A comparative supply chain sustainability evaluation of mobile pyrolysis plants and pyrolysis-based bio-refineries

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Aims

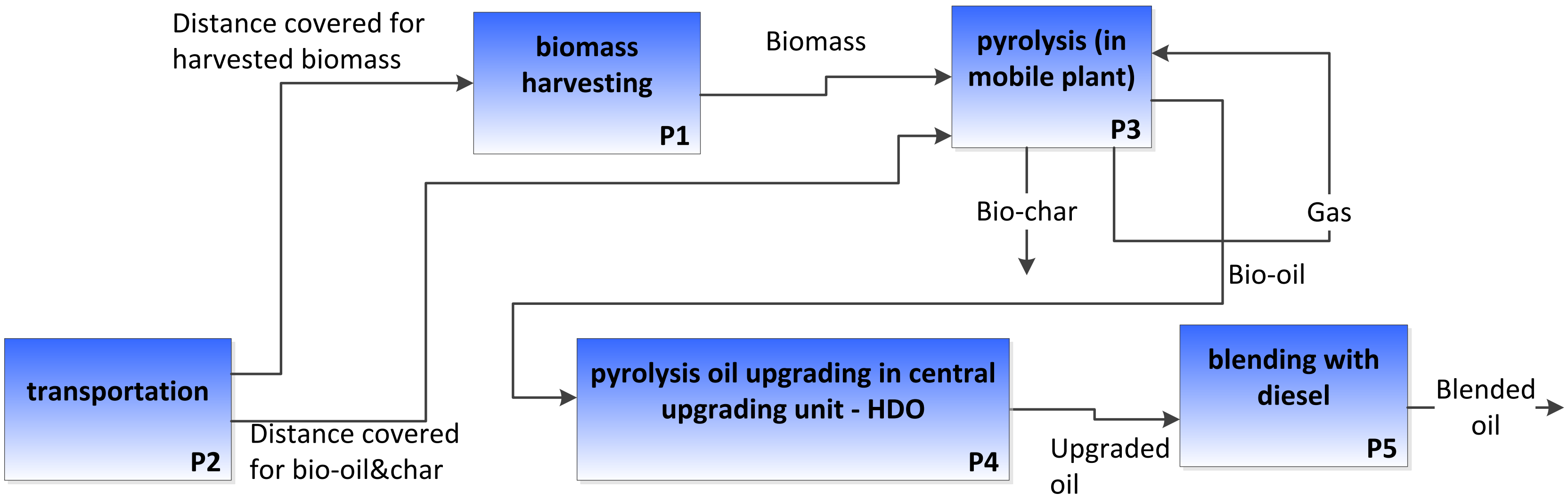
- To measure the economic and environmental sustainability of mobile pyrolysis plants compared to centrally-located bio-oil upgrading units
- To undermine the factors influencing the trade-offs emerging from different supply chain design options
- To measure the performance of different biomass collection routes for regionally dispersed biomass
- To propose practical and managerial implications for potential investors and supply chain members

Case study

- Scenario analysis for three different cases from Overijssel region (east Netherlands) with 26 municipalities

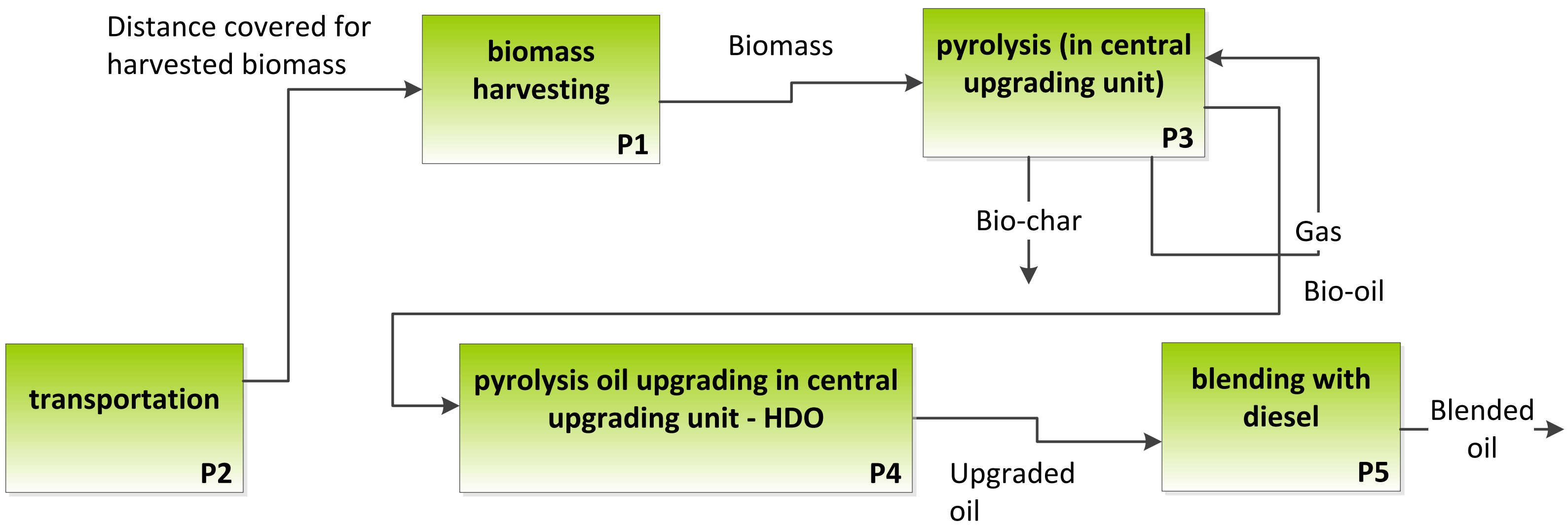
- Three types of biomass: landscape wood (LW), reed (R), and roadside grass (RG)

Scenario 1



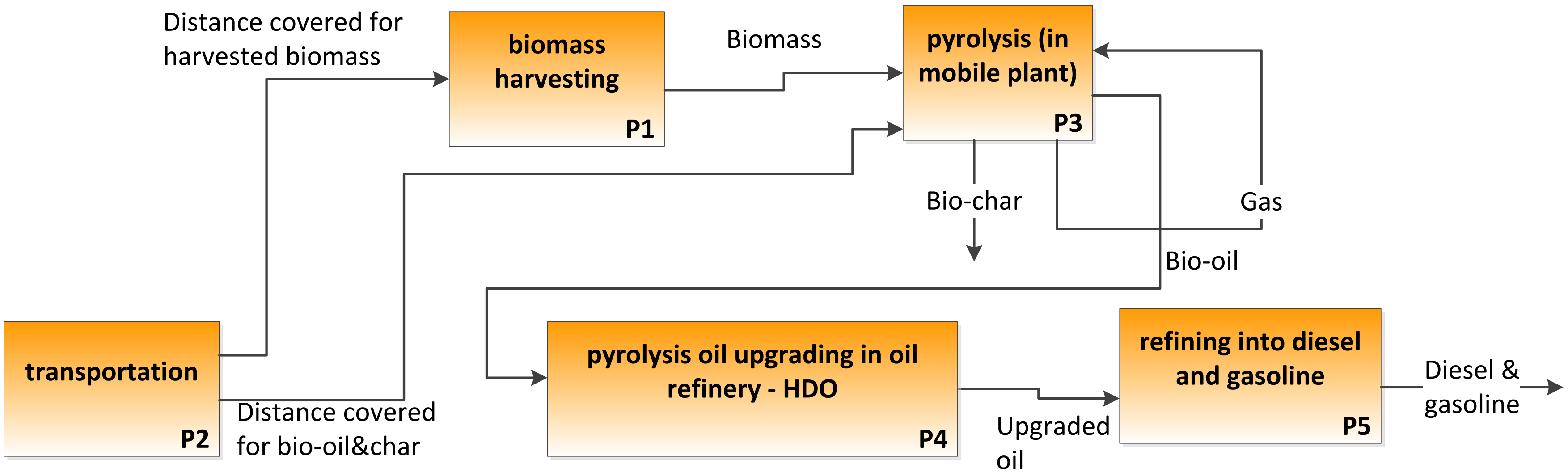
- 1 mobile pyrolysis plant
- 1 biomass truck
- 1 bio-oil & bio-char truck
- 1 regionally central upgrading unit
- Upgraded oil blended by diesel (25% - 75%)
- Final output for agricultural machinery or ship engines

Scenario 2



- 1 regionally central pyrolysis and upgrading unit
- Upgraded oil blended by diesel (25% - 75%)
- Final output for agricultural machinery or ship engines

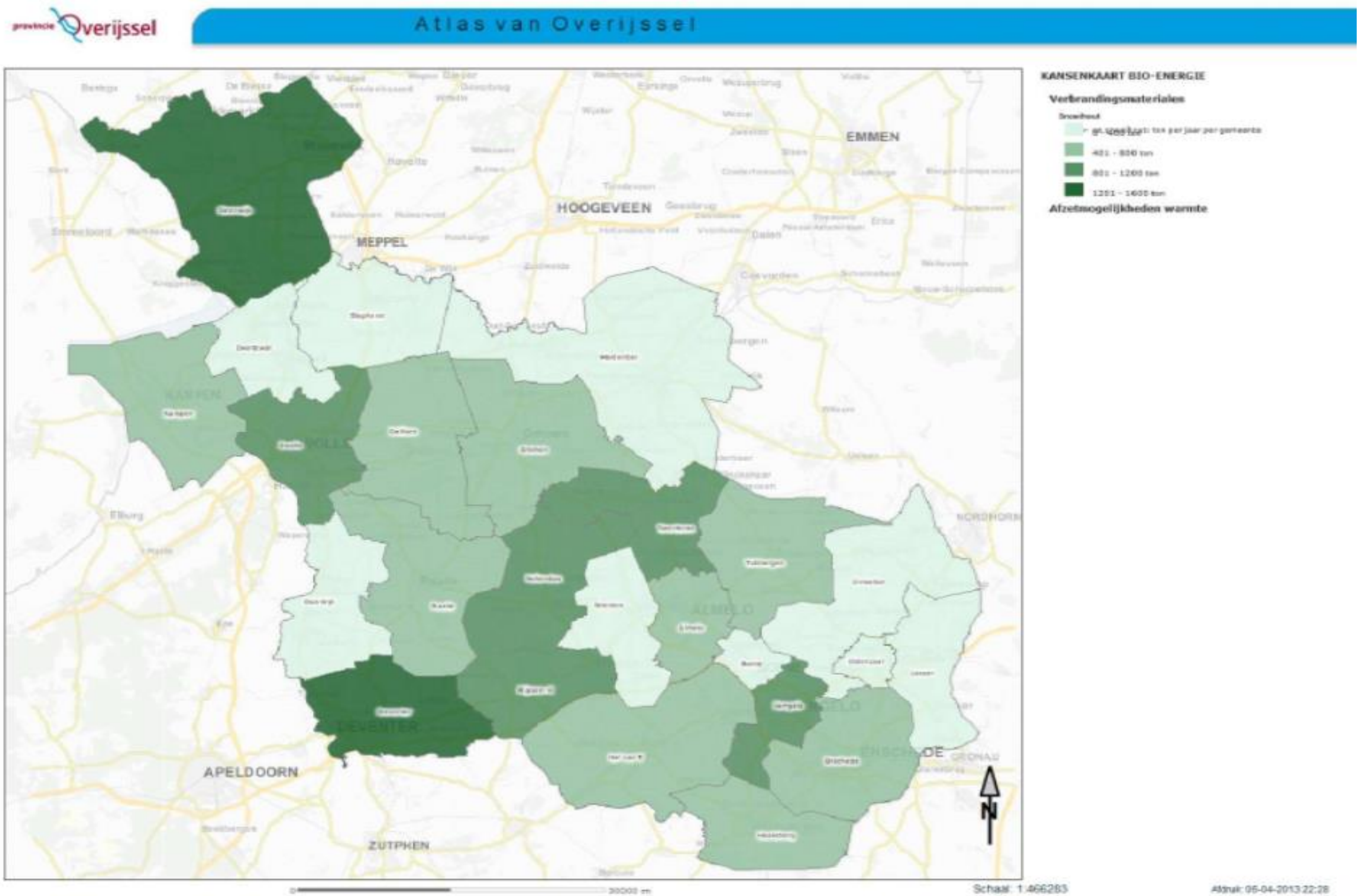
Scenario 3



- 1 mobile pyrolysis plant
- 1 biomass truck
- 1 bio-oil & bio-char truck
- Bio-oil transported to Botlek refinery
- Final output refined gasoline and diesel

Region map (landscape wood availability)

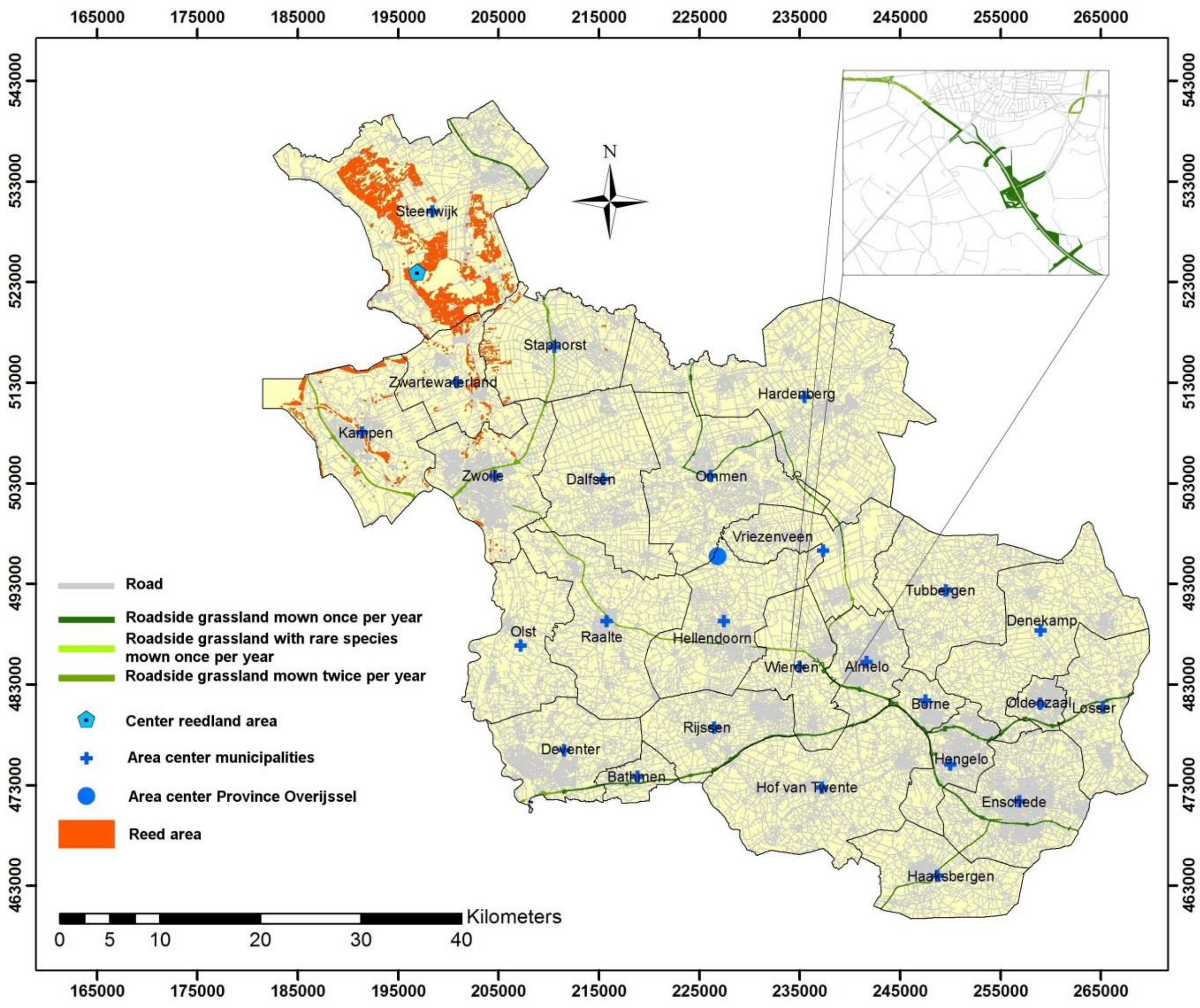
map from Overijssel province



Region map (reed & roadside grass availability &municipality centers)

LGN6 land cover data reedlands (Wageningen Research Centre)

Roadside grass (Rijkswaterstaat)



Biomass quantities & collection periods (flexible seasons)

Municipality	LW - march-april	LW - july-august	LW - november	R - december-february	RG - september-october	RG - may-june
Staphorst	134,8	134,8	67,4	880,0	225,2	225,2
Steenwijkerland	499,6	499,6	249,8	31590,0	275,9	3,4
Kampen	233,2	233,2	116,6	4690,0	843,1	843,1
Zwartewaterland	84,8	84,8	42,4	2120,0		
Zwolle	328,0	328,0	164,0	730,0	480,0	480,0
Dalfsen	277,6	277,6	138,8		32,6	32,4
Ommen	205,2	205,2	102,6		257,0	
Hardenberg	119,6	119,6	59,8		179,1	
Olst-Wijhe	1,2	1,2	0,6	590,0		
Raalte	238,0	238,0	119,0		293,1	290,7
Hellendoorn	476,8	476,8	238,4		127,7	79,0
Wierden	155,2	155,2	77,6		473,3	77,0
Almelo	175,2	175,2	87,6		643,4	129,7
Vriezenveen (twenterand)	436,4	436,4	218,2		158,4	93,0
Tubbergen	230,0	230,0	115,0			
Deventer	550,8	550,8	275,4		425,8	191,2
Rijssen-Holten	475,2	475,2	237,6		448,4	
Hof van Twente	301,6	301,6	150,8		9,1	
Borne	134,8	134,8	67,4		293,5	8,6
Denekamp (Dinkelland)	92,8	92,8	46,4		97,4	
Losser	120,8	120,8	60,4		194,7	
Oldenzaal	150,4	150,4	75,2		185,1	
Haaksbergen	220,0	220,0	110,0		97,8	
Hengelo	360,0	360,0	180,0		494,5	
Enschede	303,2	303,2	151,6		472,9	
Bathmen					253,2	
Total	**6305,2**	**6305,2**	**3152,6**	**40600,0**	**6961,2**	**2453,2**

Data (1/2)

Biomass data	LW	R	RG
Harvest rate	100%	50%	50%
Productivity	Province Overijssel	10 t/ha	8 t/ha
Moisture rate	50%	50%	75%

Operational data			
Daily work	24	hr/day	
Mobile plant capacity	18	t/cycle	6 cycles, 108 t/day
Biomass truck capacity	21	t wet matter	6 cycles, 4 hours/move
Set up time mobile plant	4	hours	
Bio-oil & bio-char truck capacity	16	t	
Harvested biomass price	20	€/t	
Transportation cost per km	1,26	€/km	
Average ransportation distance to mobile plant location	5,4	km	
Average ransportation distance to Botlek refinery	200	km	

Pyrolysis data	R & RG	LW	
Bio-oil produced	0,525	0,643	t/t dry biomass
Bio-char produced	0,250	0,140	t/t dry biomass
Gas produced	0,225	0,217	t/t dry biomass
HHV bio-oil	13,3	16,9	MJ/kg bio-oil
HHV bio-char	35,0	35,0	MJ/kg bio-char
HHV gas	11,0	11,0	MJ/kg gas
Heat required for pyrolysis	2857	2333	MJ/t bio-oil

Data (2/2)

Hydrodeoxgynegation data			
H2	237	L/kg bio-oil	
Upgraded oil	0,49	t/t bio-oil	
Acqeous phase	0,33	t/t bio-oil	
Gas (with 50% CO2)	0,04	t/t bio-oil	
Water	0,10	t/t bio-oil	

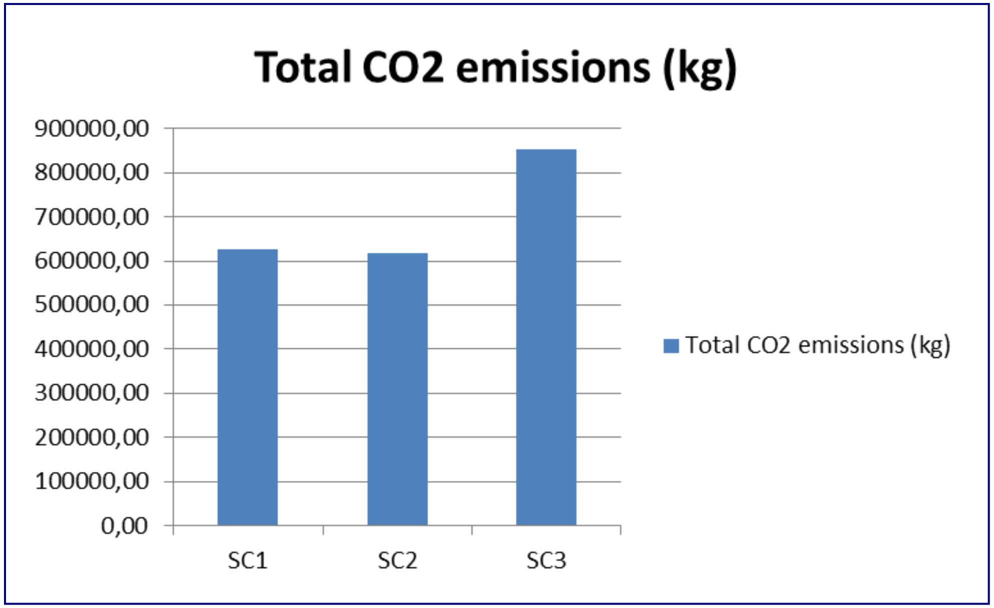
Outputs from processes

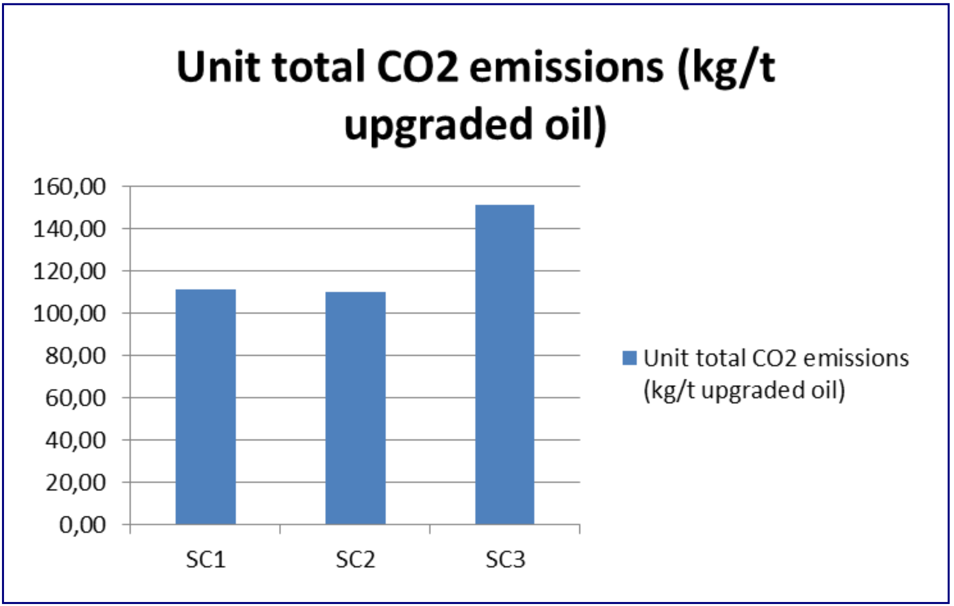
Harvested wet biomass	44300 t	15763 t LW, 20300 t R, 8238 RG	
Pyrolysis bio-oil	11478 t	5068 from LW, 5328 from R, 1081 from RG	
Upgraded oil from HDO	5624 t		
Diesel for blending (SC1)	16872 t	Total blended oil	22496 t
Diesel for blending (SC2)	16872 t	Total blended oil	22496 t
Refined gasoline an diesel (SC3)	3206 t gasoline,169 t diesel	Total blended oil	3374 t

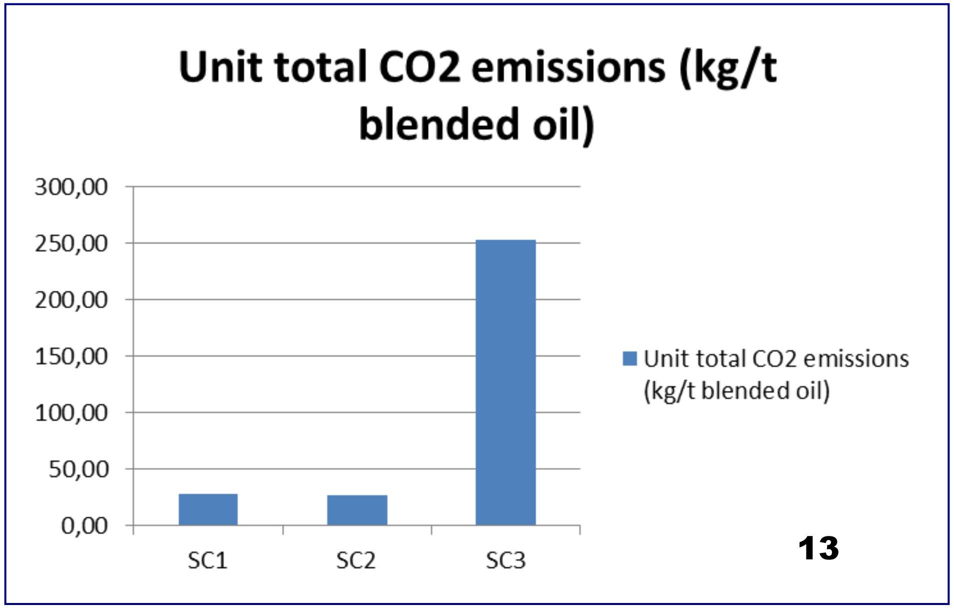
Considerations, assumptions, and remarks

- In each set-up of mobile plant, fuel-oil is used to heat the system up
- Produced (pyrolysis) gas is used to re-feed the system
- Produced bio-char is sold in the market by a price of 60 €/ton
- Unit performance (cost/t output, CO_2/t output, etc.) calculations are done according to two outputs: (i) upgraded-oil from HDO and (ii) blended-oil (or refined oil for SC3)
- Values are annual (costs, CO_2, labor created, etc.)
- For all scenarios 10% mark-up is used for final output prices: therefore unit profit is the main indicator for economic convenience
- No taxation considered
- CO_2 emissions refer to the supply chain processes (not from cradle to grave; aim is comparing scenario performance)

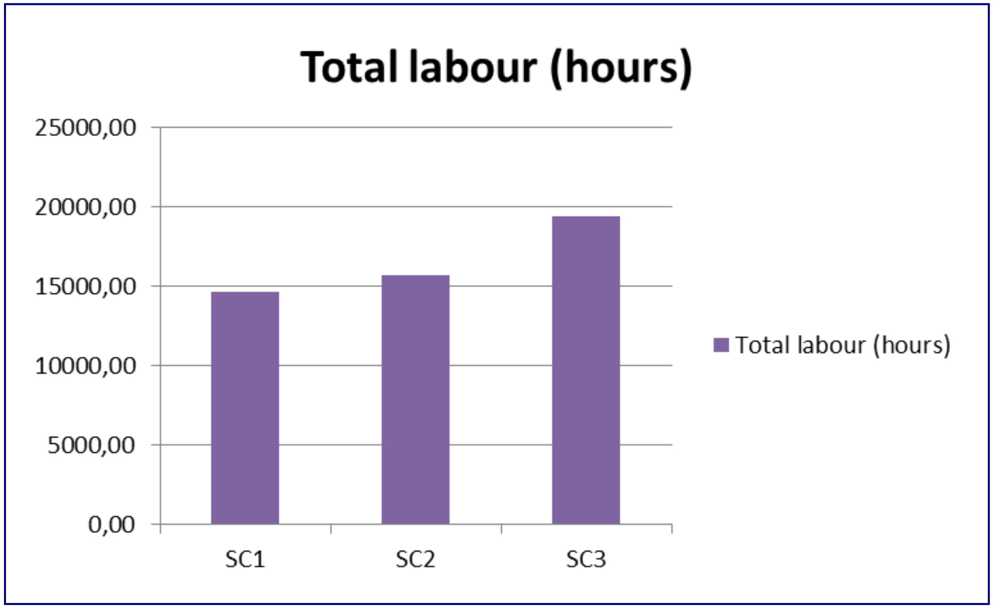
Results – CO2 emissions

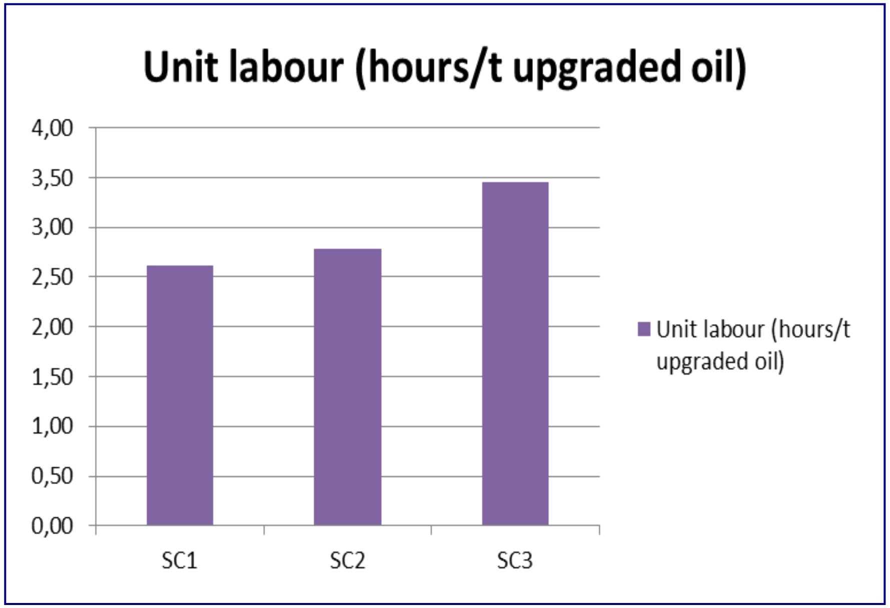


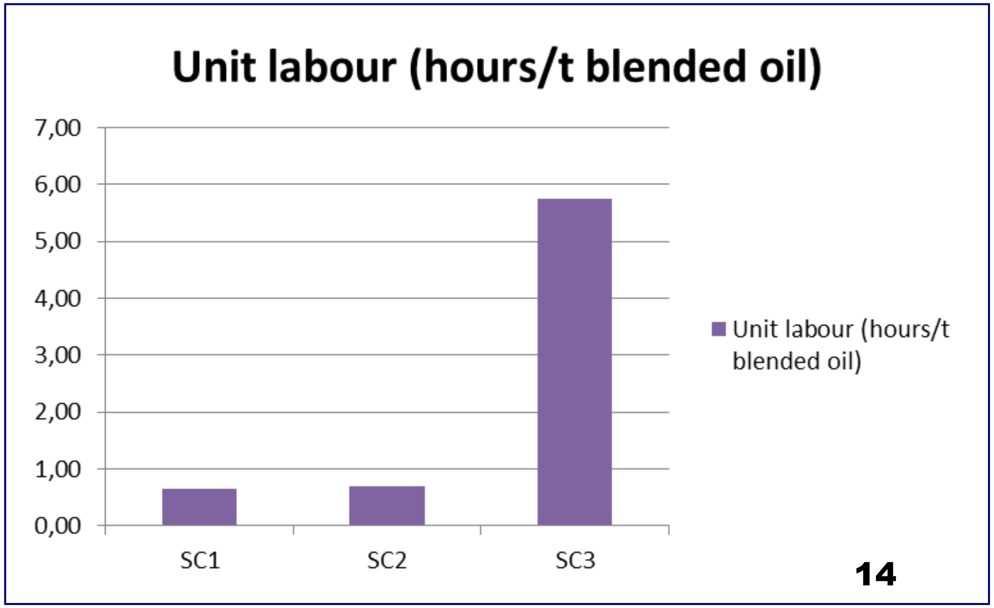




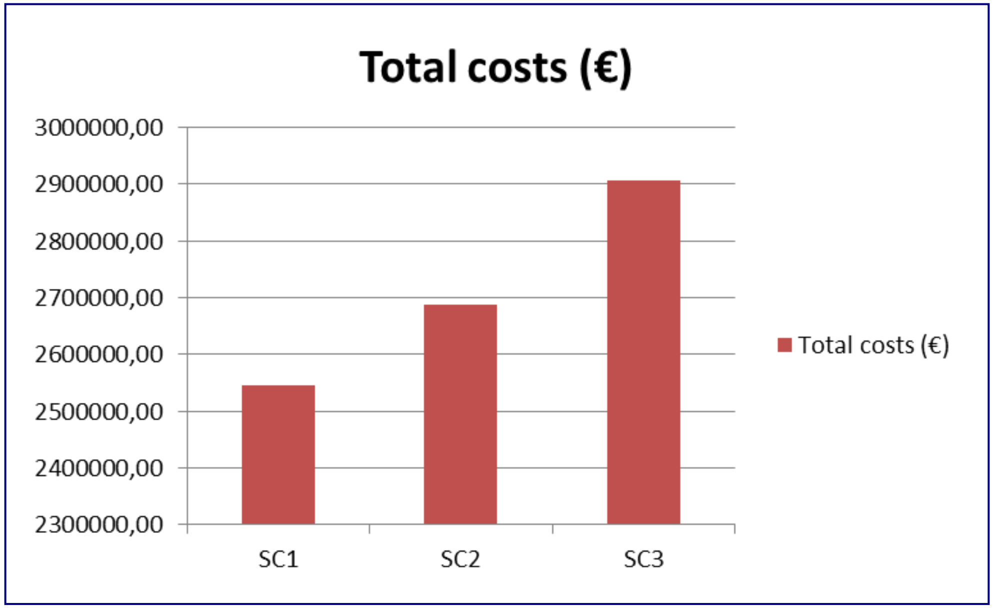
Results – labour created

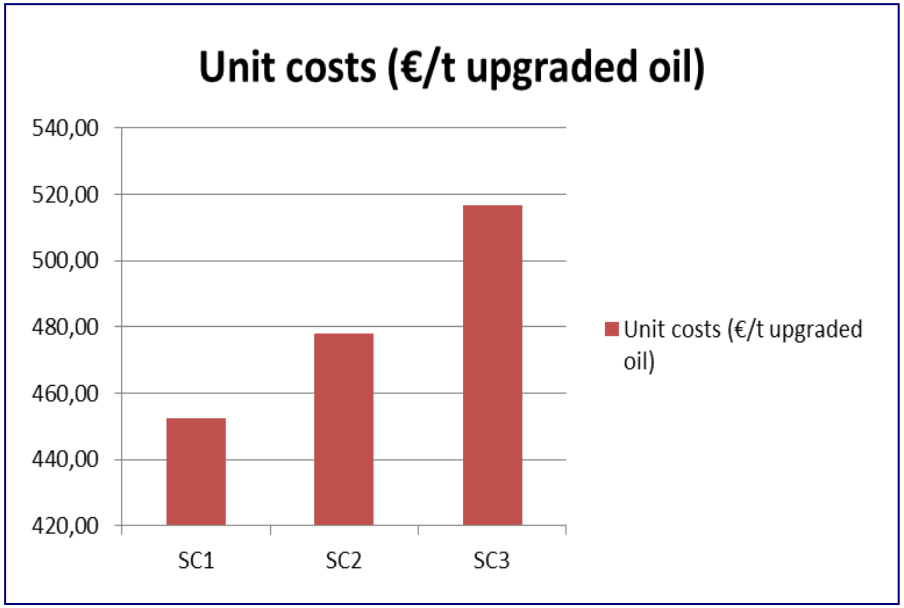


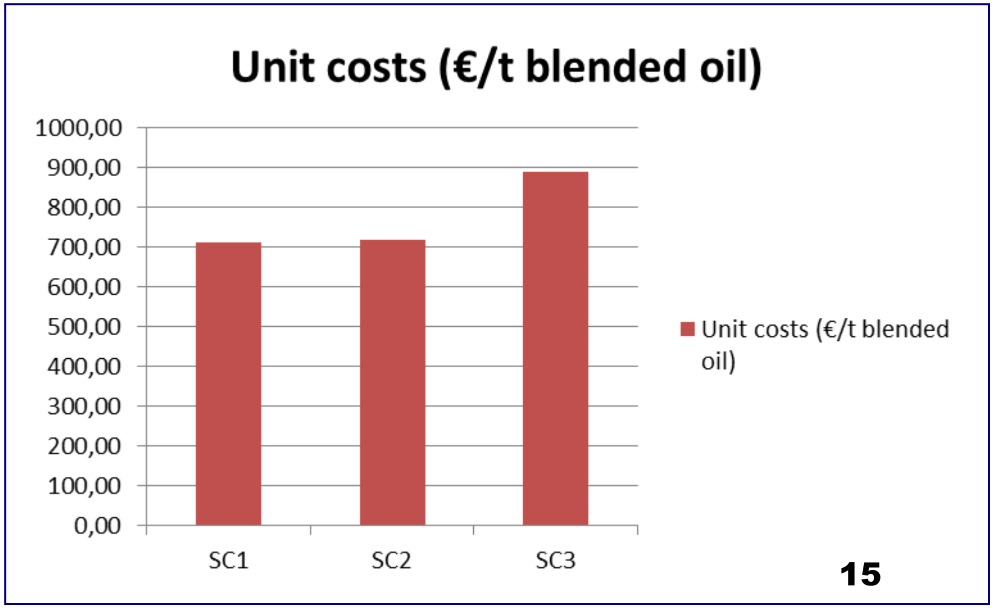




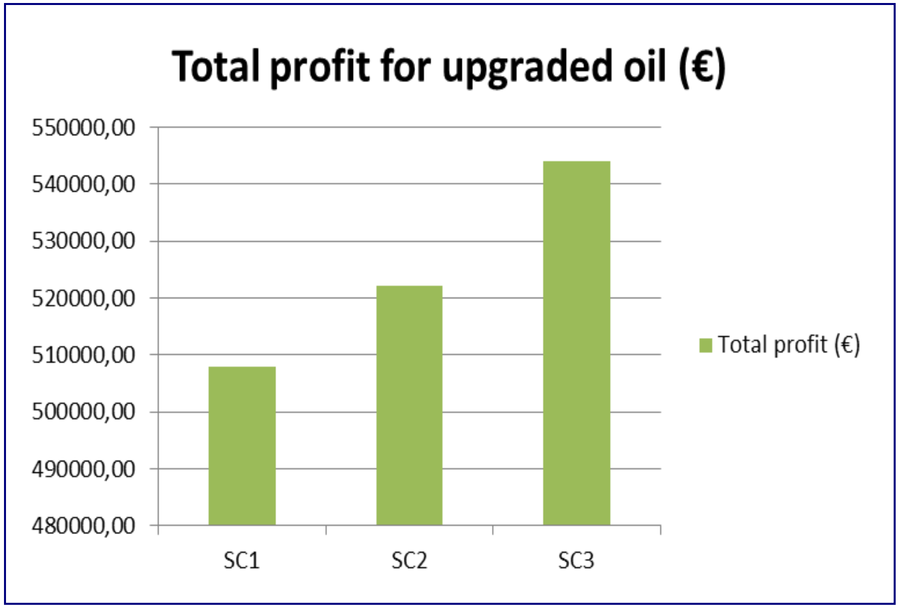
Results – total costs

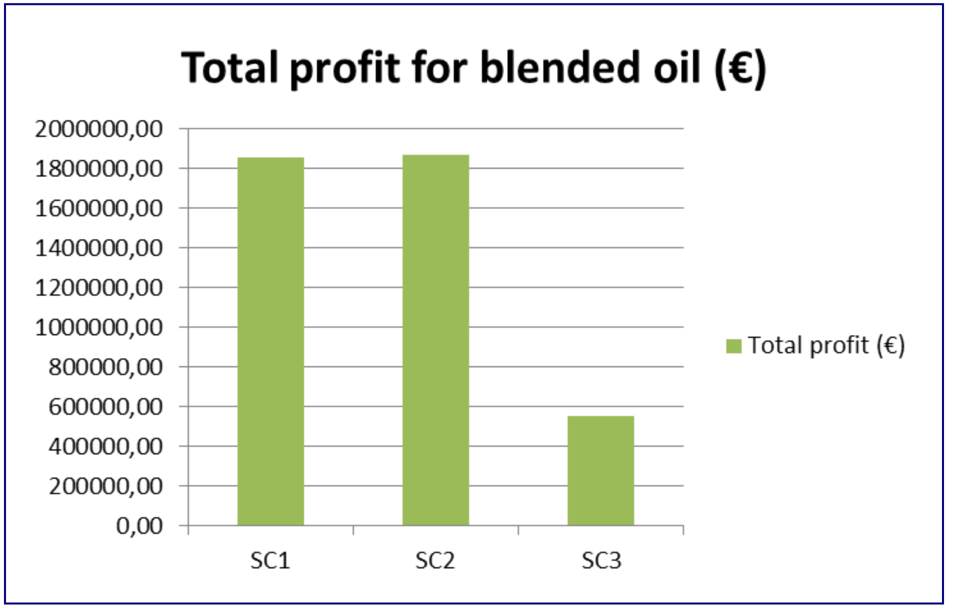


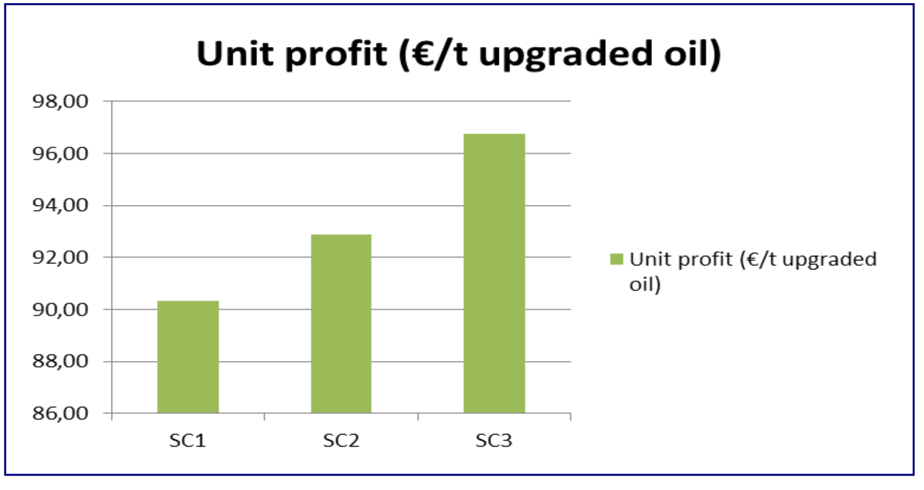


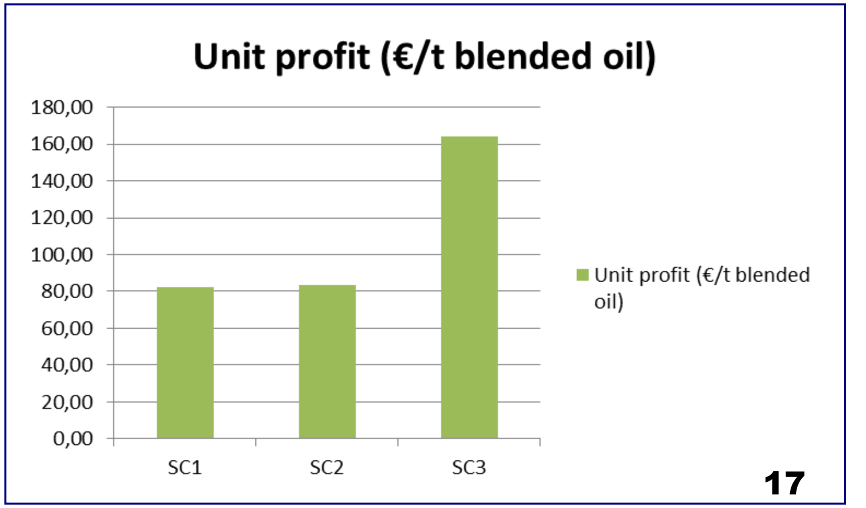


Results – profit



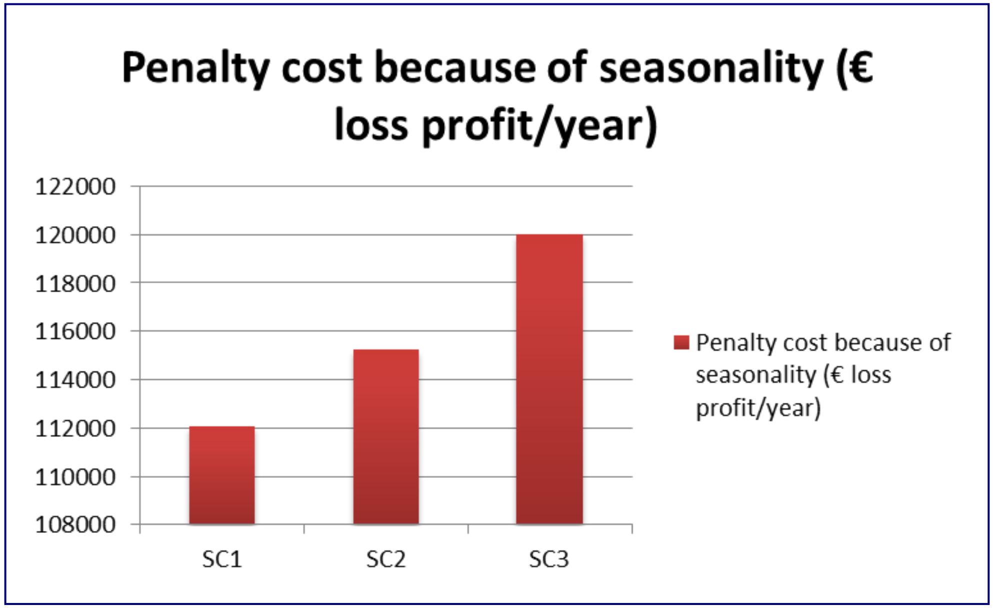






Impact of seasonality (limited collection periods)

- Collection periods are pre-defined
- No collection allowed out of the pre-defined period
- Penalty costs caused by unprocessed biomass



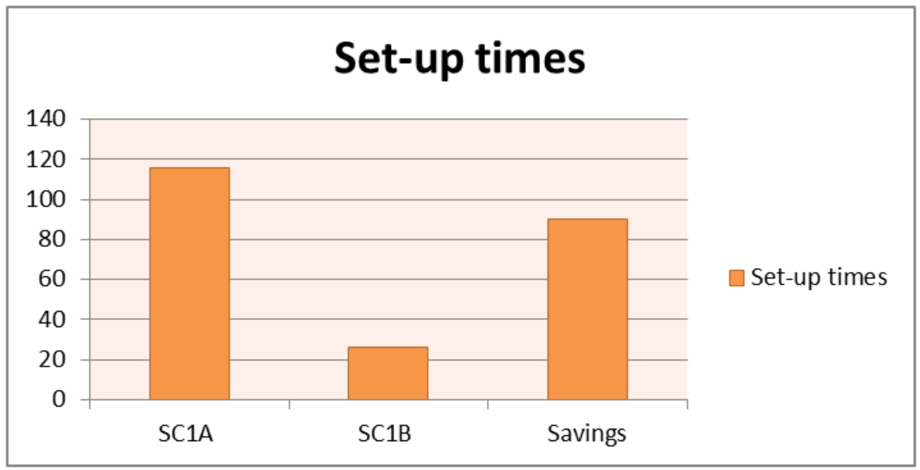
- 221t LW unprocessed on November, 18754 t R unprocessed in December-February
- 22,07% loss of total expected profit for all cases

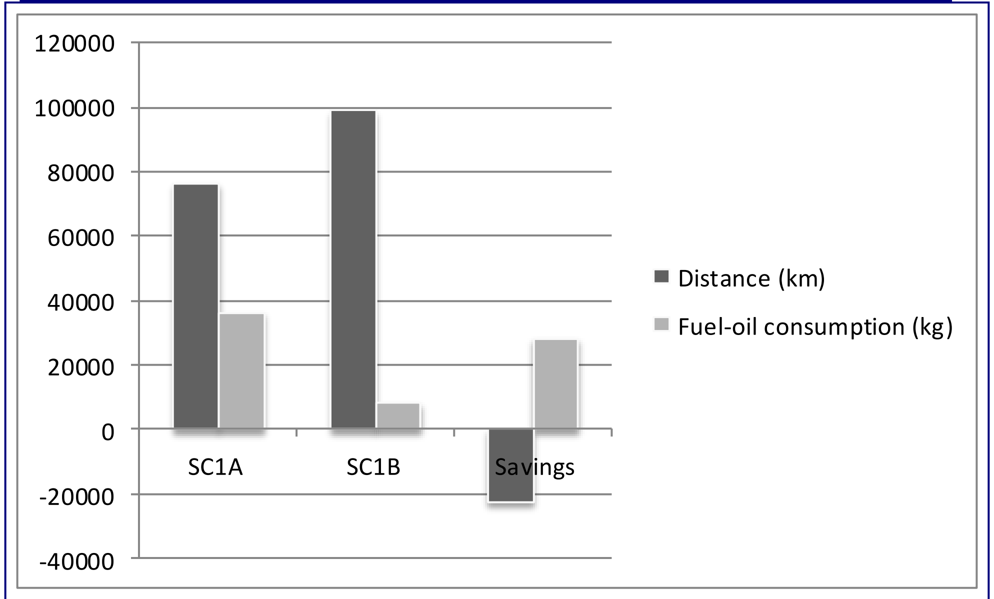
Impact of land aggregation

Municipality
Almelo
Bathmen
Borne
Dalfsen
Denekamp (Dinkelland)
Deventer
Enschede
Haaksbergen
Hardenberg
Hellendoorn
Hengelo
Hof van Twente
Kampen
Losser
Oldenzaal
Olst-Wijhe
Ommen
Raalte
Rijssen-Holten
Staphorst
Steenwijkerland
Tubbergen
Vriezenveen (twenterand)
Wierden
Zwartewaterland
Zwolle

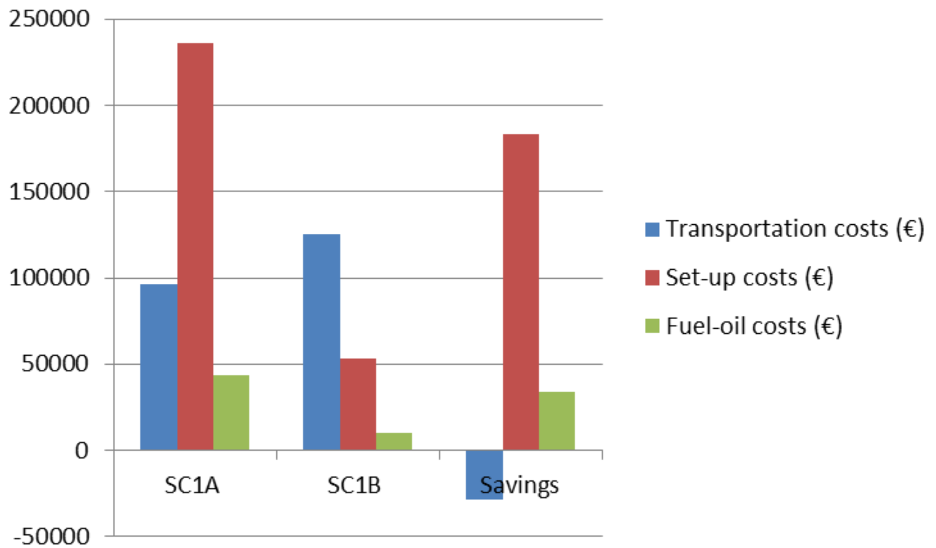
- Some municipality lands are aggregated in 5 groups
- To understand the impact of changed transportation distances and set-up times
- Average distance to mobile plant locations from 5,4 km to 13 km

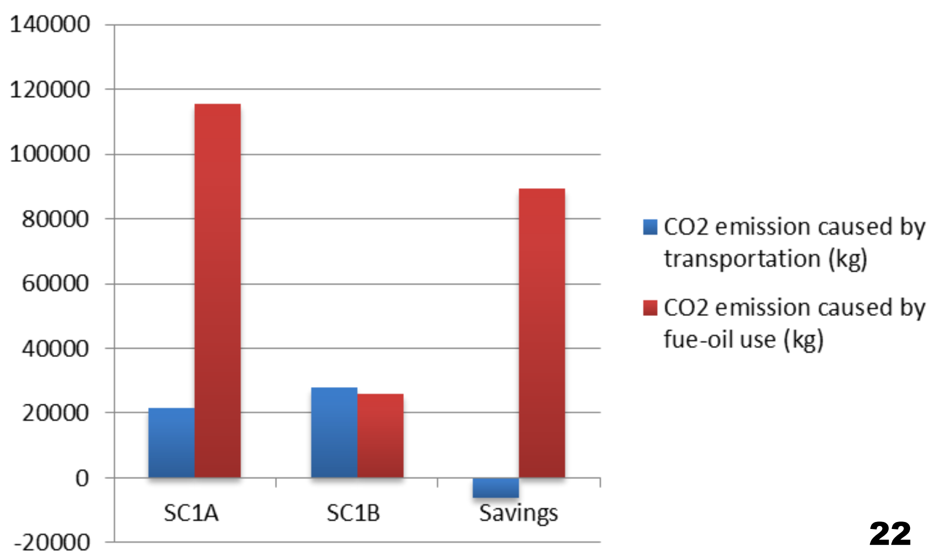
Impact of land aggregation / set-up times, distance, and fuel-oil consumption





Impact of land aggregation / CO2 emissions and costs





Practical implications

- Among the three, Scenario 1 appears as the most cost-effective: mobile pyrolysis plant convenient
- Set-up costs are more dominant cost components compared to transportation
- Harvesting costs are higher compared to transportation costs
- Sensistivity analysis: distance, truck/plant capacity, harvest rate, moisture content, dispersion degree, H2 or biomass price

Managerial implications

- Scenario 3 can still be considered as economically feasible: If no oil refinery nearby, then regional marketing options should be considered

- Scenario 3 particularly appears as the best for unit profit: Attractive for oil refineries

- Capacity of the vehicles is key factor: Capacity fit between biomass collection trucks and mobile plants to reduce operational penalty costs

- Possible reuse of blended oil in own supply chain (e.g. harvesting/collection machinery): Self-sustainability

Thanks for your kind attention!

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