Circular Bioeconomy Days

Aarhus University 25/6/2019

The dual bottom line in realising the circular bioeconomy

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Nordic Green Growth

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From linear to circular economy

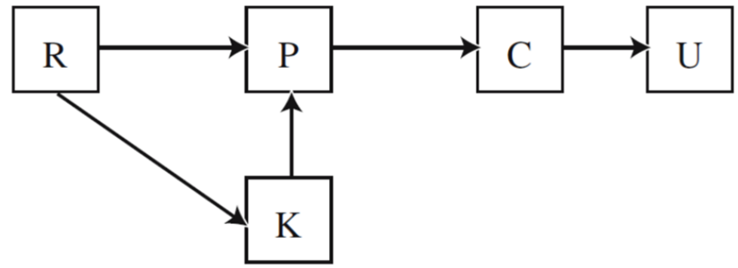
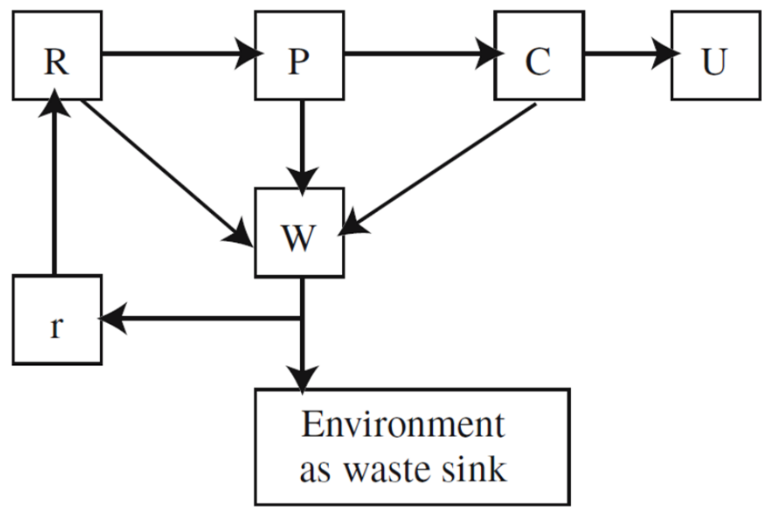


Fig. 1 The conventional open-ended economy. *P* production, *C* consumption, *K* capital goods, *U* utility, *R* natural resources



Sustain Sci (2007) 2:133–140
DOI 10.1007/s11625-006-0013-6

Fig. 2 The simplified circular economy. *r* Recycling, *W* waste

Four economic functions of the environment

- Resource base to the economy
- Waste sink for residual flows
- Life-support system
- Amenity values

Circular economy flows (utility/material/energy)

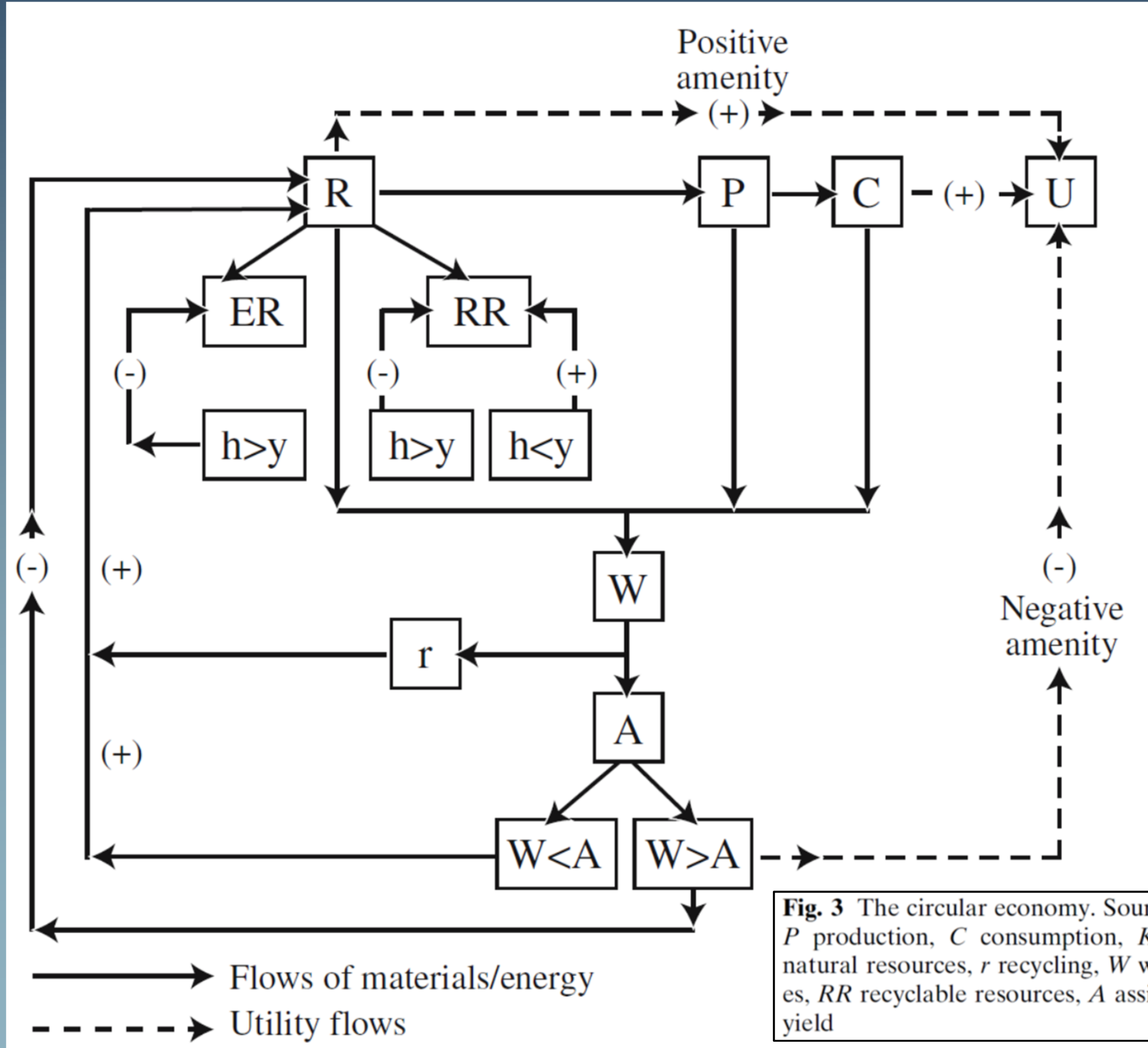
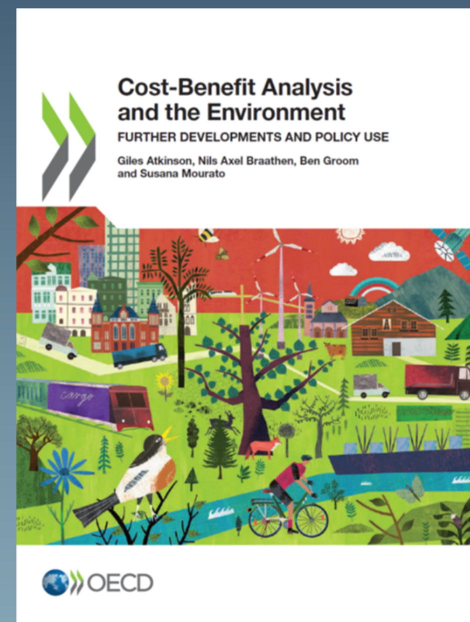


Fig. 3 The circular economy. Source: Pearce and Turner (1990). *P* production, *C* consumption, *K* capital goods, *U* utility, *R* natural resources, *r* recycling, *W* waste, *ER* exhaustible resources, *RR* recyclable resources, *A* assimilative capacity, *h* harvest, *y* yield

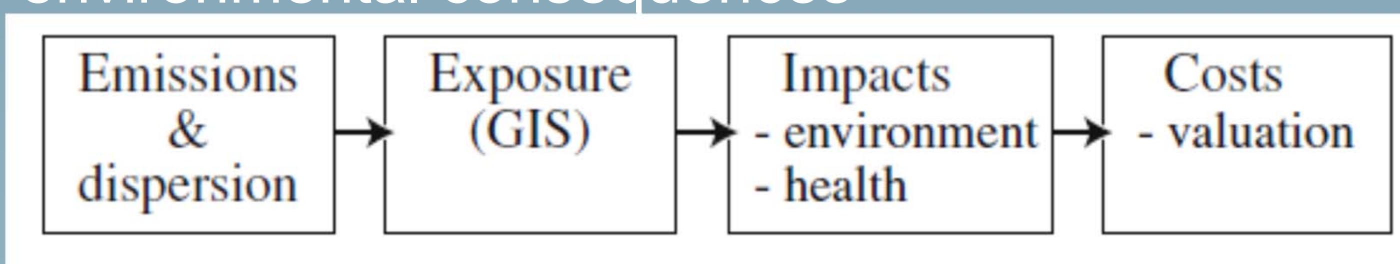
Socio-economic assessment

Sum of economic benefits should exceed sum of costs;

- Market valuation of utility
- Contingent valuation of environmental external costs

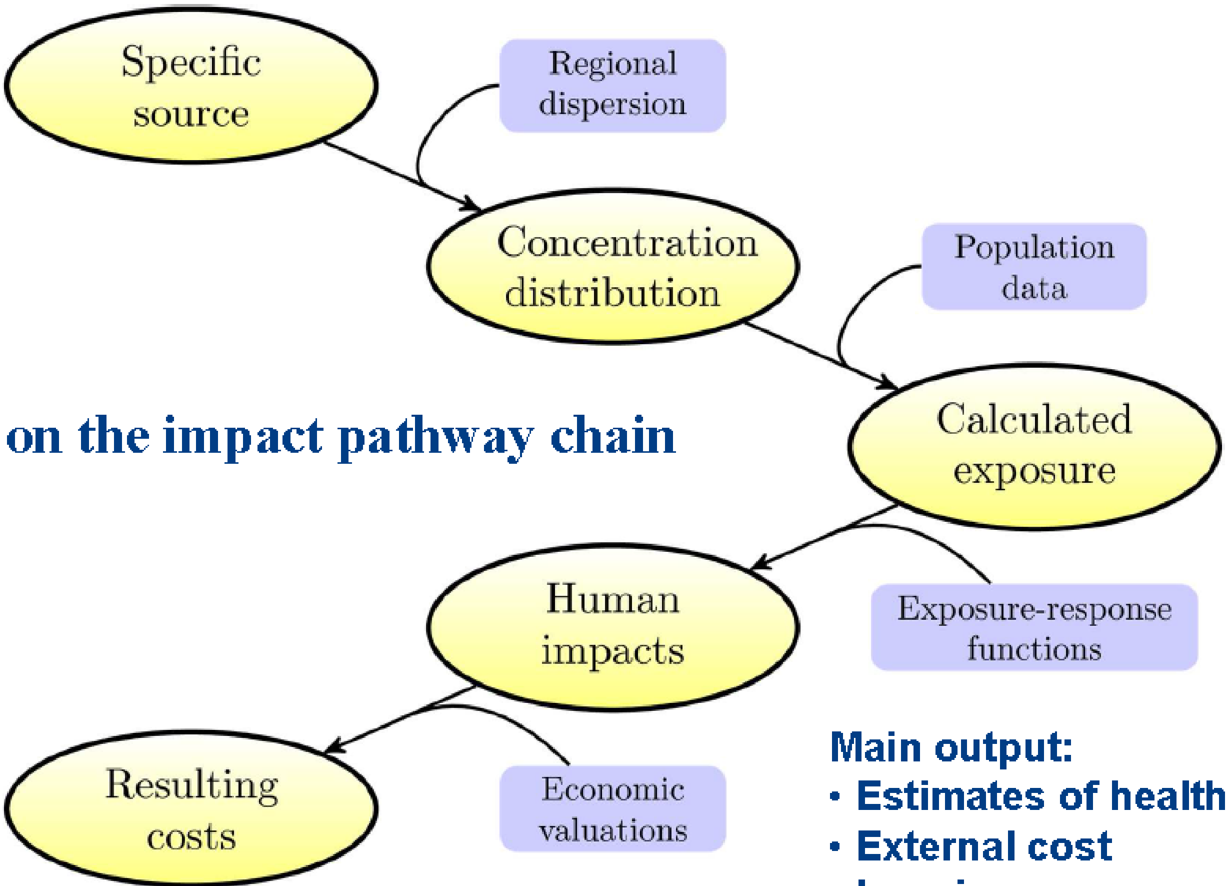


Impact pathway analysis to account for environmental consequences



Costing air pollution with the EVA model

The EVA system – Economic Valuation of Air pollution



Based on the impact pathway chain

Main output:
- **Estimates of health impacts**
- **External cost**
- **kg prices**

Brandt et al., 2013, Atm. Chem. and Phys., Vol. 13, pp. 7725-7746 & pp. 7747-7764, 2013

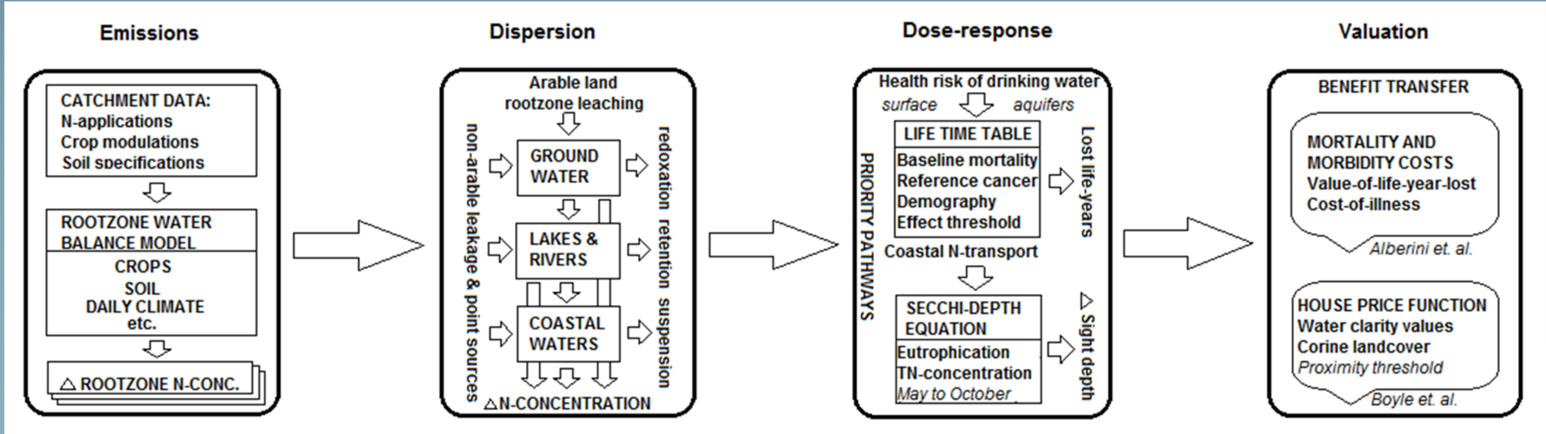
Air pollution external costs (EVA model)

External costs (Mio. €$_{2016}$)	SO_2/SO_4	O_3/NO_3	$PM_{2.5}$	NH_3/NH_4
Chronic mortality (lost lifeyears)	225	1,516	932	764
Hospitalizations	1	19	6	7
Astmatics	0	0	0	0
Bronchitis/COPD	6	37	23	19
Sickdays etc.	25	169	105	85
Lung cancer (morbidity)	0	1	1	1
Acute mortality	119	1,579	488	532
Sum	375	3.321	1,555	1,408
Share on DK territory	9%	24%	54%	17%
Emissions (tons)	9,158	97,426	20,255	70,046
Unit costs (€$_{2016}$ pr. kg)	**41**	**34**	**77**	**20**

DCE, 2019

Water pollution external costs

- Phosphorous loss to freshwater bodies;
  - Denmark tax rate: €22/kgN
- Nitrogen loss to coastal waters;
  - Denmark tax rate: €4/kgN
  - Impact pathway analysis: €6.3/kgN (average)



Marine Pollution Bulletin 140 (2019) 146–156

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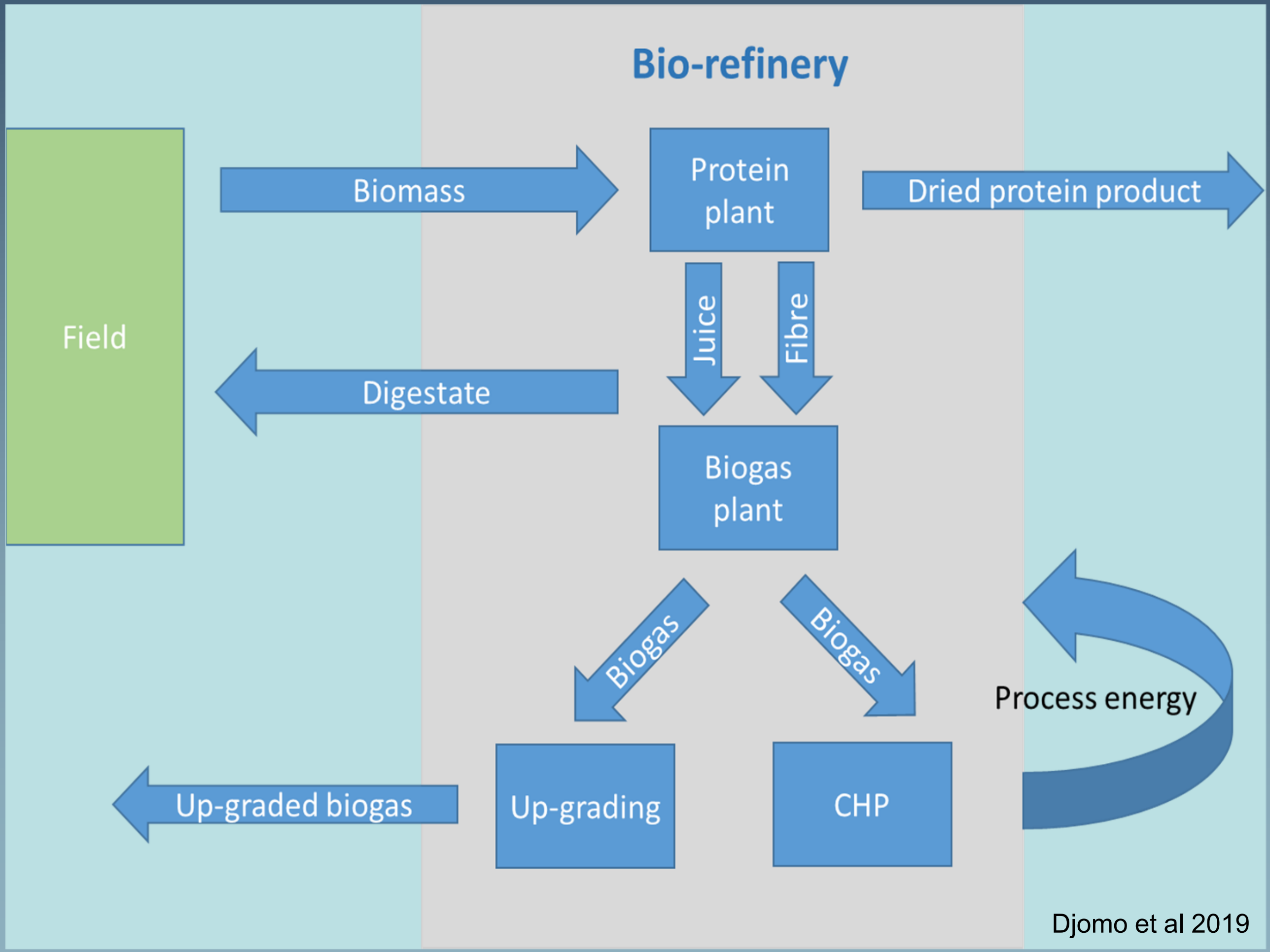
Grass Bio-refinery - Protein Plant

- Aim: substitute imported feed and fossil fuels while creating added value
- Small scale vs. large scale scenarios
- Stand alone protein plant not commercially viable

	Small scale plant	**Large scale plant**
Annual DM input (ton):	20,000	150,000
	Total (DKK/year)	Total (DKK/year)
Expenditure		
Grass – farmers	12,778,575	95,858,385
Grass – harvesting	6,925,455	55,409,325
Labour	1,800,000	7,200,000
Energy	-	-
Investment	2,744,866	16,469,194
Maintenance	1,000,000	6,000,000
Sum	*25,248,896*	*180,936,904*
Income		
Residue juice	-	-
Fibre fraction	13,758,003	
Protein product	9,455,415	70,915,611
Sum	*23,213,417*	*70,915,611*
Result	**-2,035,478**	**-110,021,293**

Source: Martinsen and Andersen, DCE, in prep.

Grass Bio-refinery for Protein Feed and Biogas



Djomo et al 2019

Grass Bio-refinery for Protein Feed and Biogas

- Add biogas CHP production based on grass residuals with manure
- with upgrading to natural gas grid
- Viable commercially with economic support for biogas

	Small scale plant	**Large scale plant**
Annual DM input (ton):	20,000	150,000
	Total (DKK/year)	Total (DKK/year)
Expenditure		
Labour	300,000	5,800,000
Energy	-	-
Investment – biogas plant	530,261	28,726,901
Maintenance – biogas plant	28,088	12,173,328
Investment - upgrading	-	11,558,974
Taxes	29,951	490,767
Sum	*888,299*	*58,749,970*
Income		
Digested biomass	767,917	23,328,750
Sale of biomethane	535,841	26,103,794
Subsidies	3,003,024	117,743,944
Sum	*4,306,782*	*167,176,488*
Net result	**3,418,483**	**108,426,518**

Source: Martinsen and Andersen, DCE, in prep.

Grass Bio-refinery – the second bottom line

LCA based	**Small scale plant**	**Large scale plant**
	Total (DKK/year)	Total (DKK/year)
External effects in DK		
GHG emissions	-166,088	4,505,256
Air pollution	-38,614	-873,147
N-leaching	201,895	-3,723,808
P-leaching	71,272	535,413
Ammonia emissions	-247,350	-1,848,750
Cadmium	-61,069	-458,048
Non road transport (field work)	25,145	188,601
Road transport	-188,583	-2,828,931
Total external effects	**-403,392**	**-4,503,415**

Source: Martinsen and Andersen, DCE, in prep.

Land use GHG emissions change - breakdown

Source of change	Small scale scenario (ton CO2-eq.)	Large scale scenario (ton CO2-eq.)
Carbon sequestration (ton/year)	-1,936	-14,517
Fertiliser substitution – change in Soil C (ton/year)	-196	-11,280
N2O emisisons – direct and indirect (ton/year)	2,960	22,204
Net change (ton/year)	828	**-3,593**

- Paradox: small plant scenario increases GHG, while large scale plant scenario reduces GHG from land use
- Due to regional differences in reference scenario for the two plants

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Observations and findings

- Bio-refinery protein plant with biogas is commercially viable for small plant scenario, and with biogas feed-in-tariffs, also for large plant scenario
- The external costs are negative for the small as well as the large plant scenario, considering Denmark
- Intensification of mineral fertilizer use is key to this result
- GHG reduction from soy substitution not considered, as soy may find other buyers in world market
- Total economic welfare is positive for the small plant scenario and negative for the large plant scenario – though uncertainties large

Nordic bio-economy targets: 5 x win ??

- Employment opportunities (JOB)
- Economically viable business models (ECON)
- Competitive biobased industries (COMP)
- Sustainable resource management (SUS)
- Climate change mitigation (CLIM)

Accomplishment of bioeconomy targets – integration ?

Table 1: Case sample

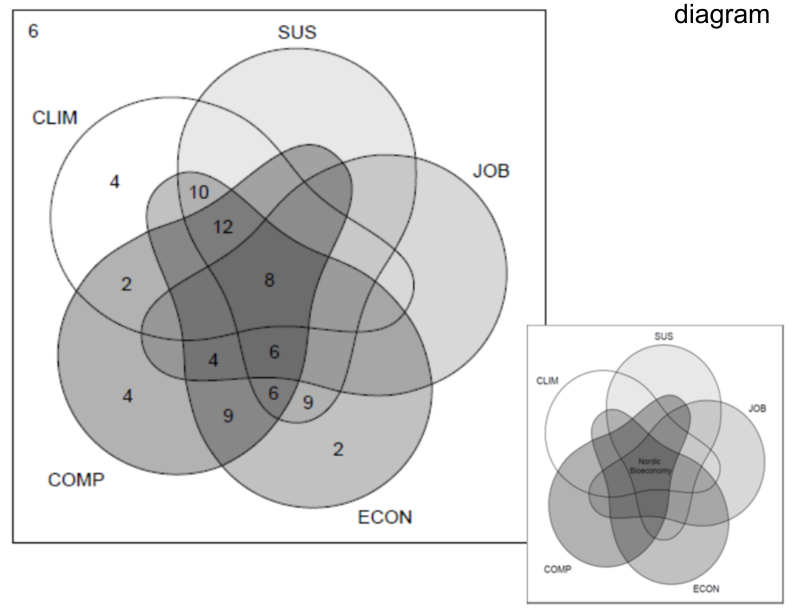
Case ID	Case name(based on JRC database)	Country
Elec1	Electricity_dairy cow slurry	DEN, FIN, SWE
Elec2	Electricity_biowaste	DEN, FIN, SWE
Elec3	Electricity_food waste	DEN, FIN, SWE
Elec4	Electricity_wheat straw	DEN, FIN, SWE
Elec5	Electricity_wood industry residues	DEN, FIN, SWE
Elec6	Electricity_agricultural residues	DEN, FIN, SWE
Elec7	Electricity_forest loggin residues	DEN, FIN, SWE
Elec8	Electricity_poplar	DEN, FIN, SWE
Elec9	Electricity_stemwood	DEN, FIN, SWE
Biodiesel1	Biodiesel_microalgae	DEN, FIN, SWE
Biodiesel2	Biodiesel_used cooking oil	DEN, FIN, SWE
Biodiesel3	Biodiesel_animal fat	DEN, FIN, SWE
Biodiesel4	Biodiesel_rapeseed	DEN, FIN, SWE
Biodiesel5	Biodiesel_sunflower seed	DEN, FIN, SWE
Bioethanol1	Bioethanol_forest logging residues	FIN, SWE
Bioethanol2	Bioethanol_wheat straw	FIN, SWE
Bioethanol3	Bioethanol_black liqour	FIN, SWE
Bioethanol4	Bioethanol_poplar	FIN, SWE
Bioethanol5	Bioethanol_giant reed	FIN, SWE
Bioethanol6	Bioethanol_cereal mix	FIN, SWE
Bioethanol7	Bioethanol_maize	FIN, SWE
Bioethanol8	Bioethanol_sugar beet	FIN, SWE
Chemi1	Chemi_1.3 propanediol	DEN, FIN, SWE
Chemi2	Chemi_lactic acid	DEN, FIN, SWE
Chemi3	Chemi_acetic acid	DEN, FIN, SWE
Chemi4	Chemi_succinic acid	DEN, FIN, SWE
Chemi5	Chemi_adipic acid	DEN, FIN, SWE
Fiber1	Fiber_viscose	DEN, FIN, SWE
Fiber2	Fiber_modal	DEN, FIN, SWE
Fiber3	Fiber_tencel	DEN, FIN, SWE

Note that there is no data on the bioethanol industry in Denmark in the JRC databases. Therefore, only 22 cases are assessed in the Danish context, while all 30 are assessed in the Finnish and Swedish contexts.

- 8 of 82 cases achieve all 5 aims

Figure 1.3: The potential for policy integration in the Nordic bioeconomy

Venn diagram

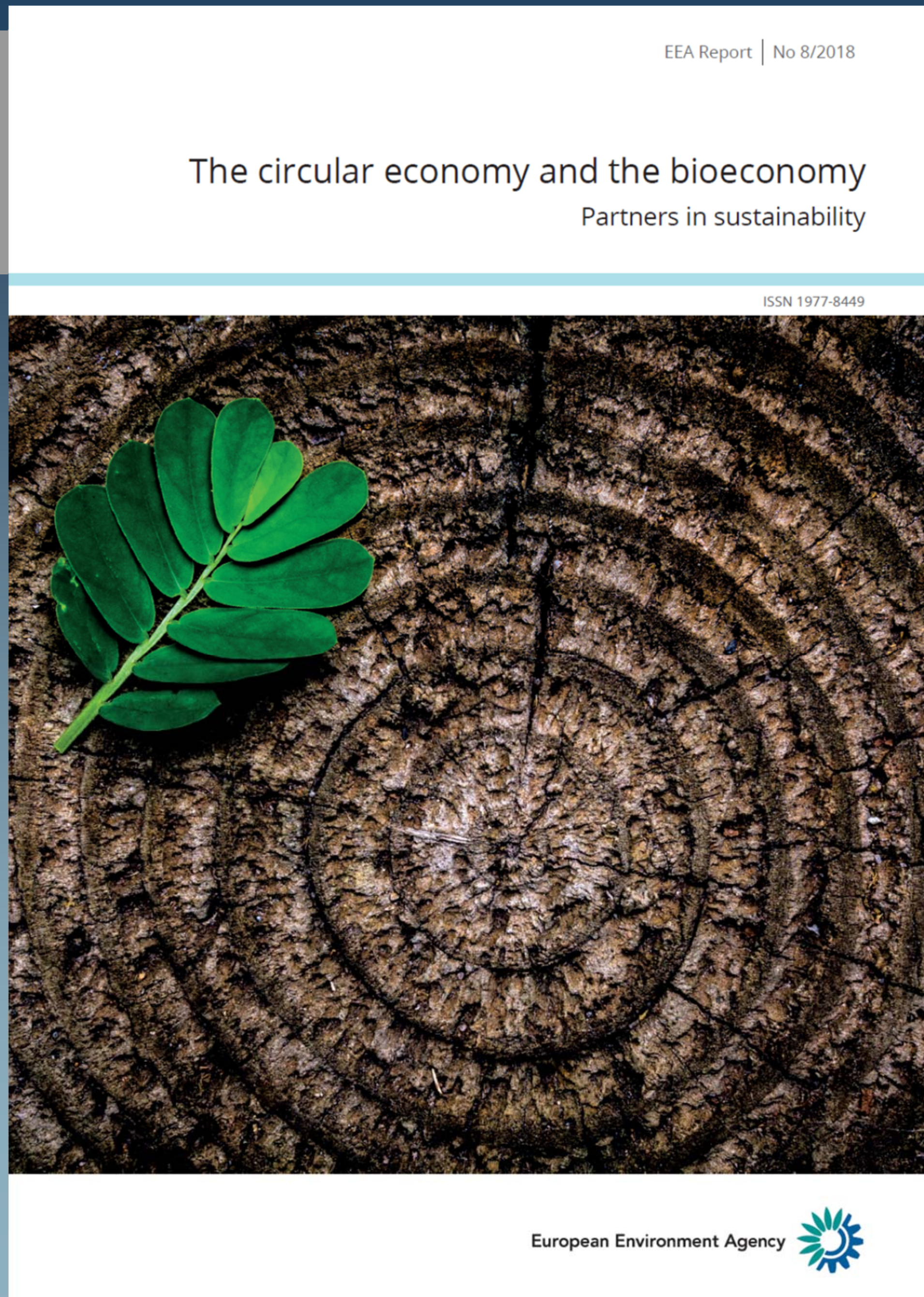


Case distribution. Compare with Figure 1.2 on page 5

Source: Lotte Dalgaard Christensen, 2019

Further reading

The upscaling of innovations aimed at improving sustainability can lead to unintended side-effects. Technological innovation starts in the confined environment of a laboratory, where elements such as supply limitations, logistics and economies of scale do not apply. These elements, however, will define the sustainability of the innovation when it is implemented on a large scale.



https://www.eea.europa.eu/publications/circular-economy-and-bioeconomy

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Thank you!

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New Nordic Ways to Green Growth.
Strengthening the foundation for technological green growth innovation policy
http://projects.au.dk/nowagg/