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Absorbing shocks: Designing an agriculture vegetative waste management system resilient to final product price fluctuations

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Research questions

The agricultural sector in Israel produces annually 1,481,421 tons of vegetative waste

- 1,167,492 tons of foliage waste (around 79%)
- 172,421 tons of woody waste (around 11%)
- 141,509 tons of fruits and vegetables waste (around 10%)

There are 6 existing technologies that were found economically feasible

- Each one can treat specific types of vegetative waste
- Investment and operational costs are known
- Prices of final outputs can be assessed ...

  but can fluctuate widely and are hard to predict

Research questions

- What is the optimal Waste Management System (WMS) for vegetative waste if entrepreneurs are indifferent to the risk of final product price fluctuation?

  (i.e., are ***risk-neutral***)

- What is the optimal WMS for vegetative waste under a ***risk-averse*** assumption?

Basic model – Risk neutrality

Treatment technologies, inputs and main outputs:

Treatment technology	Main output	Foliage	Woody	F&V	Total cost*	Market price*	Profit*
Torrefaction	Charcoal		X		124	420	296
Pyrolysis	Biochar	X	X		185	300	115
Animal feed	Mixing	X		X	153	245	92
RDF	RDF	X	X		196	272	76
Composting	Compost	X		X	119	195	76
Anaerobic	Biogas	X			73	137	64

The solution is:

- Torrefaction is the most profitable technology but it treats only woody waste. All this type will be allocated to it.
- Pyrolysis is the second best. Woody waste is already treated so all the foliage will be allocated to it.
- Animal feed is the most profitable technology for F&V waste, and all F&V will be allocated to it.

Basic model – Risk neutrality

What is the sensitivity of the model to final price fluctuations?

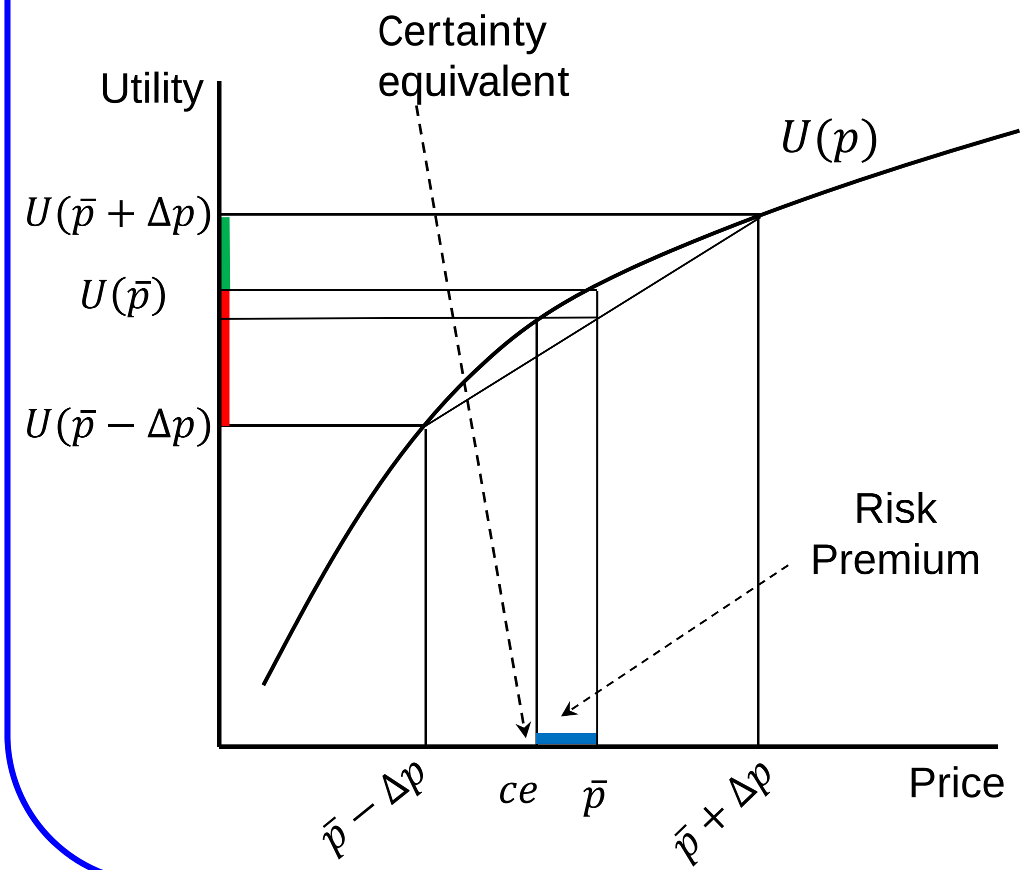
	Torrefaction	Pyrolysis	Animal-feed	RDF	Composting	Anaerobic
Torrefaction	**420**	239	216	201	200	188
Pyrolysis	481	**300**	277	262	261	249
Animal-feed	449	268	**245**	230	229	216
RDF	491	310	287	**272**	271	259
Composting	415	234	211	196	**195**	183
Anaerobic	369	188	166	150	149	**137**

The diagonal shows the original prices of each technology.

The other figures are the break-even prices between each couple.

Risk-aversion model

Risk-aversion regarding uncertain final product prices means that the marginal utility of higher prices diminishes (the utility function is concave)



Assume fluctuating prices with equal chance of increasing or decreasing relative to the mean

If price goes up, the *utility increase* is less than the *utility decrease* when price goes down

A risk-averse agent will be willing to get in certain a price lower than the average one, if the certain price provides the same utility as the average utility.

The "certainty equivalent" price equals the average price minus a "risk premium."

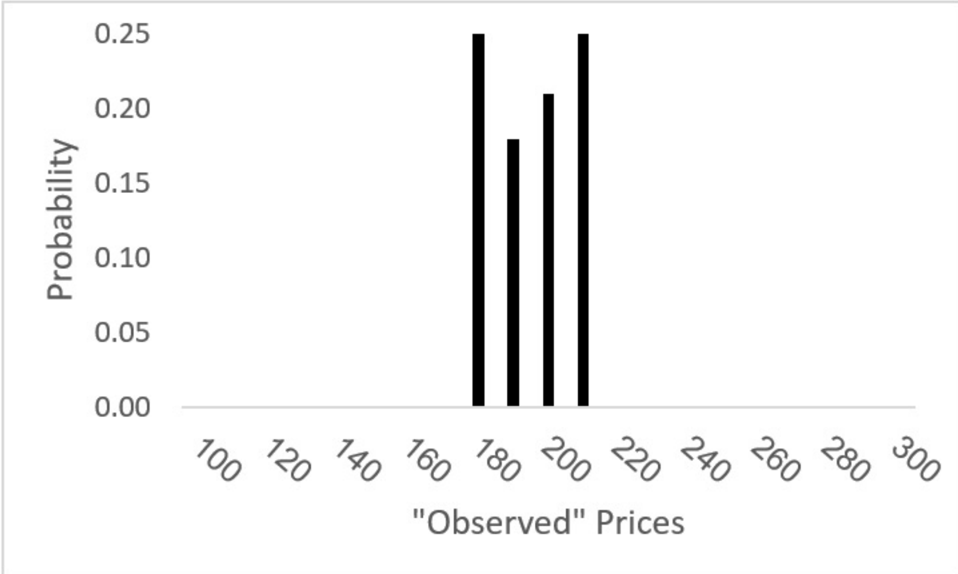
Risk-aversion model

The Certainty Equivalent (CE) is defined as

- Price minus Cost minus Risk Premium
- And that Risk Premium is related to the Coefficient of Variation (CV) of the final prices

What is the CV ?

- A measure of final prices' dispersion
- Defined as the ratio of the standard deviation to the mean (average).



Average ~ 200

Std Dev ~ 12

CV = 0.063 (very low)

Risk-aversion model

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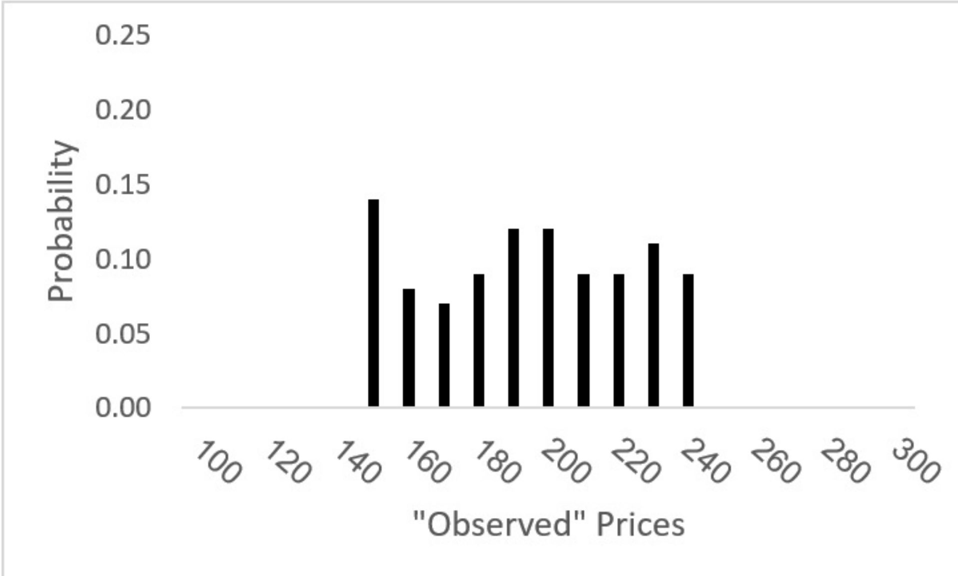

Average ~ 200

Std Dev ~ 28

CV = 0.144 (higher)

Risk-aversion model

The Certainty Equivalent (CE) is defined as

- Price minus Cost minus Risk Premium
- And that Risk Premium is related to the Coefficient of Variation (CV) of the final prices

What is the CV ?

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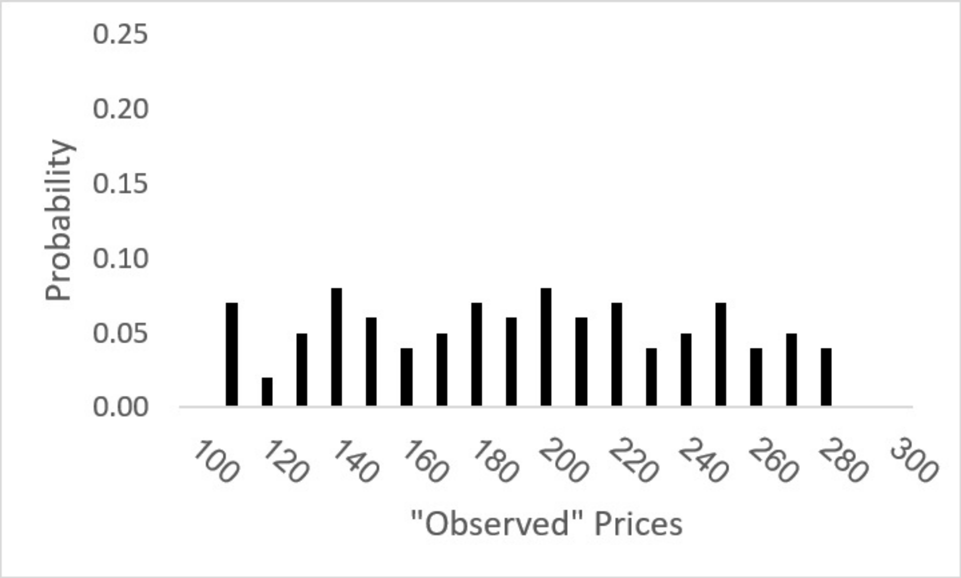


Average ~ 200

Std Dev ~ 50

CV = 0.250 (much higher)

Risk-aversion model

The Certainty Equivalent (CE) is defined as

- Price minus Cost minus Risk Premium
- And that Risk Premium is related to the Coefficient of Variation (CV) of the final prices

Conclusion 1: A higher CV means a larger price distribution and therefore ***more risk***. So the Risk Premium need to be larger...

Conclusion 2: There is a CV value so high that the Risk Premium associated with it zeroes the Certainty Equivalent ...

... and the technology is no longer viable.

Risk-aversion model

The Certainty Equivalent (CE) is defined as

- Price minus Cost minus Risk Premium
- And that Risk Premium is related to the Coefficient of Variation (CV) of the final prices

CV's of several recycled materials (*):

Product	CV
Recycled glass	0.095
Recycled paper and board	0.201
Plastic waste	0.143

* EUROSTAT, 2016. Recycling – secondary material price indicator.

Risk-aversion model

We use a risk-aversion estimate from the literature(*)

	cv_j^{max}
Torrefaction	1.519
Pyrolysis	1.120
Animal-feed	1.109
RDF	0.963
Composting	1.129
Anaerobic	1.237

For example, if the CV of the charcoal price is within the range [0, 1.519), torrefaction is still viable. If CV is higher, the technology is too risky to be implemented.

* Bar-Shira Z, Just RE, Zilberman D. Estimation of farmers' risk attitude: an econometric approach. Agricultural Economics 17 211-222 (1997)

Risk-aversion model

Using CVs we can compare the Certainty Equivalents of any pair of technologies...

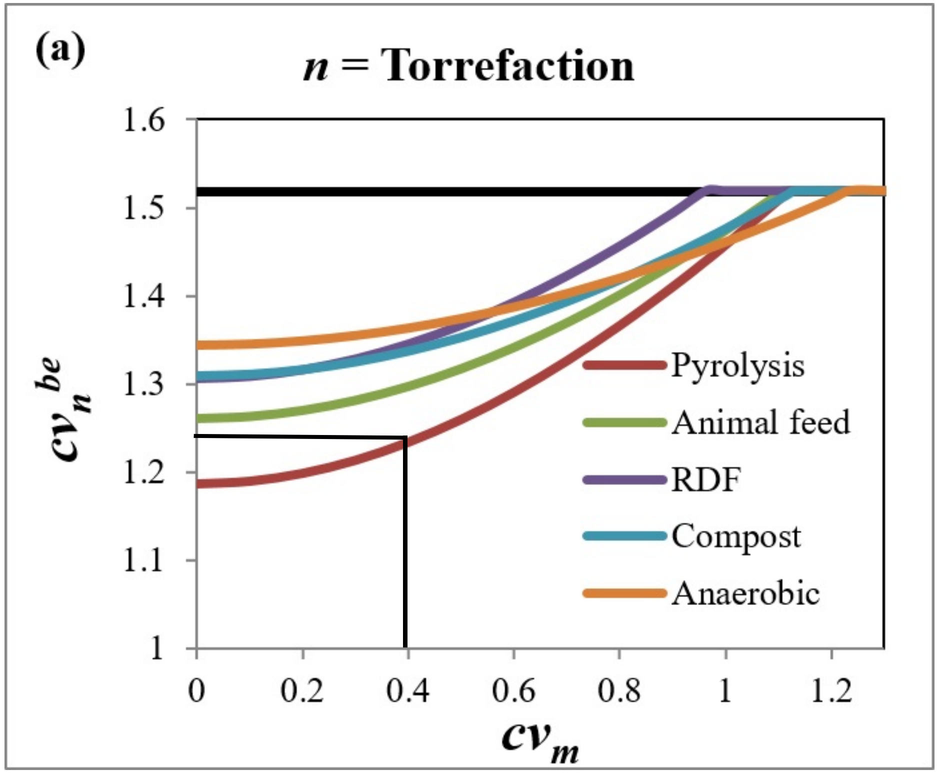
Assume *n* is a more profitable technology than *m*, we can find a *CV* of *n* and a *CV* of *m* that causes their Certainty Equivalent to be equal

In other words, even if *n* is more profitable than *m*, a risk-averse entrepreneur will choose technology *m* if the fluctuation of its final products price is moderate compared with the fluctuation expected for the final prices of *n*.

Risk-aversion model

	cv_j^{max}
Torrefaction	1.519

If the CV of Torrefaction's final prices is higher than 1.519 (the black thick line) the technology is too risky.



If the CV of Torrefaction's final prices is lower, still other technologies can compete with it (although being on average the most profitable one ...)

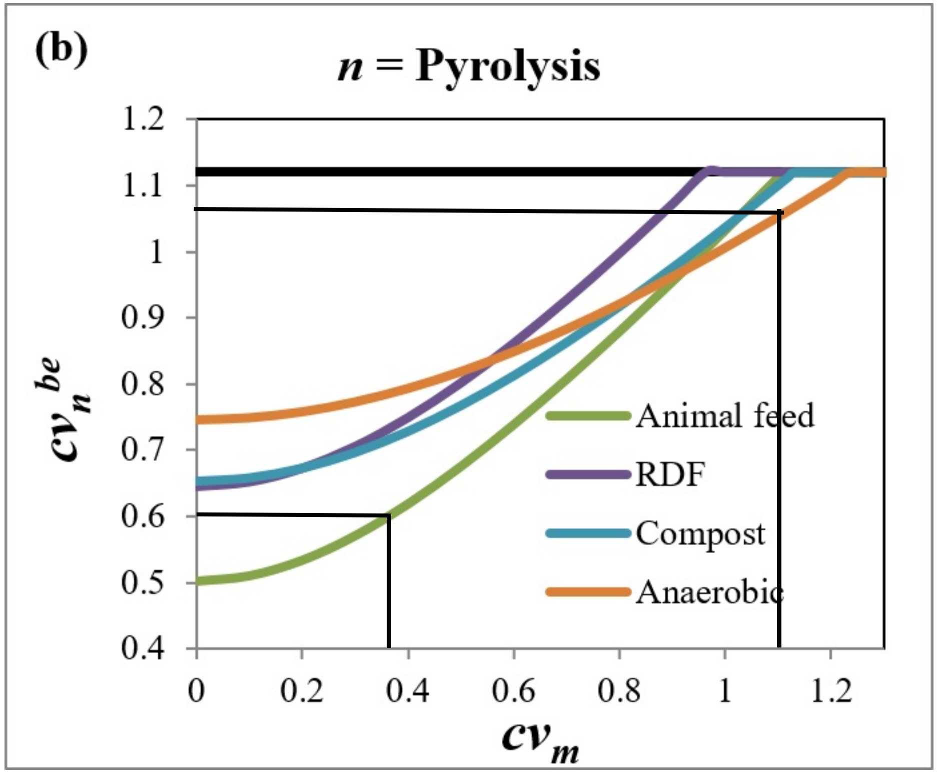
If the CV of Pyrolysis is 0.4, any CV higher than 1.25 for Torrefaction makes Pyrolysis preferable to a risk-averse agent.

Suitable waste types can be allocated to technologies based on forecasted CVs.

Risk-aversion model

	cv_j^{max}
Pyrolysis	1.120

If the CV of pyrolysis's final prices is higher than 1.12 (the black thick line) the technology is too risky.



Any pair of CVs below the colored lines means that pyrolysis is the best option

$$cv_{anaerobic} = 1.1$$

But if

$$cv_{pyrolysis} > 1.07$$

Anaerobic digestion becomes the best option

$$cv_{AnimalFeed} = 0.35$$

And if

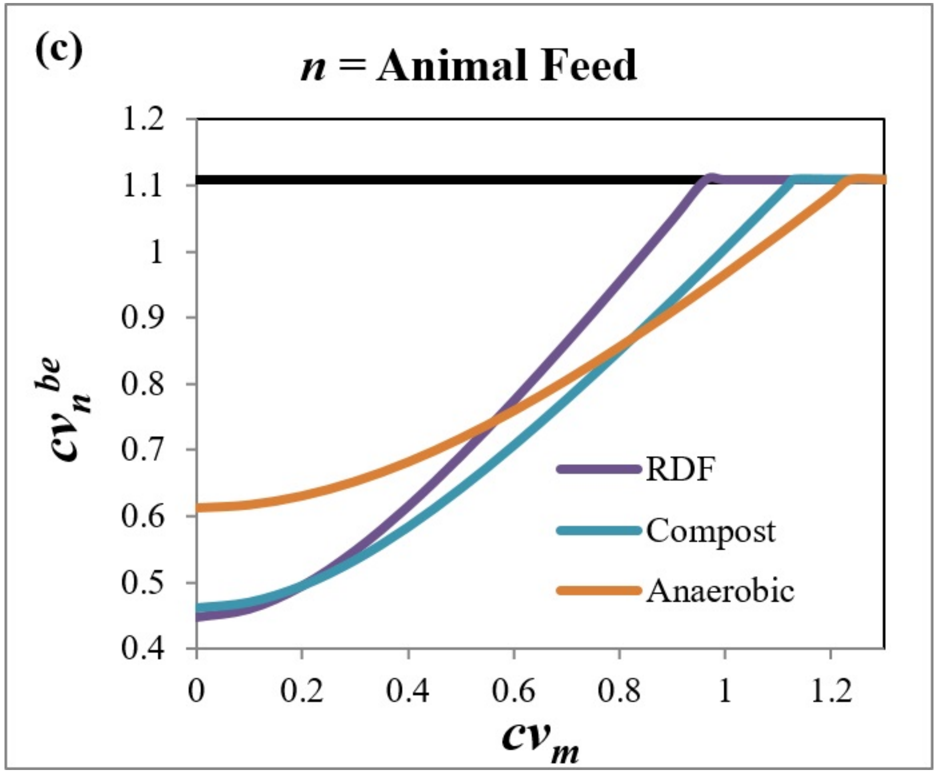
$$cv_{pyrolysis} > 0.6$$

Animal feeding becomes the best option

Then remaining (and suitable) waste types can be allocated

Risk-aversion model

	cv_j^{max}
Animal-feed	1.109



And so on …

The model allows the hierarchical allocation of vegetative waste types among competing technologies while taking into account:

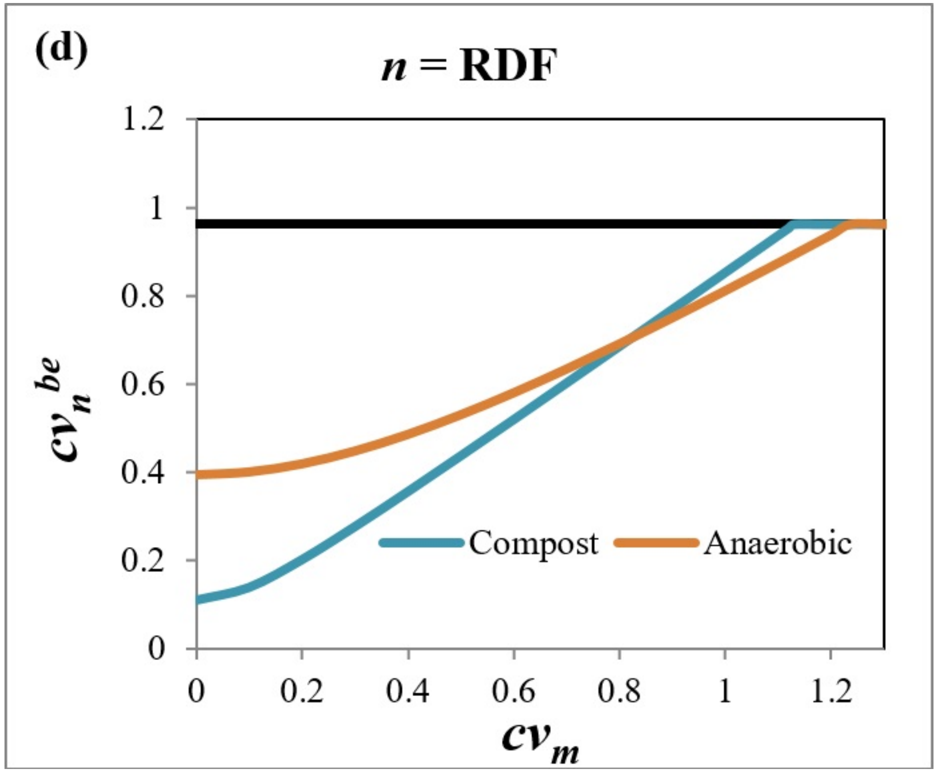
1- Observed mean final prices

2- The CVs of final prices

3- The risk-aversion level

Risk-aversion model

	cv_j^{max}
RDF	0.963



And so on …

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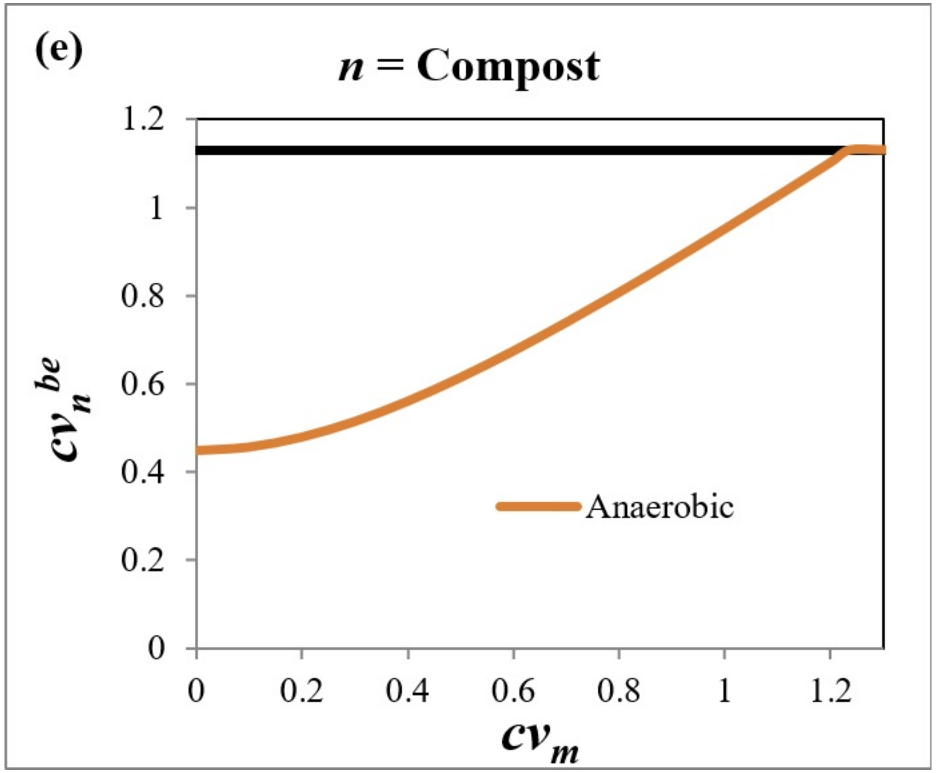
Risk-aversion model

	cv_j^{max}
Composting	1.129



And so on …

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1- Observed mean final prices

2- The CVs of final prices

3- The risk-aversion level

Summary

- We collected data about types of vegetative waste, their quantities and feasible treatment technologies
- Investing and operational cost for each technology were calculated
- The optimal (profit maximizing) WMS was designed by means of a linear programming model
- We performed a sensitivity analysis assuming risk-neutral and risk-aversion perspectives
- The risk-aversion perspective takes into account mean prices and a measure of their fluctuation, using the coefficient of variance
- The model can be applied to other types of WMS in which their final products (or recycling) prices are uncertain

Further research

- Spatial analysis of waste management under risk-aversion, referring to geographical areas and their different availability of vegetative waste

- Collection of final product price data for the considered technologies from all over the world in order to calibrate the model using expected coefficients of variance

Thank you for your attention !

Questions? Comments?