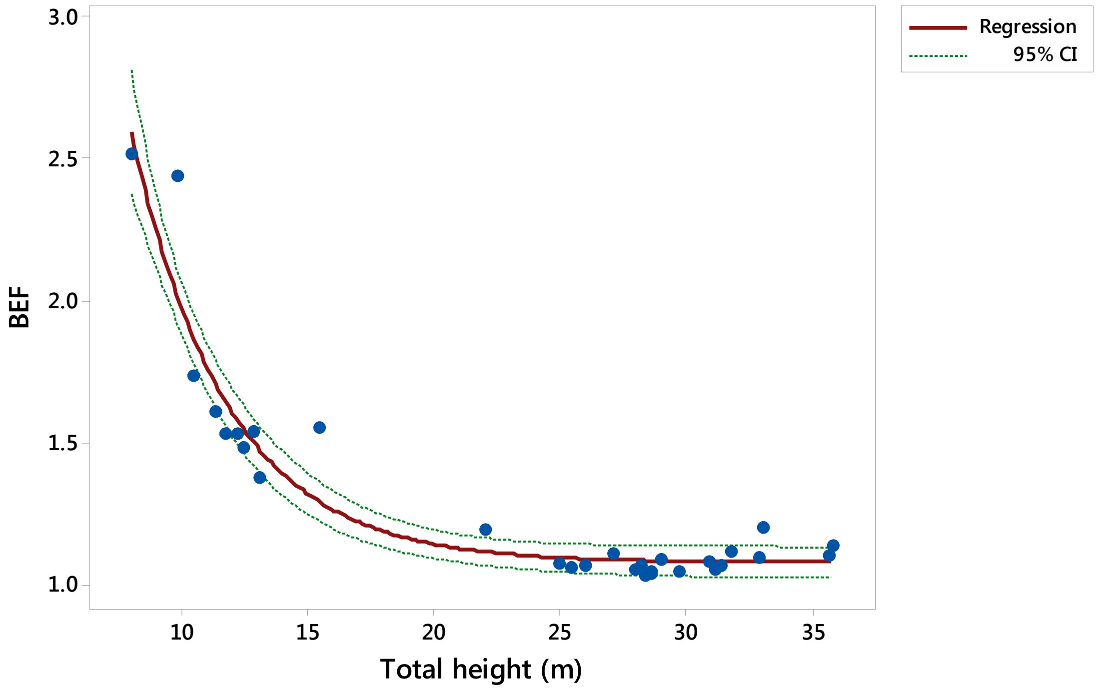
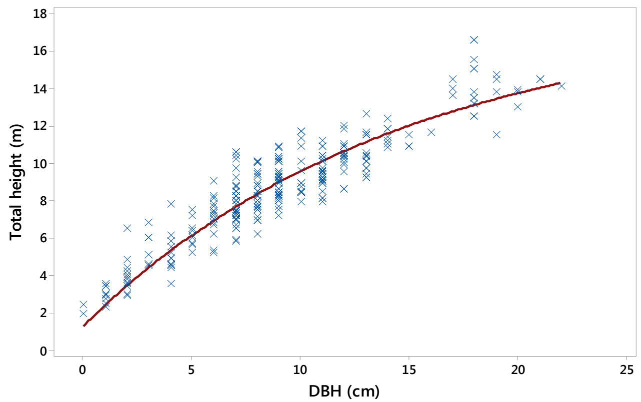
Aboveground Biomass Expansion Factor equation developed from the data



DBH to total height equation parameterised from data to use with the BEF equation



Descriptions, survival, top height, and basal area of the study sites

Site	Species	Growing Seasons	Soil Type	Soil Nutrient Regime	Soil Moisture Regime	Elevation (m)	Surviving trees ha^{-1} (incl. < 7 cm DBH)	Mortality (%)	Canopy Cover %	Standing dead trees ha^{-1}	Stocking (trees > 7 cm DBH)	No. Trees < 7 cm DBH ha^{-1}	Top height (m)	Basal Area ha^{-1} (m^2)
1	*E. nitens*	6	Brown Gley / Podzolic Gley	Poor - Medium	Fresh - Moist	189	1,600	36	43	0	1,330	270	10	9.9
2	*E. nitens*	7	Loamy Brown Earth	Medium	Moist	168	1,414	43	44	0	771	643	9	5.3
3	*E. nitens*	7	Loamy Brown Earth	Medium	Moist	173	1,863	25	66	0	1,250	613	13	11.3
4	*E. nitens*	7	Brown Gley	Poor - Medium	Very Moist	168	950	62	22	0	210	740	7	1.1
5	*E. nitens*	7	Loamy Brown Earth	Medium	Moist	169	1,400	44	48	0	1,213	187	13	14
6	*E. nitens*	7	Loamy Brown Earth / Brown Gley	Medium	Moist	172	1,467	41	42	0	417	1,050	12	4.3
7	*E. nitens*	7	Loamy Brown Earth	Medium	Moist	174	1,917	23	61	0	1,150	767	13	12.2
8	*E. nitens*	7	Gravelly Iron Pan Soils	Poor	Sl. Dry	184	1,967	21	40	1	833	1,134	9	4.9
9	*E. nitens*	7	Gravelly Brown Earth/ Podzol	Poor	Sl. Dry	151	2,217	11	53	0	1,100	1,117	9	6.1
10	*E. nitens*	7	Gravelly, Sandy Brown Earth	Poor - Medium	Sl. Dry	171	2,100	16	52	0	1,138	962	10	7.7
11	*E. nitens*	6	Podzolic Gley	Poor	Moist	153	2,200	12	55	0	1,300	900	11	8.8
12	*E. delegatensis*	22	Loamy Brown Earth	Very Poor	Mod. Dry	92	436	-	-	-	436	0	28	34.8
13	*E. nitens*	23	Podzolic Gley / Surface Water Gley	Medium	Very Moist	180	842	-	-	400	842	0	33	49.8
14	*E. gunnii*	5	Podzolic Gley	Very Poor	Moist	223	2,200	12	25	0	0	2,200	5	NA
15	*E. gunnii*	5	Podzolic Gley / Surface Water Gley	Poor - Medium	Very Moist	243	1,783	29	36	0	67	1,716	6	0.28

Productivity estimates of the study sites

Site	Species	No. of growing Seasons	QMDBH (cm)	Avg. merchantable roundwood volume per tree (m^3)	Merchantable roundwood volume (m^3 ha^{-1})	Stem Basic density (kg m^{-3})	Merch Stem Biomass per ha (odt)*	Residue biomass per ha (odt)	Wholetree biomass per ha (odt)	Productivity: whole tree biomass (odt ha^{-1} yr^{-1})
1	*E. nitens*	6	11	0.02	31		13	15	28	4.7
2	*E. nitens*	7	10	0.02	15		6	12	18	2.6
3	*E. nitens*	7	11	0.04	44	412	18	16	34	4.9
4	*E. nitens*	7	8	0.01	2		1	4	5	0.7
5	*E. nitens*	7	13	0.05	65		27	18	45	6.4
6	*E. nitens*	7	12	0.04	18		7	9	16	2.3
7	*E. nitens*	7	12	0.04	50		21	17	38	5.4
8	*E. nitens*	7	9	0.02	13		5	13	18	2.6
9	*E. nitens*	7	9	0.01	16		7	15	21	3
10	*E. nitens*	7	10	0.02	23		9	15	25	3.6
11	*E. nitens*	6	10	0.02	30		12	17	30	5
12	*E. delegatensis*	22	32	0.88	385	435	167	13	180	8.2
13	*E. nitens*	23	27	0.8	666	394	262	27	289	12.6
14	*E. gunnii*	5	0	0	0		0	0	2	0.4
15	*E. gunnii*	5	8	0	1		0	0	5	1

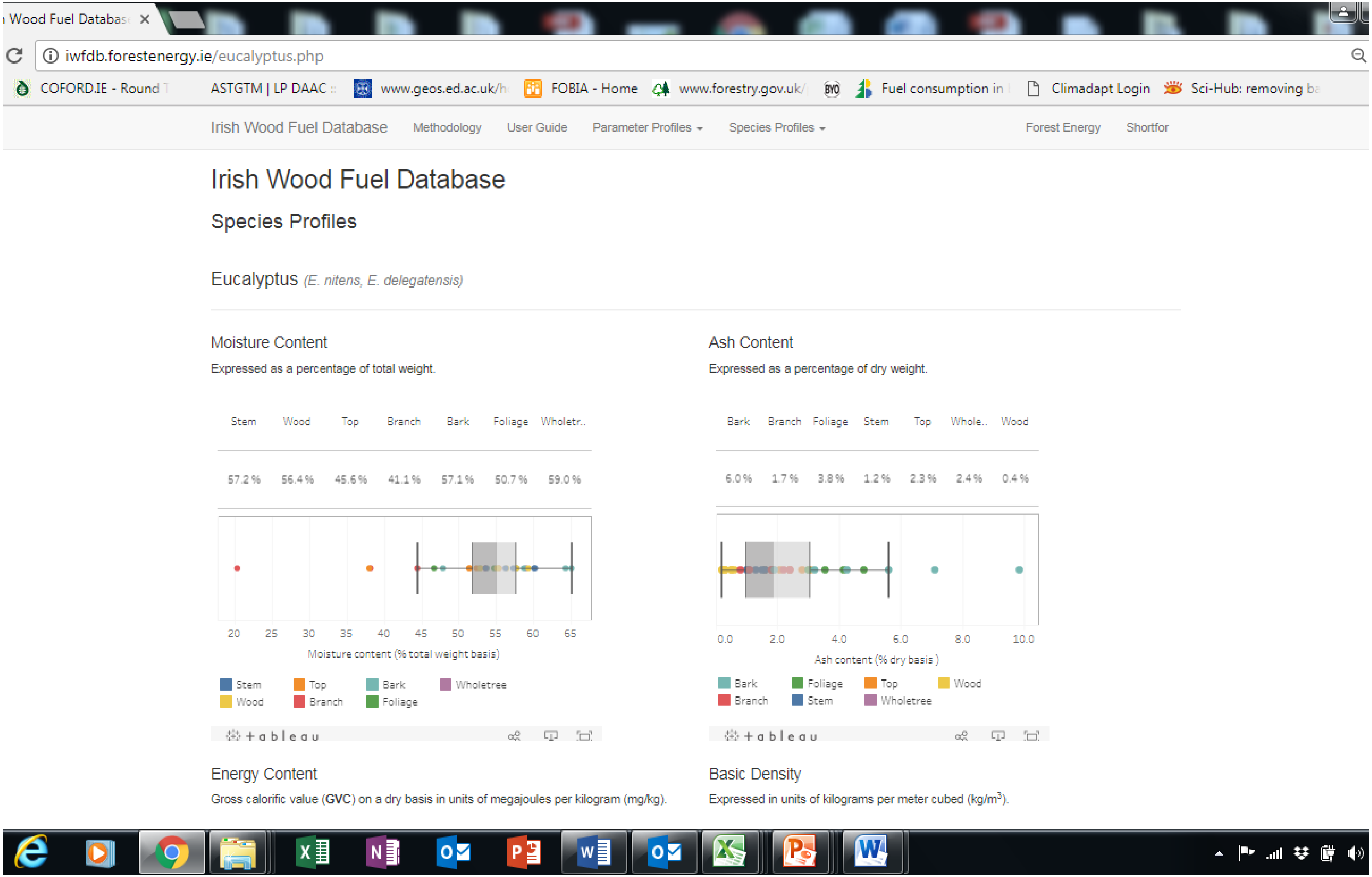
*estimated using a basic density of 412 kg m^{-3} for site no. 1-11, 14 and 15, 435 kg m^{-3} for site no. 12, and 394 kg m^{-3} for site no. 13.

Wood fuel parameters per tested partitions (standard deviations in parenthesis).

Partition	Ash content (% db)	Gross calorific value (GJ/tonne) (db)	Carbon content (% db)	Hydrogen content (% db)	Nitrogen content (% db)	Chlorine content (% db)	Sulphur content (% db)	Oxygen content (% db)	NCV (GJ Tonne) (db)	Ash Deformation: Init. deform. (°C)	Soften. (°C)	Hemisph. (°C)	Flow (°C)	Rs (°C)	Slagging potential
Stem	**1.2**	**19.2**	**46.40**	**5.70**	**0.18**	**0.08**	**0.010**	**46.41**	**17.96**	**>1,500**	**>1,500**	**>1,500**	**>1,500**	**>1,500**	**Weak**
	(0.1)	(0.1)	(2.77)	(0.16)	(0.10)	(0.03)	(0.017)	(2.89)							
Bark	**5.7**	**17.7**	**46.09**	**5.38**	**0.40**	**0.34**	**0.017**	**42.04**	**16.56**	**>1,500**	**>1,500**	**>1,500**	**>1,500**	**-**	**Weak**
	(4.7)	(1.4)	(5.92)	(0.46)	(0.13)	(0.05)	(0.015)	(2.03)							
Wood	**0.5**	**19.4**	**48.64**	**6.12**	**0.19**	**0.07**	**<0.01**	**44.48**	**18.05**	**<850**	**<850**	**<850**	**<850**	**-**	**Severe**
	(0.3)	(0.3)	(2.54)	(0.23)	(0.04)	(0.03)		(2.23)							
Live Branches	**2.2**	**19.9**	**49.92**	**5.85**	**0.51**	**0.14**	**0.013**	**41.39**	**18.61**	**<850**	**<850**	**<850**	**<850**	**-**	**Severe**
	(0.4)	(0.3)	(2.11)	(0.19)	(0.09)	(0.03)	(0.015)	(1.85)							
Dead Branches	**1.3**	**19.5**	**48.51**	**5.92**	**0.32**	**0.10**	**0.007**	**43.87**	**18.21**	**>1,500**	**>1,500**	**>1,500**	**>1,500**	**-**	**Weak**
	(0.5)	(0.1)	(2.77)	(0.31)	(0.07)	(0.10)	(0.006)	(3.18)							
Tops	**2.4**	**20.1**	**48.68**	**5.97**	**0.55**	**0.13**	**0.017**	**42.25**	**18.81**	**>1,500**	**>1,500**	**>1,500**	**>1,500**	**>1,500**	**Weak**
	(0.6)	(0.2)	(3.66)	(0.06)	(0.40)	(0.05)	(0.029)	(4.65)							
Foliage	**3.6**	**22.4**	**54.12**	**5.92**	**1.49**	**0.22**	**0.113**	**34.54**	**21.15**	**>1,500**	**>1,500**	**>1,500**	**>1,500**	**-**	**Weak**
	(0.6)	(0.5)	(3.42)	(0.15)	(0.14)	(0.04)	(0.042)	(3.71)							

		Typical Values EN 1496-1: 2009		
		Virgin Wood Materials (with of without insignificant amounts of bark and leaves	Virgin Bark	Residues
GCV	MJ/kg d	19.4 - 20.4	18.0 - 22.7	19.5 - 20
Ash	% d	0.2 - 1.0	0.8 - 3.0	2.0 - 10.0
Carbon	% d	48 - 52	47 - 55	50 - 51
Hydrogen	% d	5.9 - 6.5	5.3 - 6.4	5.8 - 6.1
Oxygen	% d	41 - 45	32 - 42	40 - 43
Nitrogen	% d	<0.1 - 0.5	0.1 - 0.8	0.3 - 0.8
Sulphur	% d	<0.01 - 0.05	<0.02 to 0.2	0.01 - 0.08
Chlorine	% d	<0.01 - 0.03	<0.01 to 0.05	<0.01 - 0.02

Data available at www.forestenergy.ie



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A financial analysis of eucalyptus short rotation forestry supply chains

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Supply Chains studied

No.	Name	Description
1	**CTL SMALL SAWLOG + PULP**	Roundwood production using a harvester and forwarder
2	**CTL SMALL SAWLOG + PULP + RESIDUE BUNDLES**	Roundwood logs & hogfuel biomass production using a harvester, forwarder, residue bundler, and a shredder.
3	**CTL SMALL SAWLOG + PULP + LOOSE RESIDUES**	Roundwood logs & biomass production using a harvester, forwarder, and a chipper.
4	**CTL SMALL SAWLOG + PULPWOOD WOOD CHIP**	Sawlog and pulpwood woodchip production using a harvester, forwarder, and a chipper.
5	**CTL SMALL SAWLOG + PULPWOOD WOODCHIP + RESIDUE BUNDLES**	Sawlog, pulpwood woodchip, and hogfuel biomass production using a harvester, forwarder, chipper, residue bundler, and shredder.
6	**CTL SMALL SAWLOG + PULPWOOD WOODCHIP + LOOSE RESIDUES**	Sawlog, pulpwood woodchip, and biomass production using a harvester, forwarder and a chipper.
7	**CTL ROUNDWOOD WOODCHIP**	Roundwood woodchip production using a harvester, forwarder and a chipper.
8	**CTL ROUNDWOOD WOODCHIP + RESIDUE BUNDLES**	Roundwood woodchip and hogfuel biomass production using a harvester, forwarder,chipper residue bundler and shredder.
9	**CTL ROUNDWOOD WOODCHIP + LOOSE RESIDUES**	Roundwood woodchip and hogfuel biomass production using a harvester, forwarder, chipper, and shredder.
10	**INTEGRATED SMALL SAWLOG AND BIOMASS**	Sawlog and biomass production using a harvester, forwarder and chipper.
11	**WHOLE TREE BIOMASS**	Wholetree biomass production using a harvester, forwarder and chipper.

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Machine Productivity

Harvester:

$$y = 60.711 \times (x^{0.6545})$$

Where: y = harvester productivity in m^3 PMH (productive machine hour). x = mean tree volume in m^3 (Jiroušek et al. 2007).

Forwarder:

$$y = 17.0068 \times \left(x^{13.2533/x}\right)$$

Where: y = productivity in m^3 per PMH. x = average extraction distance in metres (Jiroušek et al. 2007)

Residue bundler:

4.21 ODT PMH^{-1} (29.2 bundles PMH^{-1}) which is 11.6 m^3 solid PMH^{-1} (Coates et al. 2014).

Roadside chipper:

19.8 ODT PMH^{-1} (Coates et al. 2016)

Shredder:

15 ODT PMH^{-1} (Coates et al. 2014)

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Machine Rates

		Harvester: 1070D E	Forwarder: 810D E	Chipper: Komptech Chippo 5010 CD	Bundler: John Deere Bundler (1490 Base Machine)	Shredder: Jenz AZ 660	Front Loader (Generic)
Rate	**Unit**	**Amount**	**Amount**	**Amount**	**Amount**	**Amount**	**Amount**
Initial Investment	Euro	365000	235000	610000	425000	330000	100000
Machine Power	kW	136	86	397	134	357	65
Salvage Value	Euro	73000	47000	122000	85000	66000	20000
Economic Life	years	8	7	8	7	5	9
Scheduled Operating hours	hrs/year	2000	2000	2000	2000	2000	2000
Utilisation Percentage	%	65	65	40	65	75	75
Productive Machine Hours	hrs/year	1300	1300	800	1300	1500	1500
Depreciation	Euro/year	37922	27246	61000	48571	52800	8889
Interest	Euro/year	20227	13143	33703	23739	19074	5478
Insurance	Euro/year	9518	6185	15860	11171	8976	2578
Maintenance and Repair	Euro/PMH	29.2	16.8	76.3	37.4	35.2	5.9
Fuel	Euro/PMH	8.6	5.6	26.0	8.8	23.4	4.3
Lubrication	Euro/PMH	3.0	2.0	9.1	3.1	8.2	1.5
Labour incl. benefits	Euro/PMH	32.2	32.2	52.3	32.2	27.9	0.0
Overheads per SMH	Euro/SMH	4.1	3.0	6.0	4.7	5.6	0.9
Operating Profit Per SMH	Euro/SMH	7.7	5.7	11.4	8.9	10.5	1.6
Total Rate per SMH	Euro/SMH	93.0	68.7	138.2	108.3	127.5	19.7
Total Rate per PMH	Euro/SMH	143.1	105.7	345.5	166.7	170.0	26.3

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Simulation

Establisment / Maintenance / Roading Costs
- Industry consultation
- Literature

Harvest Volume / Biomass
- BFC Yield Models (poplar)
- BEF
- Basic Density
- Calorific Values

Harvesting Costs
- Machine Rates
- Productivity Models

Haulage Costs
- Literature

Price at millgate / biomass user for product
- Market Survey

Grants & Premiums
- DAFM

→ Excel Spreadsheet → Net Present Value using each supply chain for each YC and a range of Harvest Years

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Baseline:

BASELINE SCENARIO	
Ground Prep	Ripping
Initial Spacing	2.7 m
Fencing	126.5 m sheep fencing / ha
Glyphosate	2 applications
Filling in	10%
Roading	20 m / ha
Discount rate	5%
Productive area	85%
Harvest losses	15%
Average forwarder distance	250 m
Haulage distance	37.5 km
Moisture content	50%
Small sawlog price at millgate	€52 / m3
Pulp price at mill gate	€40 / m3
Energy Price	2.3 cent / kWh
Management costs	30 % of establishment and maintenance costs, 15 % of roading costs, and 10 % of harvesting revenue

Analysis done on 1 rotation. Reforestation costs included. Windrowing not applicable to supply chains that mobilise residues.

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Results:

NPV without grants and premiums

Supply chains which returned a positive NPV without grants and premiums (including reforestation costs).

Harvest Year	YC4	YC6	YC8	YC10	YC12	YC14
11						
12						
13						
14						
15						2,3,6
16					6	1,2,3,4,5,6,10
17					2,3,6,10	1,2,3,4,5,6,10
18					1,2,3,4,5,6,10	1,2,3,4,5,6,10
19					1,2,3,4,5,6,10	1,2,3,4,5,6,10
20				2,3,4,6	1,2,3,4,5,6,10	1,2,3,4,5,6,10

The numbers in the cells indicate supply chains which returned a positive NPV

Orange = Whole tree volume of less than 150 m^3 per ha, Green = whole tree volume of 150 – 300 m^3 ha, Blue = whole tree volume greater than 300 m^3 ha.

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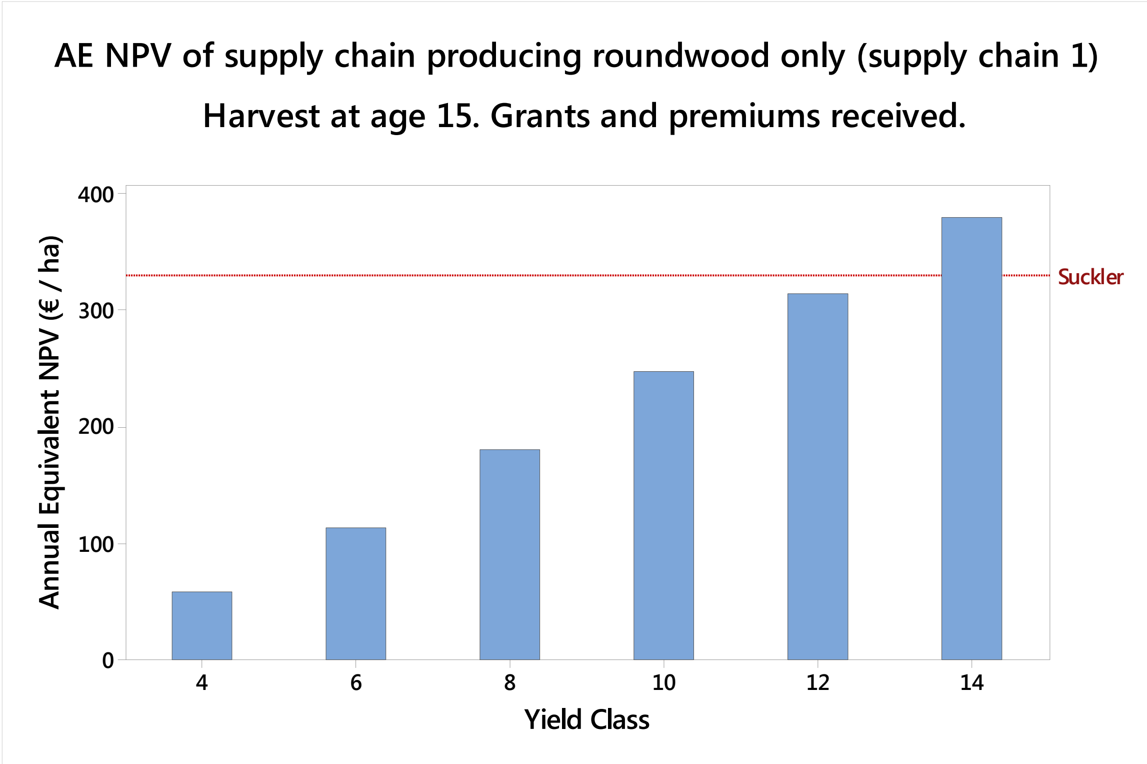
NPV with Grants and Premiums:

All supply chains returned a positive NPV (except for a harvest in year 11 and 12 for YC 4).

Roundwood Only :

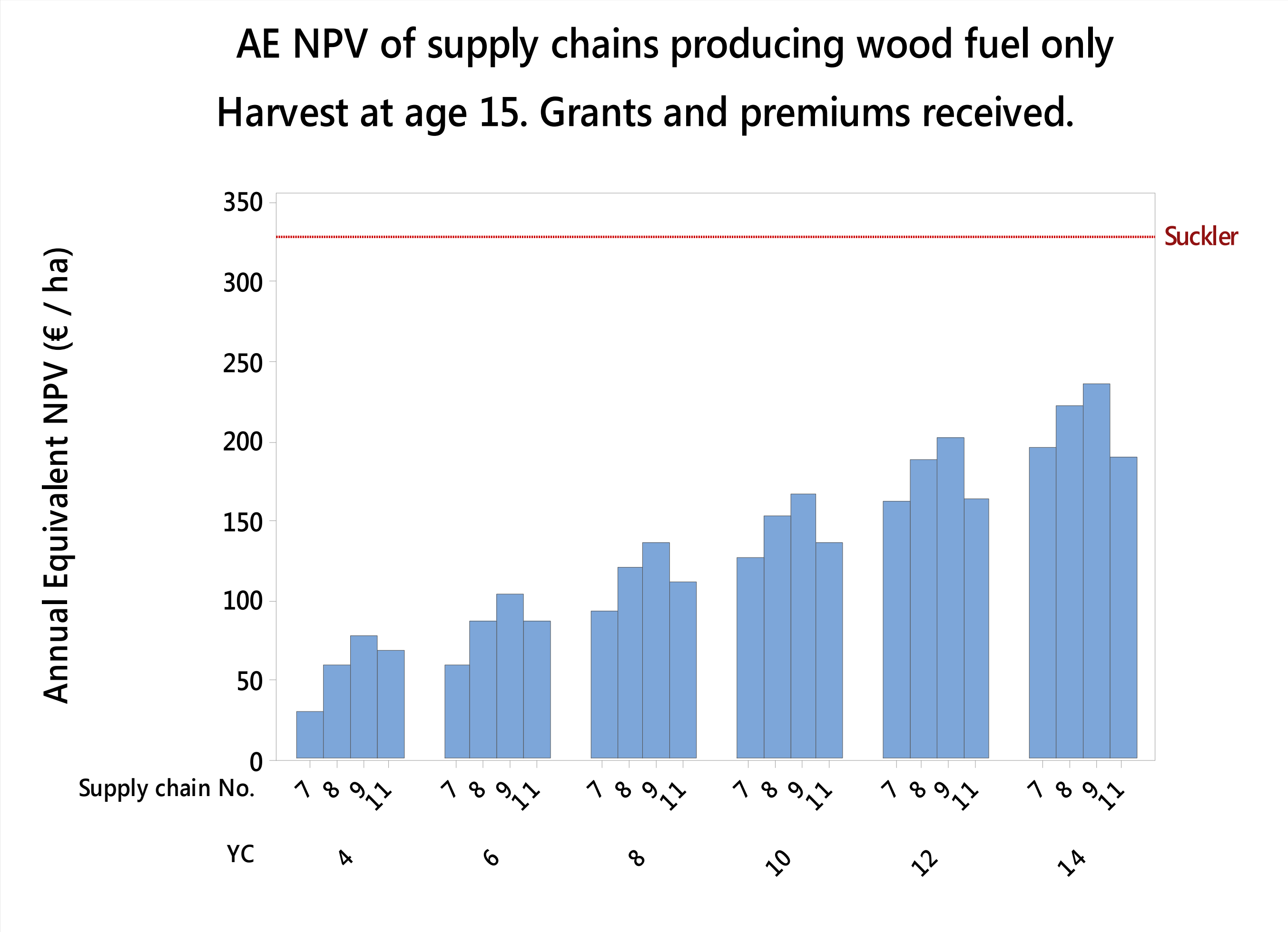


MAI ($m^3\ ha^{-1}$) at age 15:
YC 4 = 5.9
YC 6 = 9.6
YC 8 = 13.5
YC10 = 17.2
YC 12 = 21.0
YC 14 = 24.6

Supply chain 1 returned a NPV of €3944 for YC 14 harvested at age 15, which is an Annual Equivalent NPV of €380 per year.

Suckler is the income from suckler farming in 2015, as described by Ryan et al. 2016

Wood Fuel Only:

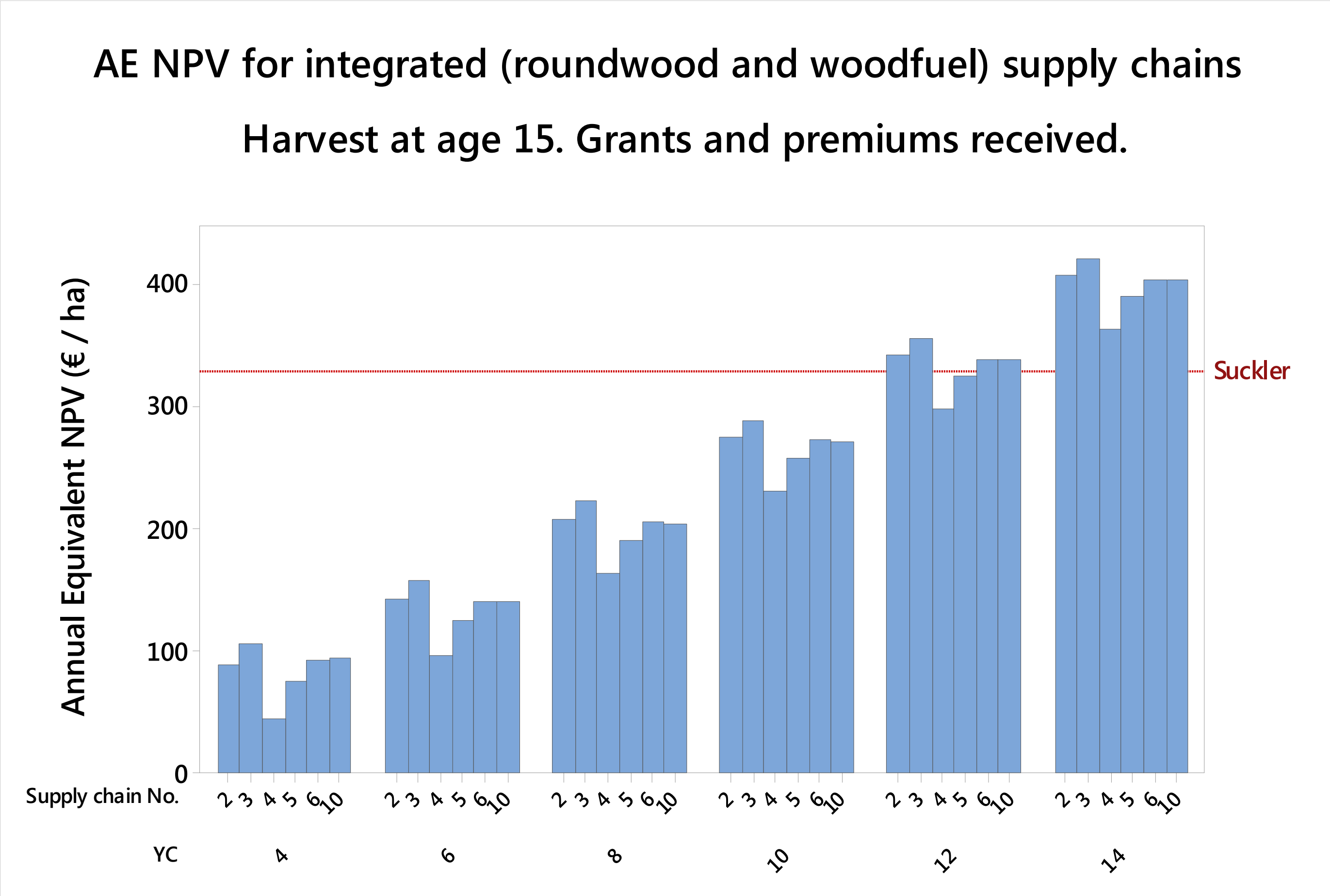


MAI (m^3 ha^{-1}) at age 15:
YC 4 = 5.9
YC 6 = 9.6
YC 8 = 13.5
YC10 = 17.2
YC 12 = 21.0
YC 14 = 24.6

Supply chain 9 (CTL roundwood woodchip and loose residues) returned an NPV of €2453 for YC 14 harvested at age 15, which is an AE NPV of €236 ha yr^{-1}

Suckler is the income from suckler farming in 2015, as described by Ryan et al. 2016

Integrated supply chains:



MAI (m^3 ha^{-1}) at age 15:
YC 4 = 5.9
YC 6 = 9.6
YC 8 = 13.5
YC10 = 17.2
YC 12 = 21.0
YC 14 = 24.6

Supply chain 3 (CTL small sawlog + pulp + loose residues) returned a NPV of €4368 for YC 14 harvested at age 15, which is an Annual Equivalent NPV of €421 ha^{-1} yr^{-1}

Suckler is the income from suckler farming in 2015, as described by Ryan et al. 2016

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Conclusions:

In the simulations, the highest NPV return was from:

Cut to length small sawlog and pulp with the mobilisation of the residues in loose form to the roadside where they were chipped.

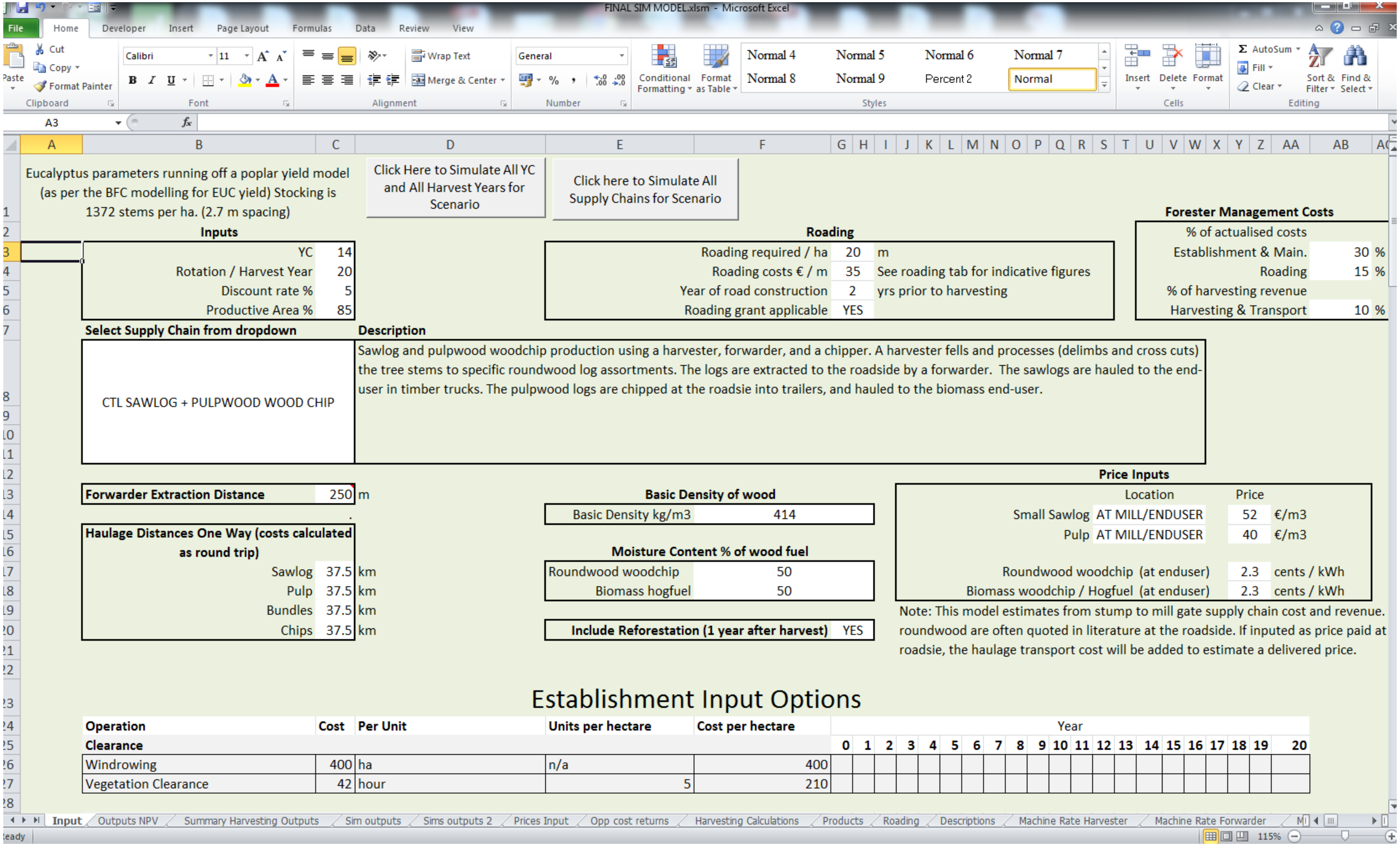
The price of 2.3 cents per kWh means that the wood fuel supply chains did not perform as well as the roundwood or integrated supply chains.

Without grants and premiums, a positive NPV value was not returned within 14 years for any supply chains at the YC tested.

With the current grant and premium rates, all supply chains returned a positive NPV within a 10 – 15 year period at all YC tested.

At YC 14, the annual equivalent return from roundwood or integrated supply chains for a harvest at age 15 was estimated to be more than the income from suckler farming.

Possibility to include other species, data, and conventional forestry systems into the model.



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Thank You.

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Coates, E., Cronin, B. and Kent, T. 2016. A comparison of biomass production and machine system productivity using three harvesting methods in a conifer first thinning. *Irish Forestry* 73: 122–140.

Coates, E., Kent, T., Horgan, B. and Mockler, N. 2014. Residue bundling – a case study in Ireland. *Irish Forestry* 71: 76–91.

Jiroušek, R., Klvac, R., Skoupý, A. 2007. Productivity and costs of the mechanised cut-to-length wood harvesting system in clear-felling operations. *J For Sci* 53: 476-482.

Ryan, M., O'Donoghue, C., Phillips, H. 2016. Modelling Financially Optimal Afforestation and Forest Management Scenarios Using a Bio-Economic Model. *Open Journal of Forestry 6:* 19-38.