Exploring the profitability potential of vermicomposting solid pig manure

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Summary In the Netherlands, there are surpluses of pig manure, which currently represent a negative value. At the same time, pig manure contains valuable ingredients for the production of biomass. These ingredients can be potentially be converted to feed and vermicompost by earthworms, such as *Eisenia fetida* and *Dendrobaena veneta*. Thereby producing alternative protein sources for feed and alternatives for artificial fertilizer. The number of feasible business cases in which the pig manure is upgraded has so far been limited. This is due both to the efficiency of the technologies used and the legislation and regulations related to the pig manure. This report explores the profitability potential of vermicomposting solid pig manure by individual pig farmers.

Samenvatting In Nederland is een overschot aan varkensmest, dat momenteel een negatieve waarde heeft. Tegelijkertijd bevat varkensmest waardevolle ingrediënten voor de productie van biomassa. Deze ingrediënten kunnen mogelijk worden omgezet naar voer en vermicompost bij aardwormen, zoals *Eisenia fetida* en *Dendrobaena veneta*. Hiermee kunnen alternatieve eiwit bronnen voor voer en alternatieven voor kunstmest worden geproduceerd. Het aantal haalbare business cases, waar varkensmest wordt opgewaardeerd, is tot nu toe gelimiteerd. Dit is zowel door de efficiëntie van de gebruikte technologieën, als wet en regelgeving rondom varkensmest. Dit rapport verkent het winstgevendheidspotentieel van het vermicomposteren van varkensdrollen door individuele varkenshouders.

Keywords: vermicompost, *Eisenia fetida*, *Dendrobaena veneta,* earthworms

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Preface

In the Netherlands, there are surpluses of manure and digestates/biogas slurries (digested manure and residual flows), which represent a negative value. At the same time, these residual flows contain valuable ingredients for the production of biomass (as raw material for food and feed products), for improving soil quality and for energy production. The number of feasible business cases in which the residual flow is upgraded has so far been limited. This is due both to the efficiency of the technologies used and the legislation and regulations related to the residual flows.

Recent information from research, scientific literature and companies provides new starting points for a biobased valorisation of manure/digestate streams and improving the efficiency of anaerobic digestion. The innovative aspect of our research is the cultivation of new types of biomass on the residual flows and the use of the conversion products to improve anaerobic digestion. This involves the use of separated manure and digestate products for the cultivation of mushrooms/fungi, worms, insects, specific bacteria and aquatic biomass. The resulting biomass can be further refined and marketed as food, feed and bio-based feedstock. There are also processed manure and digestate products that are valuable as fertilizer products for soil and plant growth, as substrate for improvement of anaerobic digestion or for export/use besides in agriculture. This gives a new interpretation to obligatory manure processing.

The aim of this project is to further explore and substantiate/test these ideas on lab and practical scale, leading to a proof of principles for new bio-based upgrading methods for manure and digestate that can be used in conjunction to better close cycles and/or sell outside regular agriculture. Bottlenecks in legislation and regulations are explored and put on the agenda. Key figures are also calculated that are necessary for assessing sustainability (e.g. costs, environmental effects) and for supporting legislation (e.g. minerals, food safety).

The livestock sector gains insight into the possibilities of biobased valorisation and better marketing of their most important residual flows. For the SMEs involved, this research provides proof of principle for their technology and input in their business cases. The combined effects of the technologies provide new knowledge, methods and research directions for science. In a social context, the use and upgrading of manure and digestates in other ways also contributes to the transition to a circular bio-economy with an efficient and sustainable agrifood sector.

A special thanks for the worm farmers that provided us with information and feedback regarding our assumptions: Mekelenkamp, B., Dutch Blackworms; Wasse, F., Wormenkwekerij Wasse; Mous, L., Live bait; Berendsen, S., Wormenkwekerij Berendsen; Kranenburg A., Wormenkwekerij A.D. Kranenburg; Bosch, M., Lasebo.

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Summary

In the Netherlands, there are surpluses of pig manure, which currently represent a negative value. At the same time, pig manure contains valuable ingredients for the production of biomass. These ingredients can be potentially be converted to feed and vermicompost by earthworms, such as *Eisenia fetida* and *Dendrobaena veneta*. Thereby producing alternative protein sources for feed and alternatives for artificial fertilizer. The number of feasible business cases in which the pig manure is upgraded has so far been limited. This is due both to the efficiency of the technologies used and the legislation and regulations related to the pig manure. This report explores the profitability potential of vermicomposting solid pig manure by individual pig farmers.

Due to limited available information, assumptions are based on practical experiments (see Annex 1), expert opinion, scientific articles and in some cases personal estimations. Therefore the financial results in this report should be considered as a first exploration into the financial feasibility of processing pig faeces with earthworms.

Under the standard assumptions the yearly profit is positive for all our scenarios. Most profitable scenario is the scenario that assumes monthly harvests of worm biomass and vermicompost. Followed by the scenario that assumes biannual harvests of worm biomass and vermicompost. Least profitable of these scenarios is the scenario assuming biannual harvests of vermicompost, without harvesting worm biomass.

However, when changing assumptions regarding worm biomass price, reduction in disposal costs, labour requirements and processing and selling costs, not all scenarios remained positive. Yet, under each variant at least one scenario had a positive yearly profit.

Samenvatting

In Nederland is een overschot aan varkensmest, dat momenteel een negatieve waarde heeft. Tegelijkertijd bevat varkensmest waardevolle ingrediënten voor de productie van biomassa. Deze ingrediënten kunnen mogelijk worden omgezet naar voer en vermicompost bij aardwormen, zoals *Eisenia fetida* en *Dendrobaena veneta*. Hiermee kunnen alternatieve eiwit bronnen voor voer en alternatieven voor kunstmest worden geproduceerd. Het aantal haalbare business cases, waar varkensmest wordt opgewaardeerd, is tot nu toe gelimiteerd. Dit is zowel door de efficiëntie van de gebruikte technologieën, als wet en regelgeving rondom varkensmest. Dit rapport verkent het winstgevendheidspotentieel van het vermicomposteren van varkensdrollen door individuele varkenshouders.

Door beperkte beschikbare informatie, zijn de aannames in dit rapport gebaseerd op praktische experimenten (zie bijlage 1), expert inschattingen, wetenschappelijke artikelen en in een aantal gevallen persoonlijke inschattingen. Daarom moeten de resultaten in dit rapport worden gezien als een eerste verkenning van de financiële haalbaarheid van het verwerken van varkensdrollen door vermicomposteren met aardwormen.

Onder de standaard aannames, is de jaarlijkse winst positief voor alle scenario's. Het meest winstgevende scenario is het scenario dat maandelijks wormenbiomassa en vermicompost oogst. Gevolgd door het scenario dat tweejaarlijks wormenbiomassa en vermicompost oogst. Het minst winstgevende scenario is het scenario dat tweejaarlijks alleen vermicompost oogst.

Wanneer aannames met betrekking tot wormenbiomassa prijzen, vermindering in mestafzetkosten, arbeidsbehoeften en verwerkings- en verkoopkosten veranderen, blijven niet alle scenario's positief. Toch blijft onder elke variant, minstens één scenario een positieve jaarlijkse winst houden.

1 Introduction

In the Netherlands there is currently a surplus of manure, which currently results in a negative value for this waste stream. Pig farmers have to pay on average 18 euros per m^3 to dispose of pig manure (KWIN-Veehouderij 2022-2023). However, manure contains valuable ingredients and nutrients for the production of biomass (when used as an input for feed products) and improving soil quality. In the PPP "Biobased opwaarderen mest en digestaat" the aim is to valorise these (manure) waste streams with negative value into products with a higher value. Currently the number of positive business cases is limited. This is due both to existing technologies and legislation surrounding manure streams. The aim of the PPS is to give new starting points for valorising manure and digestate streams in a biobased manner. One potential route for valorising is growing compost worms on substrates containing pig faeces. This results in a reduction in pig manure organic matter, new worm biomass and vermicompost, which can be used as a fertilizer (Atiyeh et al., 2001; Chan & Griffiths, 1988; Elissen et al., in preparation)). Worm biomass can be used as fish bait or as part of an aquaculture or poultry diet (Gunya & Masika, 2021; Musyoka et al. 2019; Parolini et al., 2020). Of course, when using worm biomass as feed it is important to check whether heavy metals or other toxic compounds (or pathogens) from waste streams are accumulated in the worms themselves. Suthar and Singh (2008) found an accumulation of metals in *Eisenia fetida* after processing a mix of sewage sludge and cow dung. Despite these safety aspects, growing earthworms on substrates containing waste streams can help closing cycles (reducing waste, producing new resources) and contribute to a more circular agro-food system.

The aim of this research is to do a first exploration into the financial feasibility for pig farmers to use compost worms (*E. fetida* and *Dendrobaena veneta*) to process pig faeces. This leads to a reduction in manure disposal costs and an increased income through the sales of worm biomass and fertilizer. Although literature has shown the possibility of worms to process pig faeces (Gunadi et al., 2003; Zhou et al. 2021) large scale applications have not been found yet. Therefore a lot of assumptions had to be made regarding the investments for the setup, labour requirements, processing time of substrates, product margins and prices as well as the reduction of substrates. These assumptions are based on practical experiments (see Annex 1), expert opinion, scientific articles and in some cases personal estimations. Therefore the financial results in this report should be considered as a first exploration into the financial feasibility of processing pig faeces with compost worms.

There is limited legislation surrounding the production of earthworms, the use of different substrates and using earthworms as feed. In Dutch legislation earthworms are considered production animals. Earthworms are also considered category III material (Vo. (EG) nr. 1069/2009) in the feed legislation. They are not explicitly mentioned in the list of forbidden/unsanctioned feeds (Vo. (EG) 767/2009), however they are also not explicitly mentioned to be allowed (Vo. (EG) Nr. 999/2001). This means the production of earthworms with the intention as feed is still in a grey area, but legislation is expected to follow that of insect larvae produced for feed purposes. It is unlikely that earthworms raised on manure are currently allowed to be fed to poultry and fish, since it is currently not allowed to feed category II material (Vo. (EG) nr. 1069/2009) to farm animals. However, there is an exception for using worms as fish bait. Worms produced for fish bait are allowed to be fed on category II material (Vo. (EU) nr. 142/2011), and thus manure.

Compared to insect legislation, the earthworm legislation is quite a bit behind. Earthworms are no insects, since they do not have exoskeletons. Earthworms are terrestrial invertebrates belonging to the Annelida phylum. Therefore the legislation specific to insect production does not translate one to one to the earthworm case. However, there are some similarities, i.e. they are both considered production animals and have the ability to process a wide variety of waste streams. Therefore it is not unthinkable earthworm legislation could follow into the insect legislation's footsteps, at least in spirit. However an important difference is that earthworms can also behave as a kind of filter feeders consuming soil with organic substances in it. If earthworm legislation would follow insect legislation, earthworms produced for feed would only be allowed to be raised on the same substrates as insects and be allowed to be fed to pigs, poultry, aquaculture fish and pets.

2 Assumptions financial Model

2.1 Description of the farming system

The described farming system is a low-input vermicomposting system. It is assumed that the farmers process the pig faeces onsite in an already existing building structure. The pig faeces and starting substrates are stored for 2 weeks (a pre-composting step) in a manure or trench silo, before being processed by the worms. This is necessary according to literature to avoid heat build-up, and to prevent high levels of ammonia in the pig faeces (which is toxic to earthworms).

The worm beds are assumed to be trench silos of 2m by 20m by 0.8m. Initially 5kg/m^2 worms are put in a base substrate layer equal to the amount of pig faeces processed every week. Consequently, after shredding the pig faeces are distributed weekly over the beds in a small layer with a manure spreader. The worms can travel between the stable base layer and pig faeces to feed. Depending on the scenario the worms and vermicompost are harvested at a worm density of 7 kg/m2 every month (scenario I), 12 kg/m2 (scenario II) every 6 months, or only the vermicompost is harvested (scenario III). When worms are not harvested, a stable worm population of 12 kg/m2 (Sherman, 2018; personal communication B. Mekelenkamp, 2021) is assumed. When harvesting both worms and vermicompost, they are separated by a sieve. Then a new base layer is created and 5 kg/m2 of worms (from the harvested stock) is added back in. If the substrate becomes too dry, the substrate can be misted. The structure will be ventilated with a ventilator every 50 m2. It is assumed that after processing by the worms the pig faeces are reduced by 30% in weight. Both worms and vermicompost are assumed to be marketable for a positive price. The costs for processing, and selling these products are currently unknown, so it is assumed the costs for these activities constitute 20 % of the product revenues (i.e. 80 % of the vermicompost and worm biomass revenues are left as potential (gross) profit, before other costs).

2.2 Scenarios and variants

Scenario I: Higher intensity worms and vermicompost harvesting at 7kg/m2, every month.
Scenario II: Low intensity worms and vermicompost harvesting at 12kg/m2, every 6 months.
Scenario III: Low intensity vermicompost harvesting, every 6 months.

Variant A: Standard assumptions.
Variant B: The price of worm biomass is € 0.35 per kg, equal to the price of fishmeal in December 2022 (€ 1.75 per kg; World bank, 2023) multiplied by the dry matter percentage of earthworms (20 %; Parolini et al., 2020).
Variant C: The price of vermicompost is 0 per tonne. The price of disposal of the remaining vermicompost is equal to the disposal costs for manure per tonne.
Variant D: Doubling of all standard labour requirements.
Variant E: Processing and selling costs of worm biomass are assumed to be 50 % of the worm biomass revenues and processing and selling costs of vermicompost are assumed to be 50 % of the vermicompost revenues

2.3 Overview of the assumptions

Assumptions regarding the waste streams and substrates can be found in table 2.3.1 See Annex 1 for the results of an experiment growing earthworms on pig faeces.

Table 2.3.1 *Assumptions regarding the waste streams and substrates.*

	Assumption	Source
Amount of pig faeces processed (WM)	902 tonnes/year	Groeneveld et al. (2021)
Amount of starter substrate (WM)	Scenario I: 208 tonnes/year Scenario II: 35 tonnes/year Scenario III: 0 tonnes/year* *Initial starter substrate for scenario III is assumed to be negligible	Personal estimation
Weight reduction of substrate processing into vermicompost	30 %	Reeh et al. (1992); Experiment from Annex I

Assumptions regarding worm growth and harvests can be found in table 2.3.2

Table 2.3.2 *Assumptions regarding worm growth and harvests.*

	Assumption	Source
Time between harvests	1 month (scenario I) 6 months (scenario II) 6 months *only vermicompost (scenario III)	Personal estimation Personal communication B. Mekelenkamp (2021)
Starting amount of worms (initially and after harvest)	5 kg/m2	Personal communication B. Mekelenkamp (2021)
Amount of worms at harvest	7 kg (scenario I) 12 kg (scenario II)	Personal communication B. Mekelenkamp (2021)
Amount of worms at stabilized point without harvesting	12 kg/m2 (scenario III)	Personal communication B. Mekelenkamp (2021); Sherman, R. (2018)
Percentage of (fresh) body weight processed per day from (fresh) pig faeces (WM)	30 %	Sherman, R. (2018)
Percentage of (fresh) body weight processed per day from (fresh) starting substrate (WM)	50 %	Sherman, R. (2018)
Density of worm compost	654.3 kg wet weight/m^3	El-Haddad et al. (2014)

Assumptions regarding business details can be found in tables 2.3.3

Table 2.3.3 *Assumptions regarding business details.*

	Assumption	Source
Discount rate (low)	3%	Personal estimation
Discount rate (high)	7%	Personal estimation
Processing and selling cost margin for worm biomass	20% of worm biomass revenues	Personal estimation
Processing, and selling cost margin for vermicompost	20% of vermicompost revenues	Personal estimation

Assumptions regarding prices can be found in table 2.3.4

Table 2.3.4 *Assumptions regarding prices.*

	Assumption	Source
Price of labour	€ 23.14 / hour* *(Gross labour costs + 30% employer costs)	CBS (2021)
Price of live worms	€ 9 / kg	Personal communication B. Mekelenkamp, (2021); Personal communication F. Wasse, (2022); Personal communication L. Mous, (2022); Personal communication S. Berendsen, (2022)
Price of bulking material	€ 2 / tonne	Personal communication B. Mekelenkamp (2021)
Price of worm compost	€ 30 / m3	Personal communication B. Mekelenkamp (2021)
Price of live starter worms	€ 12.50 / kg	Personal communication B. Mekelenkamp (2021)
Disposal costs pig faeces (WM)	€ 18 / tonne fresh weight	KWIN Veehouderij 2022-2023 (2022)

Assumptions for investments and fixed capital can be found in tables 2.3.5 to 2.3.7

Table 2.3.5 *Assumptions regarding investments.*

	Assumption	Source
Trench silo price per m^2 of floor surface	€ 45	KWIN Veehouderij 2022-2023 (2022)
Trench silo price per m^2 of wall surface	€ 92.50	KWIN Veehouderij 2022-2023 (2022)
Trench silo vertical dimensions	3m wide, 1.5m high, length depends on storage requirements	Personal estimation
Storage capacity per m2 of trench silo	1.5 m^3 of vermicompost	Personal estimation
Manure spreader (6-7 tonne capacity)	€ 19,200	KWIN Veehouderij 2022-2023 (2022)
Misting system price per m2	€ 8	KWIN Veehouderij 2022-2023 (2022)
Storage tank pig faeces per 40 m3	€ 19,200	KWIN Veehouderij 2022-2023 (2022)
Ventilator	€400	KWIN Glastuinbouw (2019)
Shredder	€ 2,310	Jansen-Versand (n.d.)
Sieve	€ 23,750	Mascus.nl (n.d)
Compost harvester	€ 43,075	Pon Equipment BV (n.d).

Table 2.3.6 *Assumptions regarding depreciation and maintenance.*

	Depreciation	Maintenance	Source
Worm beds (2m*20m*0.8m)	5%	1.0%	Personal estimation
Starter worms	5%	0%	Personal estimation
Manure spreader	9%	4%	KWIN Veehouderij 2022-2023 (2022)
Misting system	10%	2%	KWIN Veehouderij 2022-2023 (2022) KWIN Glastuinbouw (2019)
Storage substrate and vermicompost	5%	1.0%	Personal estimation
Ventilators	10%	2.5%	Personal estimation
Trommel	10%	2.5%	Personal estimation
Shredder	10%	2.5%	Personal estimation
Sieve	10%	2.5%	Personal estimation
Compost harvester	10%	2.5%	Personal estimation

Table 2.3.7 *Assumptions regarding quantities of inventory required.*

Quantities of inventory	Scenario I	Scenario II	Scenario III
Manure spreader (6-7 tonnes capacity)	1	1	1
Ventilators	1 per 50 m2	1 per 50 m2	1 per 50 m2
Shredder	2	2	2
Sieve (1800W)	8	6	0
Compost harvester (transport weight 2700 kg)	1	1	1

Assumptions regarding labour requirements can be found in table 2.3.8

Table 2.3.8 *Assumptions regarding labour requirements.*

Assumption		Source
General labour requirements per week (worm beds)	• The first 10 worm beds take 8 hours (linearly) • Every worm bed after that takes an additional 45 minutes	Personal estimation
Harvesting labour requirements per year	• Harvesting a worm bed takes 1.5 hours per bed	Personal estimation

3 Results

3.1 Vermicompost and fresh worms produced

Furthermore in scenario I approximately 900 tonnes of vermicompost and 38 tonnes of live worm biomass is produced from the initial 902 tonnes of pig faeces and 208 tonnes of starter substrate. In scenario A.II approximately 700 tonnes of vermicompost and 15 tonnes of live worm biomass is produced (from 902 tonnes of pig faeces and 35 tonnes of starter substrate), while in scenario A.III approximately 600 tonnes of vermicompost is produced from 902 tonnes of pig faeces. The difference in vermicompost production is due to the amount of starter substrate added. The difference in worm biomass can be contributed to additional starter substrate and different assumed growth rates. See table 3.1.1 for the overview of produced vermicompost and worm biomass.

Table 3.1.1 *Overview of produced vermicompost and worm biomass.*

	Scenario I	Scenario II	Scenario III
Fresh vermicompost produced[1] (kg/year)	923,000	680,000	632,000
Vermicompost produced[2] (m^3)	1,410	1,040	970
Fresh worms produced for sale[1] (kg/year)	38,000	15,000	-
Minimum land area required[2] (m^2)	1580	690	1050

[1] Rounded to thousands; [2] Rounded to tens.

3.2 Variant overviews

3.2.1 Variant A: Standard scenarios

In variant A the standard assumptions of as described in chapter 2 are assumed. As can be seen in the table 3.2.1.1 and figure 3.2.1.1 all scenarios in this variant turn a positive yearly profit. The most profitable scenario is scenario A.I, where worms are harvested every month, resulting in a profit of approximately €216,000. This is our most optimistic scenario regarding potential worm growth. The payback period is less than 3 years for scenario A.I. For scenario A.II and A.III the yearly profits are approximately €82,000 and €5,000, while the payback period is less than 4 and less than 12 years respectively (table 3.2.1.2). Figure 3.2.1.2 shows that most revenue comes from the sales of worm biomass in scenarios A.I and A.II, while for scenario A.III the largest share of revenue comes from the sales of vermicompost. Figure 3.2.1.3 shows that for all scenarios in this group labour costs, depreciation costs as well as the processing and selling costs make up the main part of the costs, although in different ratios. Starter substrate costs are negligible for all scenarios.

Table 3.2.1.1 *Overview of profits, costs and revenues for variant A.*

Profit, costs and revenues[1]	Scenario A.I	Scenario A.II	Scenario A.III
Total Yearly Revenues	€ 399,000	€ 180,000	€ 45,000
Total Yearly Costs	€ 183,000	€ 98,000	€ 40,000
Total Yearly Profits	€ 216,000	€ 82,000	€ 5,000

[1] Rounded to thousands

Table 3.2.1.2 *Overview of cashflow, initial investment and payback period for variant A.*

Financial and investment numbers	Scenario A.I	Scenario A.II	Scenario A.III
Yearly Cashflow[1]	€ 260,000	€ 116,000	€ 20,000
Initial investment[1]	€ 600,000	€ 444,000	€ 226,000
Payback period (in years)	2.30	3.84	11.25

[1] Rounded to thousands

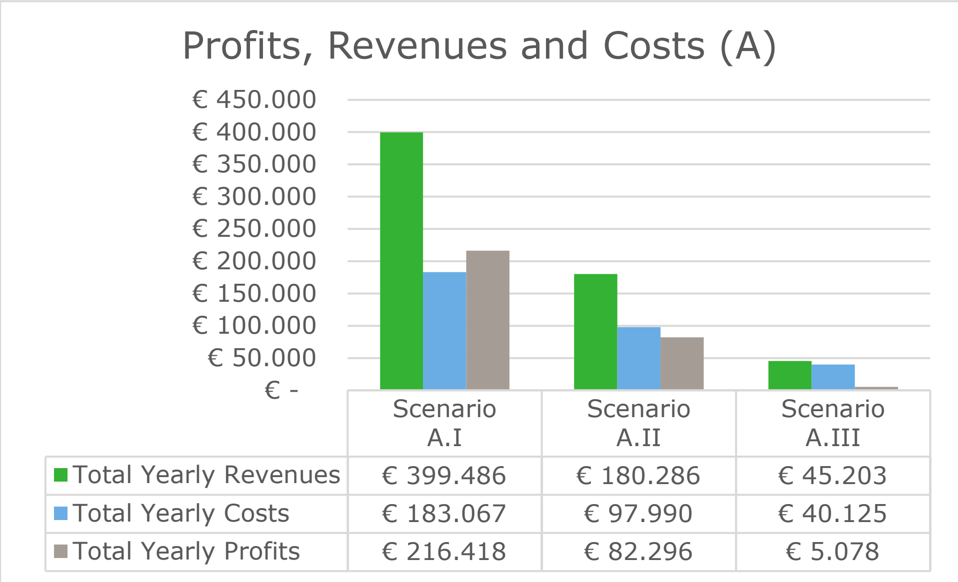


Figure 3.2.1.1 *Profits, revenues and costs for variant A*

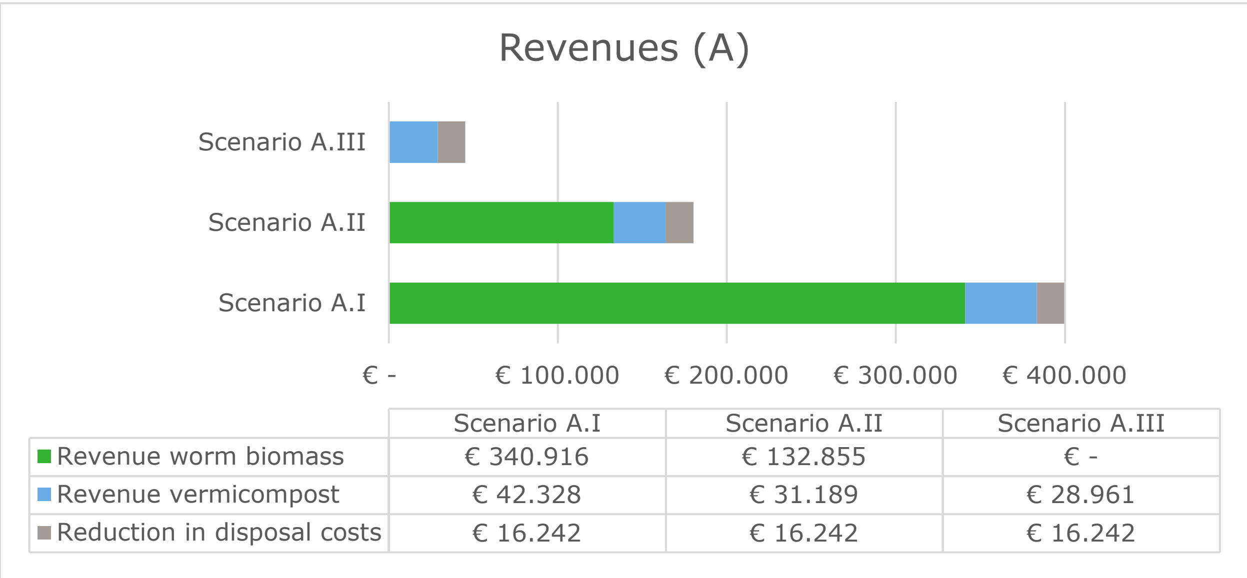
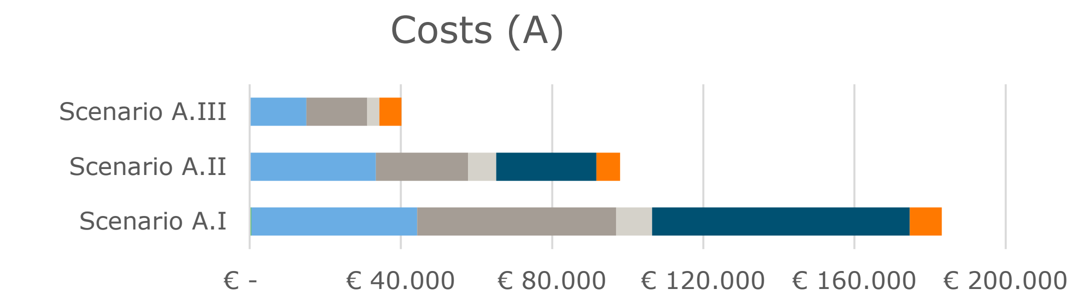


Figure 3.2.1.2 *Revenues split out per type for variant A*



	Scenario A.I	Scenario A.II	Scenario A.III
Starter substrate costs	€ 416	€ 69	€ -
Yearly depreciation costs	€ 43.891	€ 33.304	€ 14.983
Yearly labour costs	€ 52.646	€ 24.391	€ 16.095
Yearly maintenance costs	€ 9.466	€ 7.417	€ 3.256
Processing and selling costs worm biomass	€ 68.183	€ 26.571	€ -
Processing and selling costs vermicompost	€ 8.466	€ 6.238	€ 5.792

Figure 3.2.1.3 *Costs split out per type for variant A*

3.2.2 Variant B: Reduced worm biomass price

In variant B the standard assumptions as described in chapter 2 are assumed, however it is assumed the price for a kg of live worms (fresh matter) is €0.35 instead of €9.00. This price reflects the price of a kg of fishmeal in December 2022 (World Bank, 2023) multiplied by the dry matter content (20%) of earthworms. As can be seen in table 3.2.2.1, only scenario B.III turns a positive yearly profit of approximately €5,000. Scenario B.I and B.II both turn a negative profit of approximately €46,000 and €20,000 respectively. The cashflows of Scenario B.I and B.II are positive, which show that without depreciation costs, scenarios B.I and B.II would be positive. The payback period of scenarios B.I and B.II are approximately 15 years, while for these scenarios the average depreciation time of the investment is approximately 13 and 14 years. Thus new investments would be required before the payback period is over, thus resulting in a negative yearly profit.

Figure 3.2.2.2 shows that most revenue comes from the sales of vermicompost for all scenarios. Figure 3.2.2.3 shows that for all scenarios in this group labour costs, depreciation costs as well as processing and selling costs make up the main part of the costs, although in different ratios.

Table 3.2.2.1 *Overview of profits, costs and revenues for variant B.*

Profit, costs and revenues[1]	Scenario B.I	Scenario B.II	Scenario B.III
Total Yearly Revenues	€ 72,000	€ 53,000	€ 45,000
Total Yearly Costs	€ 118,000	€ 72,000	€ 40,000
Total Yearly Profits	€ - 46,000	€ - 20,000	€ 5,000

[1] Rounded to thousands

Table 3.2.2.2 *Overview of cashflow, initial investment and payback period for variant B.*

Financial and investment numbers	Scenario B.I	Scenario B.II	Scenario B.III
Yearly Cashflow[1]	€ 41,000	€ 30,000	€ 20,000
Initial investment[1]	€ 600,000	€ 444,000	€ 226,000
Payback period (in years)	14.76	14.80	11.25

[1] Rounded to thousands

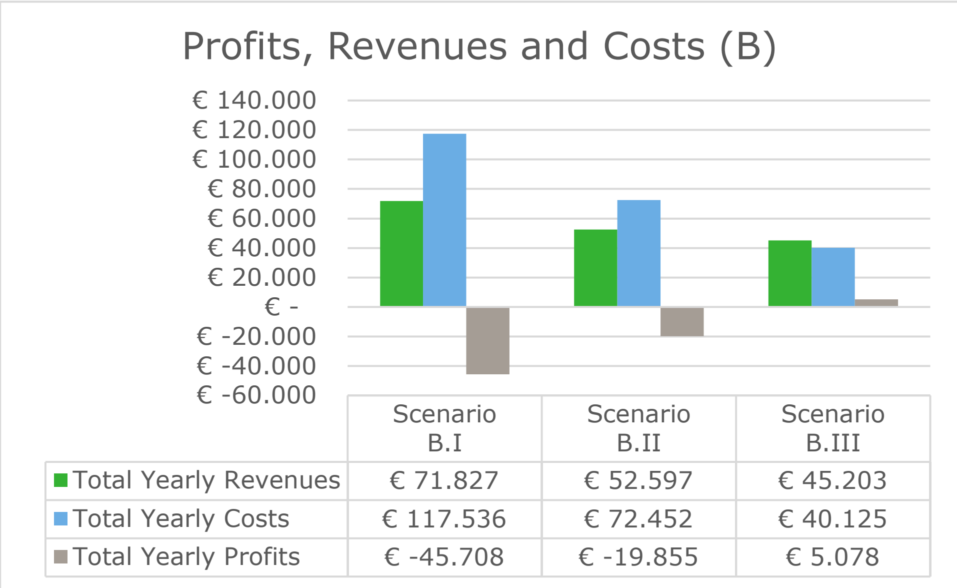


Figure 3.2.2.1 *Profits, revenues and costs for variant B*

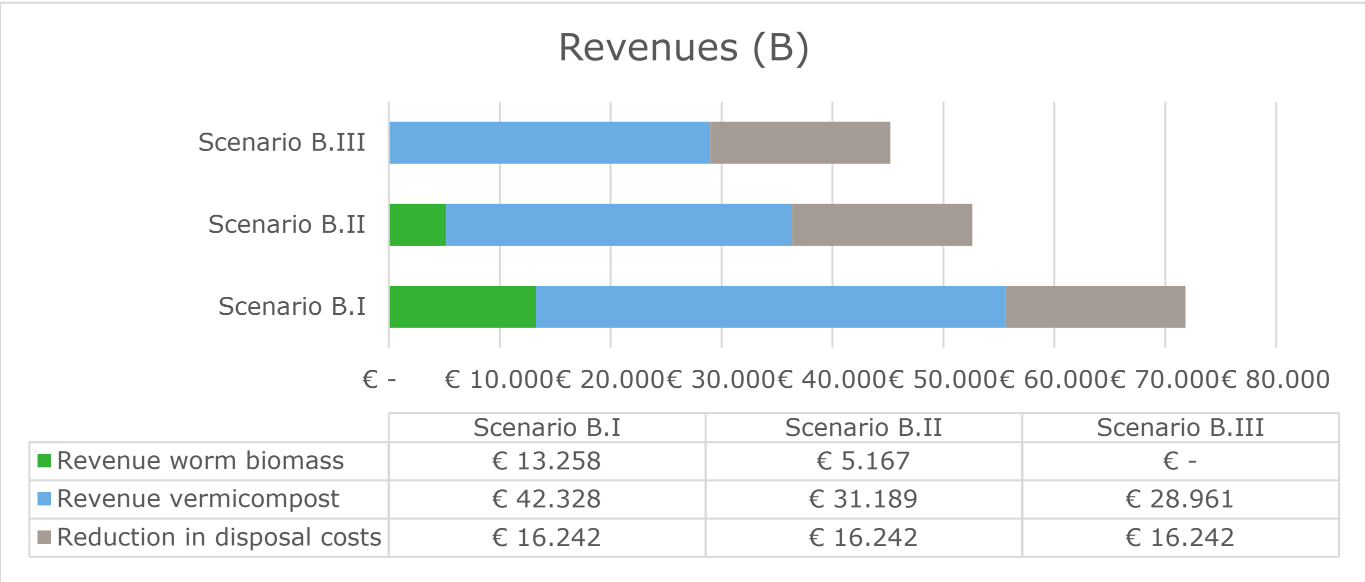
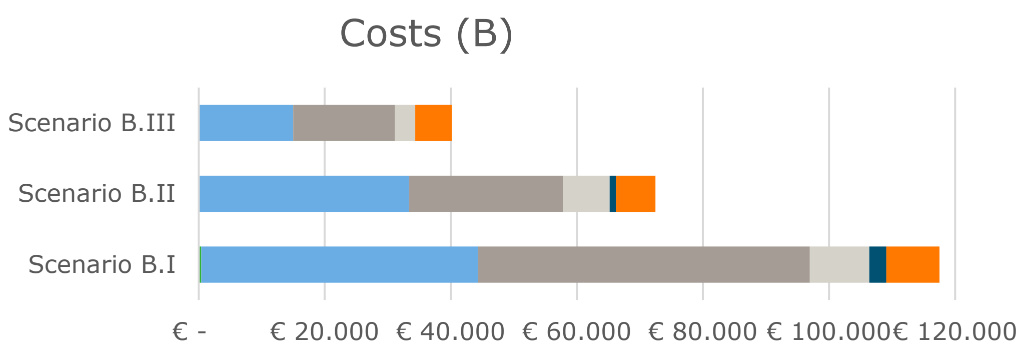


Figure 3.2.2.2 *Revenues split out per type for variant B*



	Scenario B.I	Scenario B.II	Scenario B.III
Starter substrate costs	€ 416	€ 69	€ -
Yearly depreciation costs	€ 43.891	€ 33.304	€ 14.983
Yearly labour costs	€ 52.646	€ 24.391	€ 16.095
Yearly maintenance costs	€ 9.466	€ 7.417	€ 3.256
Processing and selling costs worm biomass	€ 2.652	€ 1.033	€ -
Processing and selling costs vermicompost	€ 8.466	€ 6.238	€ 5.792

Figure 3.2.2.3 *Costs split out per type for variant B*

3.2.3 Variant C: No reduction in disposal costs and revenue from vermicompost

In variant C the standard assumptions as described in chapter 2 are assumed, however it is assumed that the price of vermicompost is reduced to 0, and that vermicompost will have to be disposed of at the same price as manure. This is done to highlight the fact that these worms are raised on pig faeces. Although legislation is limited, it could very well be that the pig faeces will not lose the label of manure after being processed by earth worms. If this is the case, it would perhaps still be possible to sell vermicompost for a positive price, due to its function as soil improver and fertilizer. However, for this exploration of the financial business case, the most extreme case was chosen: processed vermicompost from manure will have to be disposed of at the same price as manure.

As can be seen in table 3.2.3.1 only scenario C.III turns a negative yearly profit of approximately €29,000. Even the cashflow for scenario C.III is negative. This is to be expected, since it was shown in previous variants that the no harvesting scenario III was for a large share of its revenues dependent on revenues from selling vermicompost. Scenario C.I and C.II both turn a yearly profit of approximately €167,000 and €45,000, with a payback period of less than 4 and 7 years respectively (table 3.2.3.2).

Figure 3.2.3.2 shows that almost all revenue now comes from the sales of worm biomass in scenarios C.I and C.II. In scenario C.III only a small reduction in disposal costs is left, due to a reduction in organic mass of vermicompost compared to the initial pig faeces. Figure 3.2.3.2 shows a negative revenue for reduction in disposal costs for scenario C.I. This is due to the fact that the starter substrate mixed in with the pig faeces will also be seen as "manure" after being processed to vermicompost in this scenario. Apparently the reduction in pig faeces volume was not enough to offset the costs for added starter substrate in this scenario. Figure 3.2.3.3 shows that the processing and selling costs for vermicompost are now considered zero. This is due to these costs being calculated based on revenue from selling vermicompost, which is zero in this scenario. However, since it is assumed that disposal costs of vermicompost are in this scenario equal to manure, the costs of transporting and selling vermicompost are still somewhat realistically covered.

Table 3.2.3.1 *Overview of profits, costs and revenues for variant C.*

Profit, costs and revenues[1]	**Scenario C.I**	**Scenario C.II**	**Scenario C.III**
Total Yearly Revenues	€ 341,000	€ 137,000	€ 5,000
Total Yearly Costs	€ 174,000	€ 92,000	€ 34,000
Total Yearly Profits	€ 167,000	€ 45,000	€ - 29,000

[1] Rounded to thousands

Table 3.2.3.2 *Overview of cashflow, initial investment and payback period for variant C.*

Financial and investment numbers	**Scenario C.I**	**Scenario C.II**	**Scenario C.III**
Yearly Cashflow[1]	€ 211,000	€ 78,000	€ - 15,000
Initial investment[1]	€ 600,000	€ 444,000	€ 226,000
Payback period (in years)	3.85	6.66	

[1] Rounded to thousands

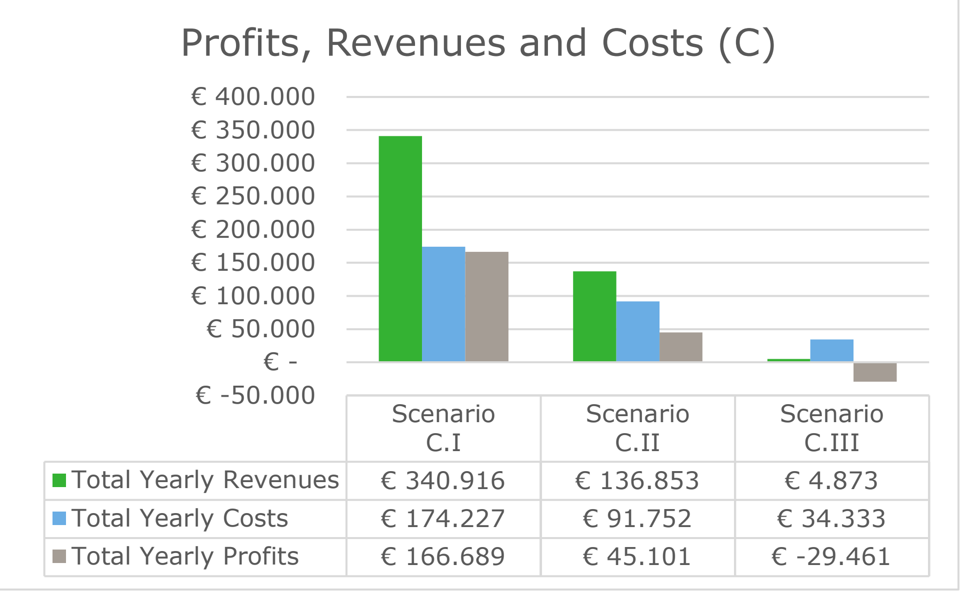


Figure 3.2.3.1 *Profits, revenues and costs for variant C*

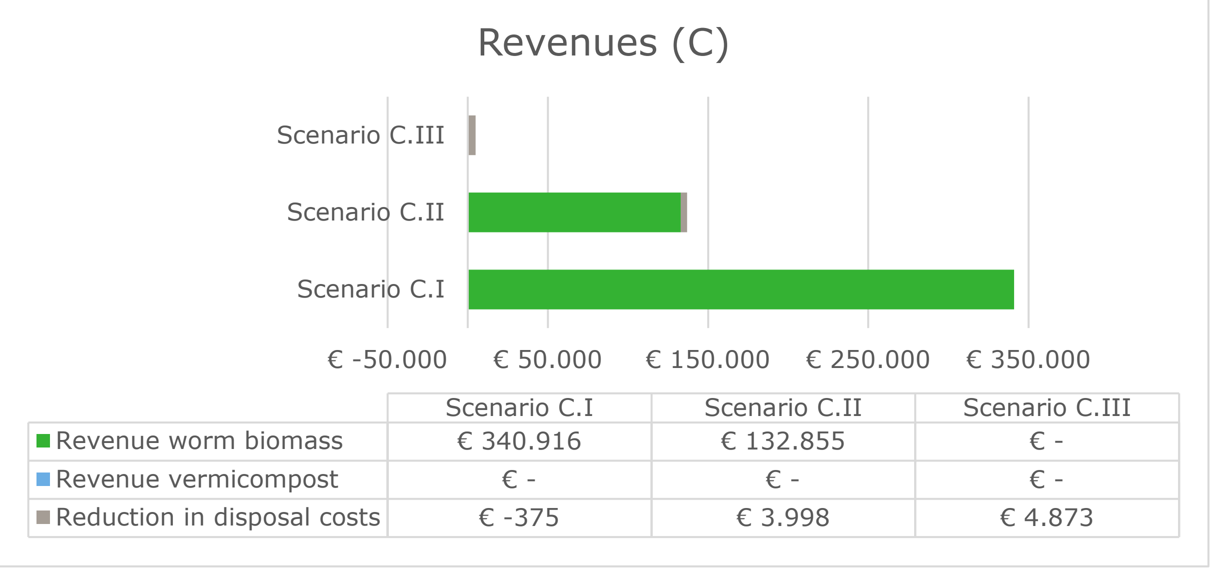
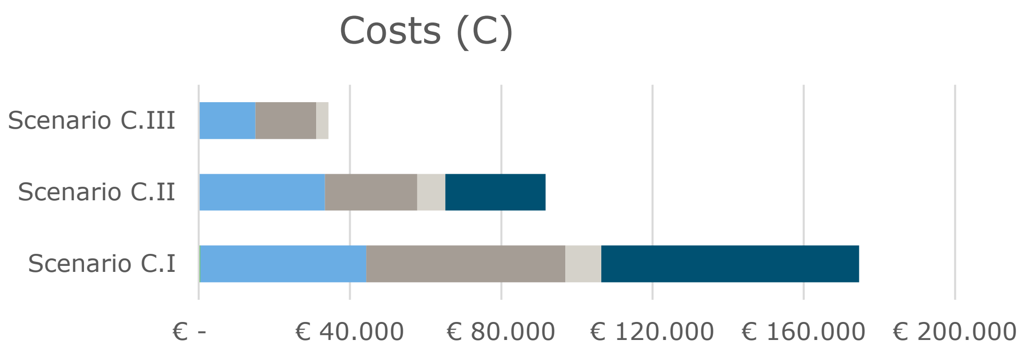


Figure 3.2.3.2 *Revenues split out per type for variant C*



	Scenario C.I	Scenario C.II	Scenario C.III
Starter substrate costs	€ 416	€ 69	€ -
Yearly depreciation costs	€ 43.891	€ 33.304	€ 14.983
Yearly labour costs	€ 52.646	€ 24.391	€ 16.095
Yearly maintenance costs	€ 9.466	€ 7.417	€ 3.256
Processing and selling costs worm biomass	€ 68.183	€ 26.571	€ -
Processing and selling costs vermicompost	€ -	€ -	€ -

Figure 3.2.3.3 *Costs split out per type for variant C*

3.2.4 Variant D: Double the labour requirements

In variant D the standard assumptions as described in chapter 2 are assumed, however it is assumed that the labour requirements are doubled. There is limited information available on the labour requirements associated with the general upkeep, feeding and harvesting of earthworms. Therefore a personal estimation was made. To see the effect of a higher labour requirement, it is interesting to look at the results of variant D.

As can be seen in table 3.2.4.1 only scenario D.III turns a negative yearly profit of approximately €11,000. This is likely due to the fact that the increase in labour costs is higher than the total yearly profits in scenario A.III. Scenario D.I and D.II both turn a yearly profit of approximately €163,000 and €58,000, with a payback period of less than 4 and 6 years respectively. This is quite a bit lower compared to similar scenarios from variant A, 24% and 30% respectively. However, scenario D.I and D.II are still both quite financially feasible.
Figure 3.2.4.3 shows the increased share of labour costs for all scenarios in this group, although in different ratios.

Table 3.2.4.1 *Overview of profits, costs and revenues for variant D.*

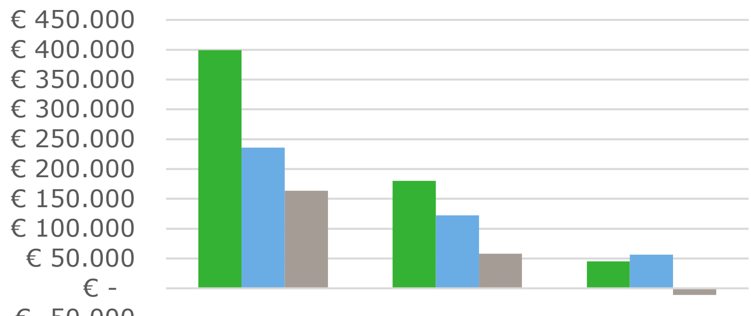
Profit, costs and revenues[1]	Scenario D.I	Scenario D.II	Scenario D.III
Total Yearly Revenues	€ 399,000	€ 180,000	€ 45,000
Total Yearly Costs	€ 236,000	€ 122,000	€ 56,000
Total Yearly Profits	€ 164,000	€ 58,000	€ - 11,000

[1] Rounded to thousands

Table 3.2.4.2 *Overview of cashflow, initial investment and payback period for variant D.*

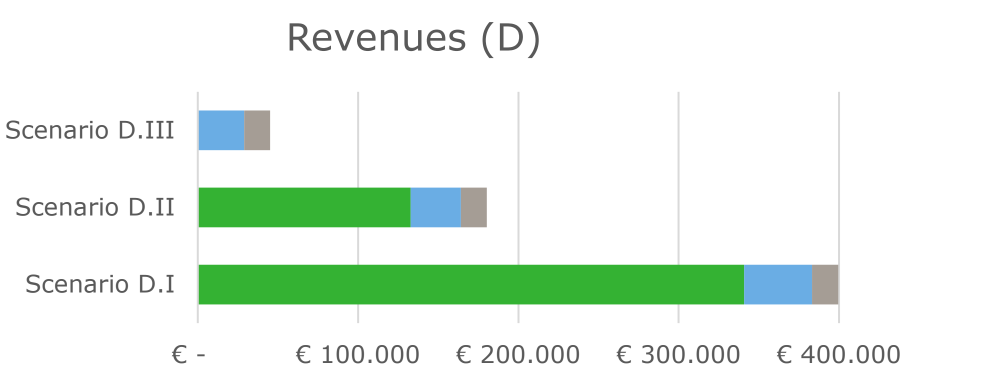
Financial and investment numbers	Scenario D.I	Scenario D.II	Scenario D.III
Yearly Cashflow[1]	€ 208,000	€ 91,000	€ 4,000
Initial investment[1]	€ 600,000	€ 444,000	€ 226,000
Payback period (in years)	3.89	5.86	57.89

[1] Rounded to thousands



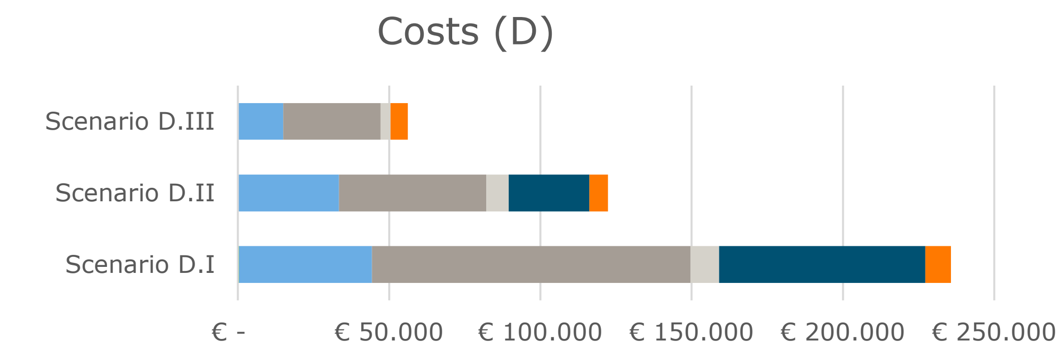
	Scenario D.I	Scenario D.II	Scenario D.III
Total Yearly Revenues	€ 399.486	€ 180.286	€ 45.203
Total Yearly Costs	€ 235.713	€ 122.380	€ 56.220
Total Yearly Profits	€ 163.773	€ 57.905	€ -11.017

Figure 3.2.4.1 *Profits, revenues and costs for variant D*



	Scenario D.I	Scenario D.II	Scenario D.III
Revenue worm biomass	€ 340.916	€ 132.855	€ -
Revenue vermicompost	€ 42.328	€ 31.189	€ 28.961
Reduction in disposal costs	€ 16.242	€ 16.242	€ 16.242

Figure 3.2.4.2 *Revenues split out per type for variant D*



	Scenario D.I	Scenario D.II	Scenario D.III
Starter substrate costs	€ 416	€ 69	€ -
Yearly depreciation costs	€ 43.891	€ 33.304	€ 14.983
Yearly labour costs	€ 105.292	€ 48.781	€ 32.190
Yearly maintenance costs	€ 9.466	€ 7.417	€ 3.256
Processing and selling costs worm biomass	€ 68.183	€ 26.571	€ -
Processing and selling costs vermicompost	€ 8.466	€ 6.238	€ 5.792

Figure 3.2.4.3 *Costs split out per type for variant D*

3.2.5 Variant E: Higher processing and selling costs

In variant E the standard assumptions as described in chapter 2 are assumed, however it is assumed that the prices of processing and selling are much higher. The processing and selling costs for worm biomass and vermicompost are both assumed to be 50% of the corresponding product revenue. There is limited information available on the processing and selling costs associated with producing worm biomass and vermicompost. Therefore a personal estimation was made. To see the effect of higher processing and selling costs, it is interesting to look at the results of variant E.

As can be seen in table 3.2.5.1 only scenario E.III turns a negative yearly profit of approximately €4,000. Scenario E.I and E.II both turn a yearly profit of approximately €101,000 and €33,000, with a payback period of more than 5 and less than 8 years respectively (table 3.2.5.2). Figure 3.2.5.3 shows that for all scenarios E.I and E.II more than half of their costs are due to processing and selling costs.

Table 3.2.5.1 *Overview of profits, costs and revenues for variant E.*

Profit, costs and revenues[1]	**Scenario E.I**		**Scenario E.II**		**Scenario E.III**	
Total Yearly Revenues	€	399,000	€	180,000	€	45,000
Total Yearly Costs	€	298,000	€	147,000	€	49,000
Total Yearly Profits	€	101,000	€	33,000	€	- 4,000

[1] Rounded to thousands

Table 3.2.5.2 *Overview of cashflow, initial investment and payback period for variant E.*

Financial and investment numbers	Scenario E.I	Scenario E.II	Scenario E.III
Yearly Cashflow[1]	€ 145,000	€ 66,000	€ 11,000
Initial investment[1]	€ 600,000	€ 444,000	€ 226,000
Payback period (in years)	5.12	7.68	20.84

[1] Rounded to thousands

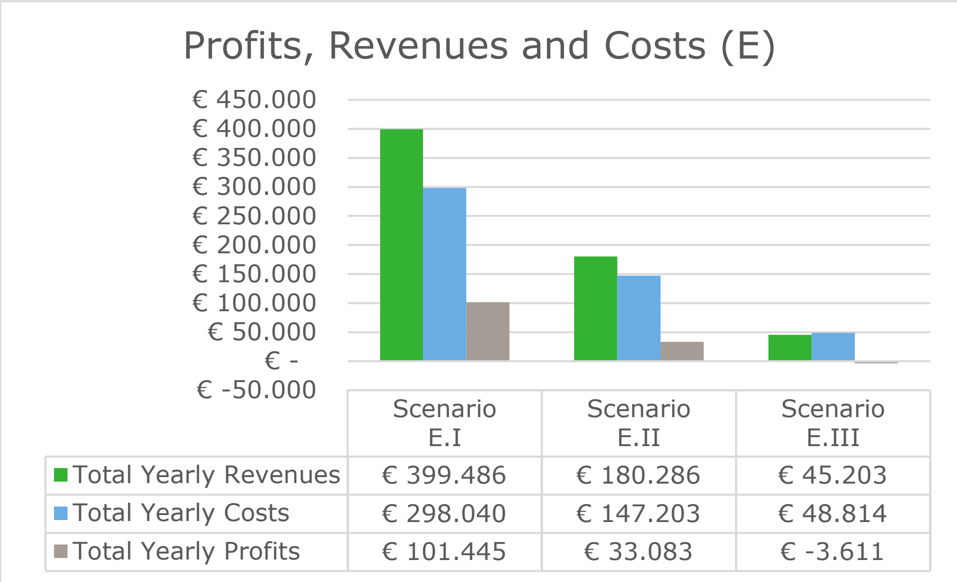


Figure 3.2.5.1 *Profits, revenues and costs for variant E*

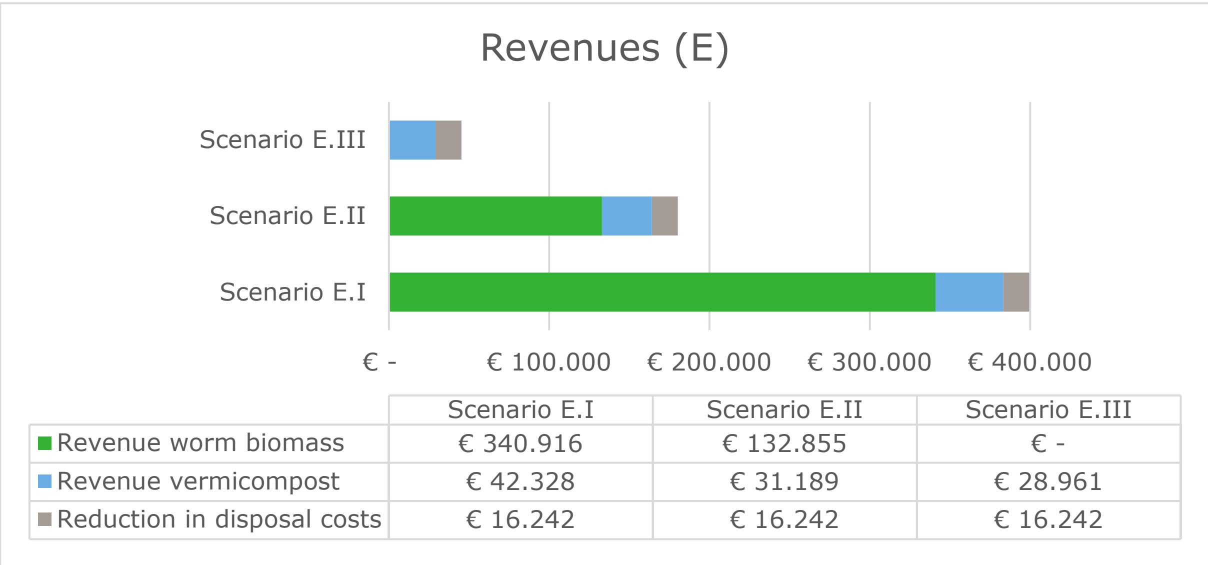
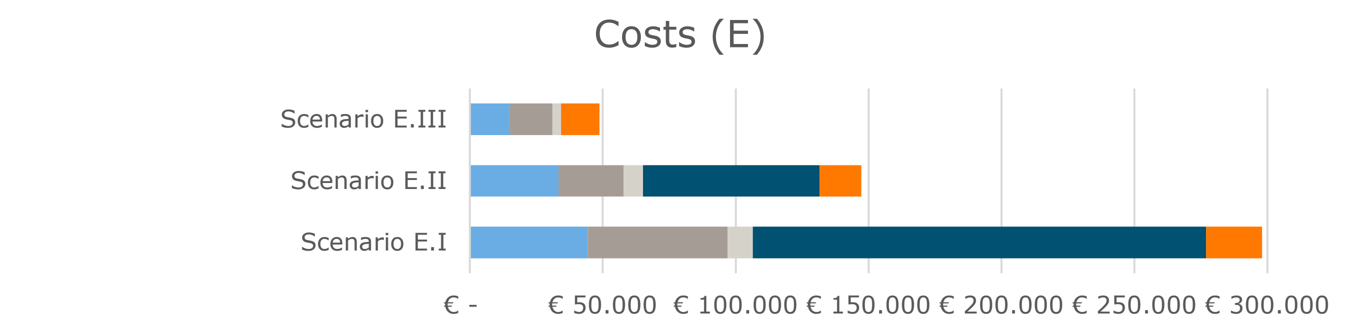


Figure 3.2.5.2 *Revenues split out per type for variant E*



	Scenario E.I	Scenario E.II	Scenario E.III
Starter substrate costs	€ 416	€ 69	€ -
Yearly depreciation costs	€ 43.891	€ 33.304	€ 14.983
Yearly labour costs	€ 52.646	€ 24.391	€ 16.095
Yearly maintenance costs	€ 9.466	€ 7.417	€ 3.256
Processing and selling costs worm biomass	€ 170.458	€ 66.427	€ -
Processing and selling costs vermicompost	€ 21.164	€ 15.594	€ 14.480

Figure 3.2.5.3 *Costs split out per type for variant E*

3.3 Scenario overviews

3.3.1 Overview profits per scenario

Figures 3.3.1.1 to 3.3.1.3 give an overview of the total yearly profits, revenues and costs for each variant for scenarios I, II, and III. For scenario I, variant A has the highest yearly profit, followed by variants C, D, E. Variant B is slightly negative for scenario I.

For Scenario II, variant A has the highest profit, followed by variants D, C and E. Variant B is slightly negative for scenario II.

For scenario III, variant A and B have the same assumptions and thus result in the same net profit. All other variants are negative for scenario III. Variant C has the most negative result, variant D the second most negative result, and Variant E has the least negative result of these variants.

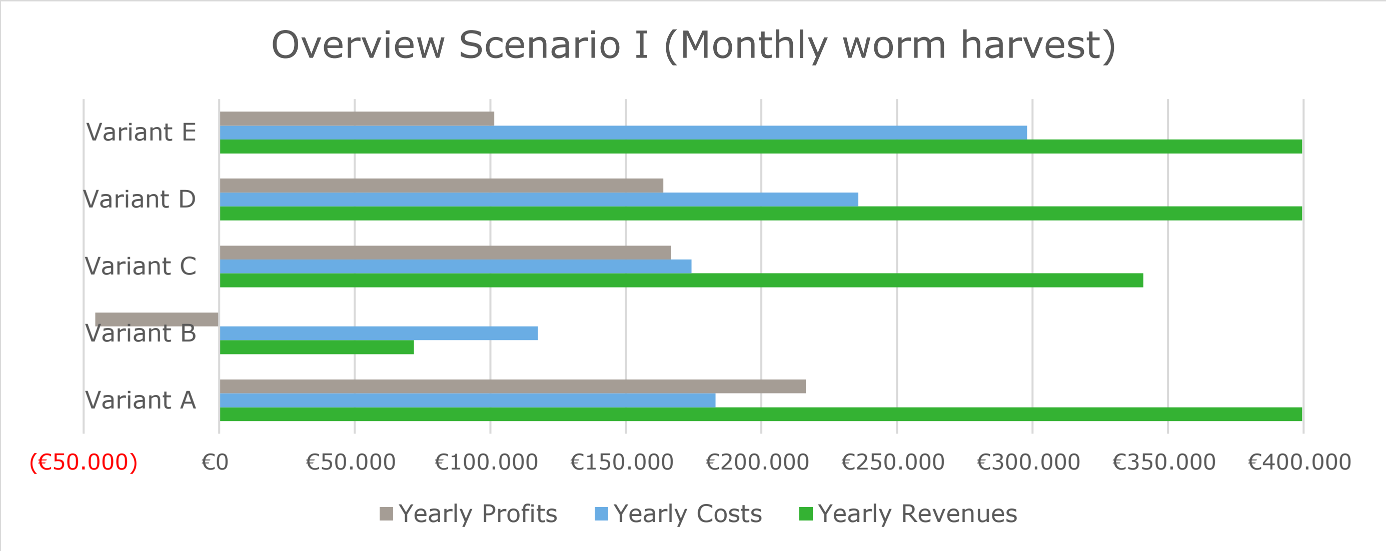


Figure 3.3.1.1 Overview total profits, revenues and costs for scenario I per variant

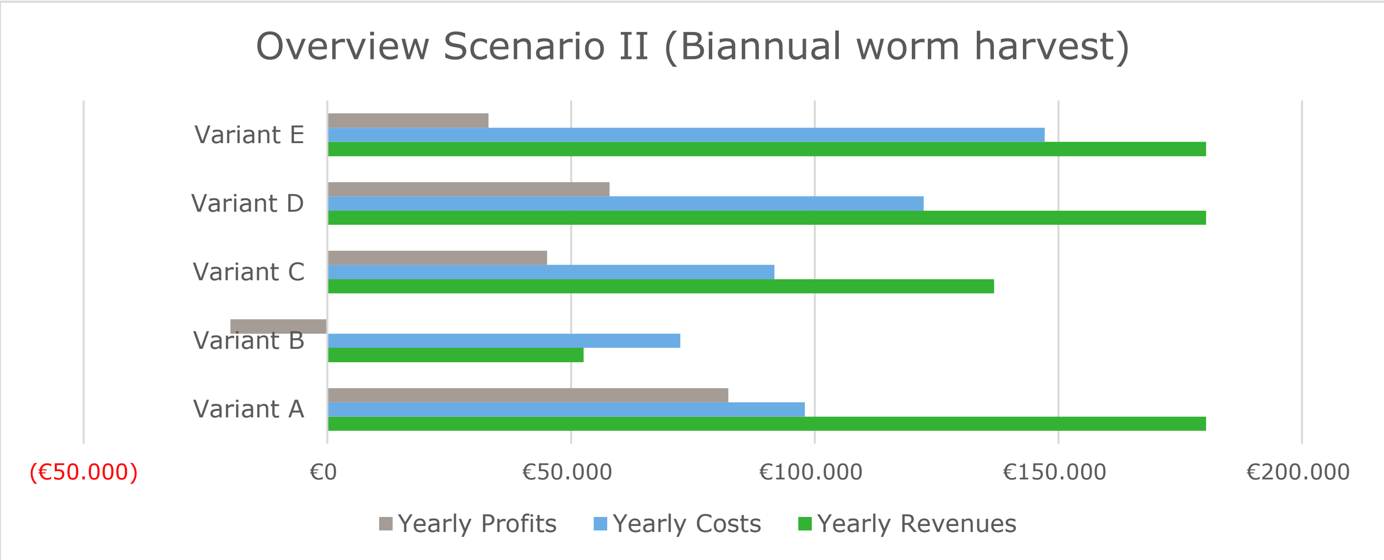


Figure 3.3.1.2 Overview total profits, revenues and costs for scenario II per variant

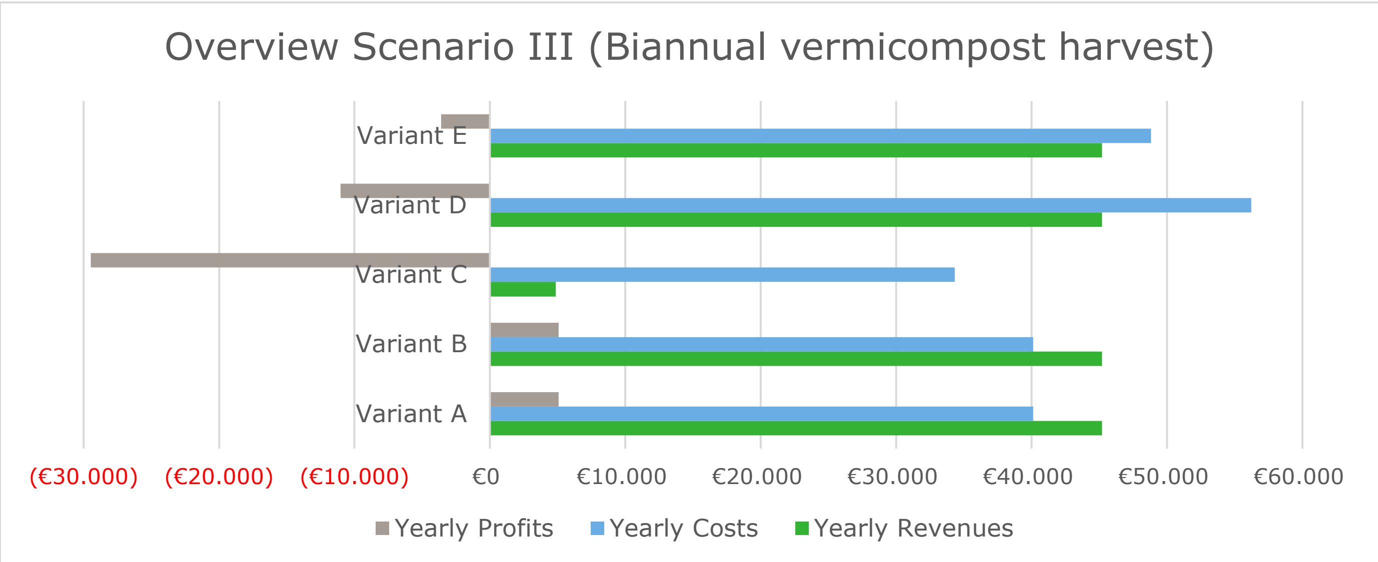


Figure 3.3.1.3 Overview total profits, revenues and costs for scenario III per variant

3.3.2 Overview revenues per scenario

Figures 3.3.2.1 to 3.3.2.3 give an overview of the revenues for each variant for scenarios I, II, and III. The revenues are the same for variant A, D and E.

For scenario I, variant C does not contain revenues from vermicompost. Variant C even has higher costs for disposal (and thus negative revenues for reduction of disposal costs). This is due to the required starter substrate, which resulted in more volume to dispose of compared to no processing. Variant B has the lowest revenues, because of a reduction in revenues from worm biomass due to a lower assumed price per kg of fresh worms.

For scenario II, variant C does not contain revenues from vermicompost. Variant C does have a small reduction in disposal costs. Variant B has the lowest revenues, because of a reduction in revenues from worm biomass due to a lower assumed price per kg of fresh worms.

For scenario III, there are no revenues from selling worm biomass. In addition variant C does not contain revenues from vermicompost. Variant C does have a small reduction in disposal costs. Variant B is equal to variants A, D, and E.

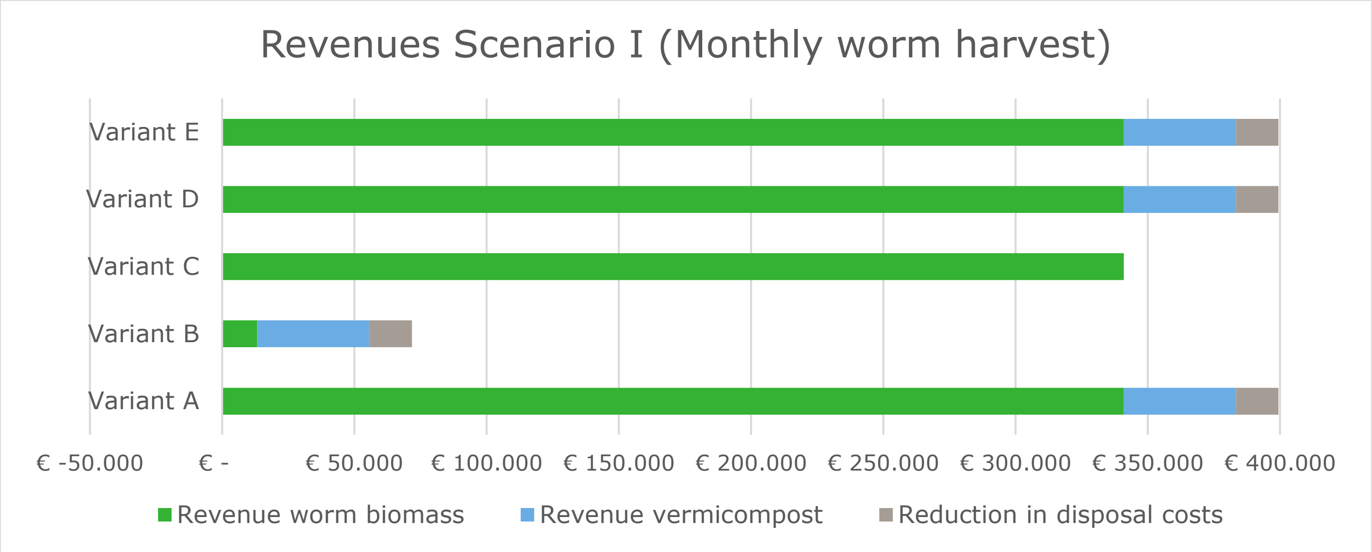


Figure 3.3.2.1 Overview revenues split out per type for scenario I per variant

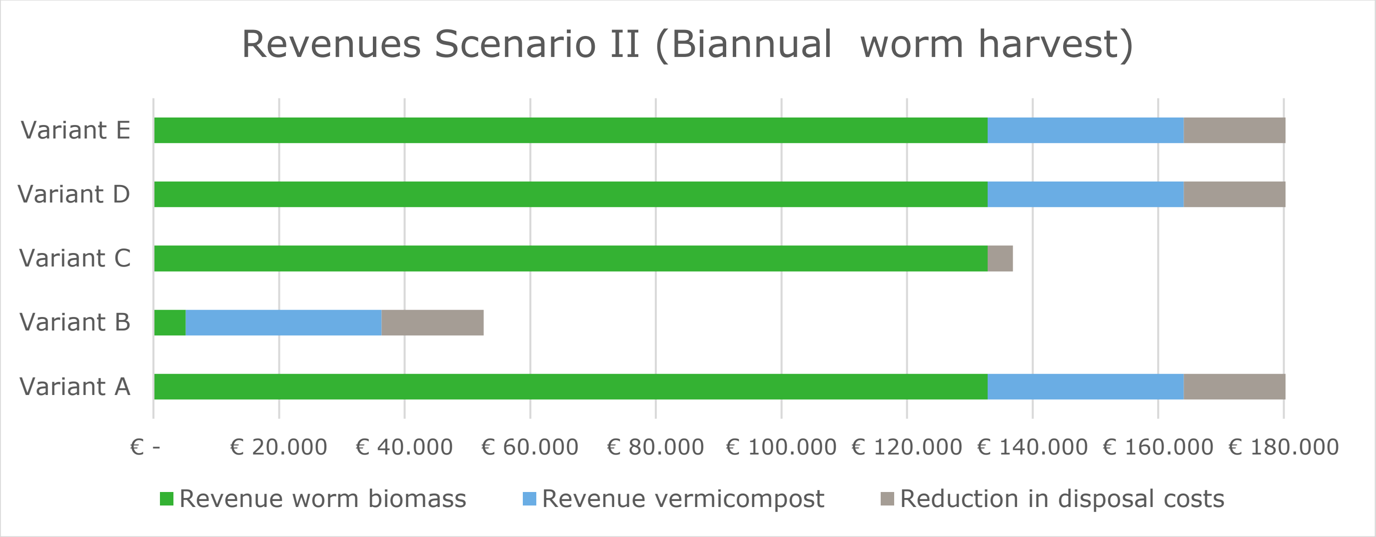


Figure 3.3.2.2 Overview revenues split out per type for scenario II per variant

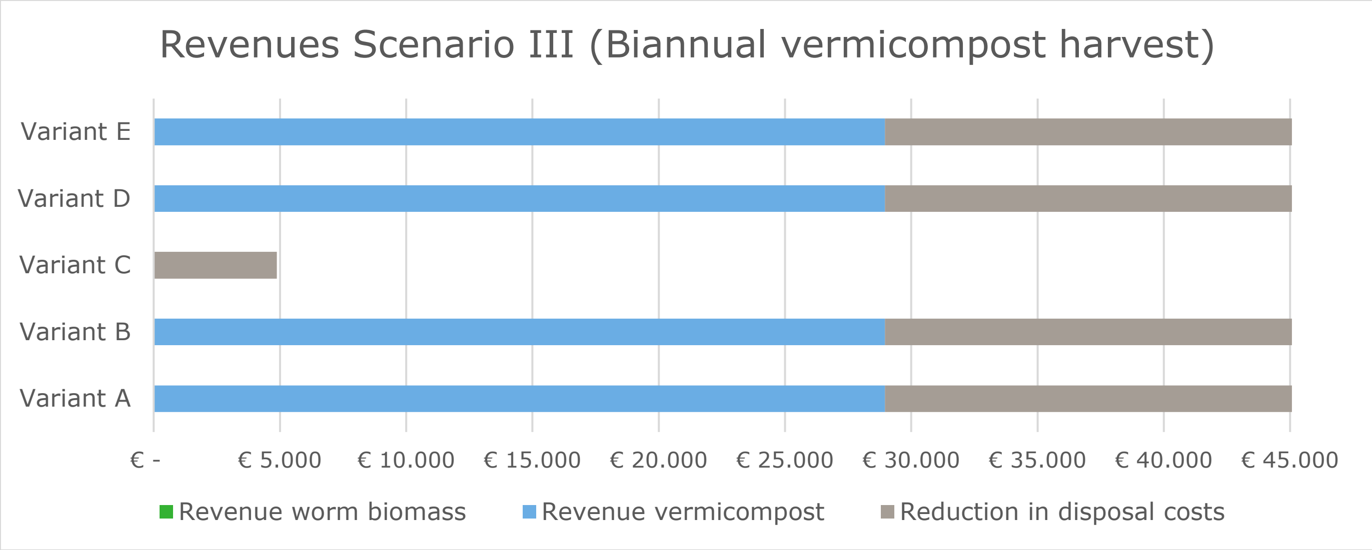


Figure 3.3.2.3 Overview revenues split out per type for scenario III per variant

3.3.3 Overview costs per scenario

Figures 3.3.3.1 to 3.3.3.3 give an overview of the costs for each variant for scenarios I, II, and III. For scenario I, variant E has the highest costs, followed by variant D, A, C and B. Variant A, B, C, and E all have the same depreciation, labour and maintenance costs. Variant E has a higher margin for processing and selling costs for worm biomass and vermicompost. Variant D has double the labour costs. And variant C has no processing and selling costs for vermicompost, since this cost is calculated as a percentage of the revenues gained from vermicompost sales.

For scenario II, variant E has the highest costs, followed by variant D, A, C and B. Variant A, B, C, and E all have the same depreciation, labour and maintenance costs. Variant E has a higher margin for processing and selling costs for worm biomass and vermicompost. Variant D has double the labour costs. And variant C has no processing and selling costs for vermicompost, since this cost is calculated as a percentage of the revenues gained from vermicompost sales.

For scenario III, variant D has the highest costs, followed by variant E, A/B and C. Variant A, B, C, and E all have the same depreciation, labour and maintenance costs. Variant E has a higher margin for processing and selling costs for vermicompost. Variant D has double the labour costs. And variant C has no processing and selling costs for vermicompost, since this cost is calculated as a percentage of the revenues gained from vermicompost sales.

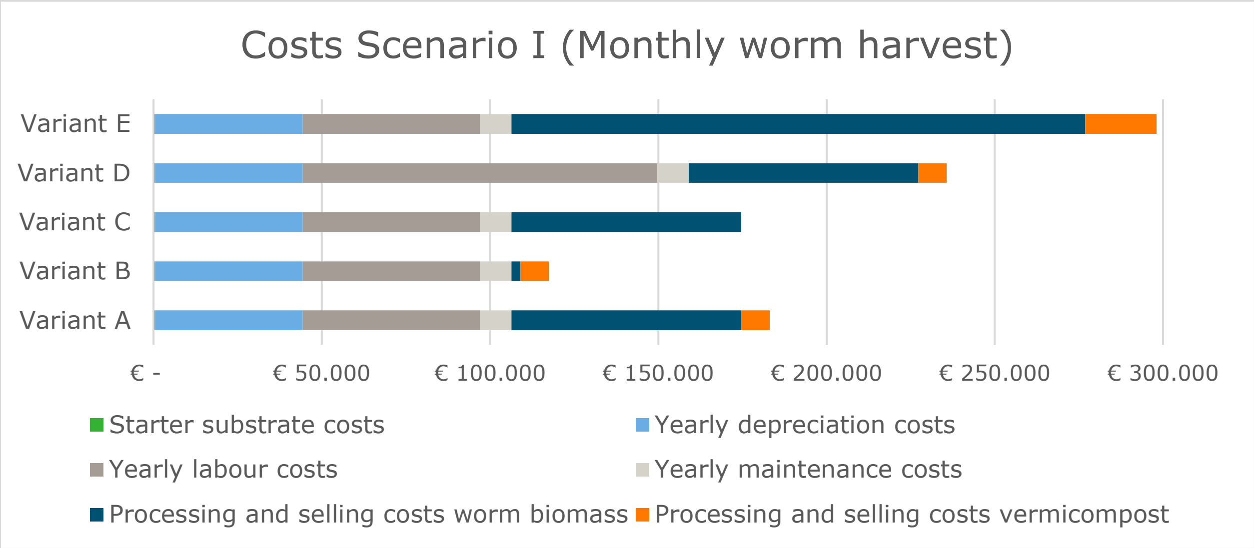


Figure 3.3.3.1 Overview costs split out per type for scenario I per variant

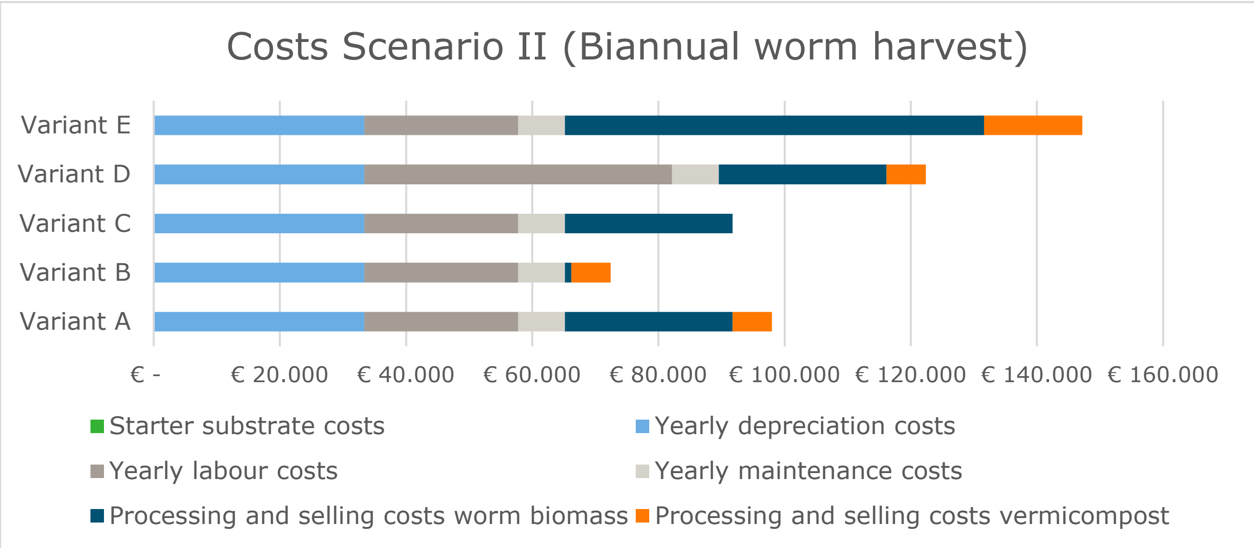


Figure 3.3.3.2 Overview costs split out per type for scenario II per variant

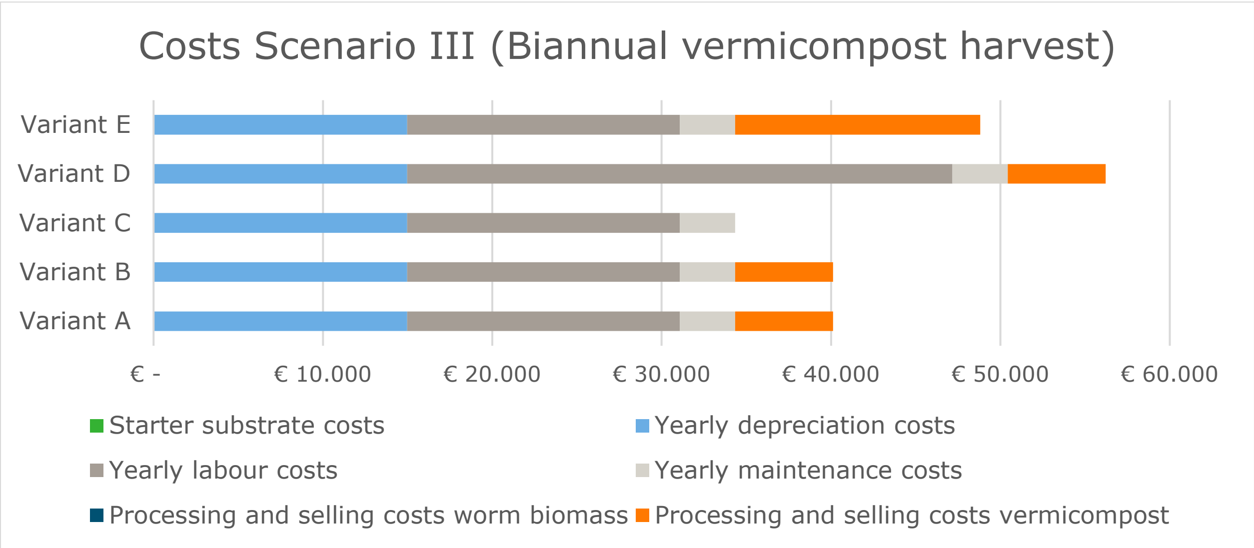


Figure 3.3.3.3 Overview costs split out per type for scenario III per variant

4 Discussion

Using earthworms to process pig manure is not yet seen in many practical applications. A majority of the literature focuses on using earth worms to process pig manure is lab scale. To explore the financial feasibility potential of this concept a lot of assumptions had to be made, since there is no blueprint for set up, growth rates and sales of vermicompost and worm biomass raised on pig faeces. Therefore the assumptions are based on some literature, but mainly on expert opinions and personal estimations. The generated numbers should be seen as an exploration of the feasibility of raising earth worms on pig faeces.

The investments for the scenarios are only applicable to the worm growing set up as described in chapter 2.1. More automated high input systems, will likely result in higher investments and lower labour requirements. Similarly, it might also be possible to skip the trench silo's. An example of this would be to make worm windrows on cement floors, especially if the main focus is on harvesting vermicompost. This would reduce investments (in our low harvesting scenarios the investment required in trench silos as worm beds is approximately 133,000), however it might be a bit more effort to control the substrate and environmental conditions in these windrows.

The growth of earthworms is also considered to be constant over the seasons and it is assumed no external heat is required to maintain the worm beds and worm population. The temperature of the beds can be managed by changing the input of fresh organic matter, which can increase the temperature of the worm bed (Personal communication B. Mekelenkamp (2021). However, it is reasonable that there is a seasonal effect, since earthworms do have an optimal temperature range. Edwards (1985) indicates that temperatures of 15-20 ºC, a pH of 5-9 and a moisture content of 80-90% are optimal for growth of *Eisenia fetida* in animal wastes. Edwards (1985) also indicated that per tonne of animal wastes, a 100kg of worms could be grown, with a conversion efficiency of 10% on a dry mass basis. Ranges from 15 to 27 degrees ºC have been reported to be optimal for earthworms by Sherman (2003), where 15-20 ºC were stated to be optimal for cocoon production and hatching. So during colder months it is not unlikely worm activity decreases somewhat, which is not accounted for in this exploration. Furthermore, it is to our knowledge unclear what the effects are of possible worming agents residuals in the composted pig faeces on the growth and mortality rate.

The prices for worm biomass also vary widely. Wholesale prices seem to be around 9 euros per kg of live worms. However, prices for individual consumers seem to range from €15 to €30 per kg live worms in the Dutch context. These worms are often *Dendrobaena veneta* and not *Eisenia fetida* (Personal communication Wasse, F., 2022; Personal communication Kranenburg, A., 2022; Personal communication Mous, L., 2022; Personal communication Bosch, M., 2022; Personal communication Berendsen, S., 2022). Furlong et al. (2017) described prices ranging from $ 4.25 to 41.50 per kg for the Indian market and prices ranging from $15 to $57 per kg for the South African market. Another source indicates a range from $15-$30 depending on the scale (Sherman, 2018). Similarly the price ranges for vermicompost seem very wide. Sherman (2018) indicates prices for vermicompost ranging from $260 to $2600 per m3 in the worm handbook, this seems quite high compared to some prices on webshops, which seem to range from €79 (Struiz, n.d.) to €185 (Biogroei, n.d.) per m3 for small scale vermicompost sales. However from an expert opinion, it was assumed that €30 per m3 for large scale vermicompost sales was more likely and more in line with other compost types prices in the Netherlands (Personal communication, Mekelenkamp, B.,2021). Furthermore, if processing of pig faeces becomes prevalent on a large scale, supply of worm biomass and vermicompost will increase. Leading to an expected drop in worm biomass and vermicompost prices. Especially if part of the produced worm biomass is expected to be sold for feed purposes.

In the presented scenarios costs surrounding the building structure were not regarded and assumed to be zero. It was assumed that the pig faeces could be processed in an old left over barn, with virtually zero building costs associated with it. Since vermicomposting can take up quite some area, it would be interesting for follow up research to attempt to incorporate potential building costs related to the surface area.

In the chosen scenarios pig faeces are processed by earthworms and it is assumed that the resulting vermicompost can be just be sold for "regular" vermicompost prices. However, it is unlikely that vermicompost based on animal manure, will not be labelled as animal manure. Vermicompost produced from organic, non-manure sources, unmixed with manure substrates, should ideally not be considered manure under legislation, since earthworms living naturally in our soils also consume soil with organic substances. Thus, it is likely that vermicompost produced from manure substrates must adhere to manure legislation. Although it should be noted, that the vermicompost might still have added value as a soil improver and fertilizer compared to manure, for example because vermicompost is more stable and contains components such as humic acids and more readily available macronutrients and lower ammonia concentrations (Atiyeh et al., 2001; Chan et al, 1988; Elissen, in preparation).

Furthermore, it was assumed no air washer was necessary to reduce potential emissions from the pig faeces. An air washer with a capacity of 25,000 m3/hour would need an additional investment of €70,000 to €90,000. Resulting in an additional yearly depreciation and maintenance costs of approximately €7,000 - €10,000. On top of that depending on the type of air washer chosen yearly operational expenses of the air washer will range from €10,000 to €20,000 (Personal communication, Vermeij, I., 2023).

5 Conclusion

Despite limited information availability, the scenarios show there are certain situations in which processing pig faeces with earth worms will lead to a net profit. The scenarios that assumed monthly harvesting with a growth from 5 to 7 kg/m2, were generally the most profitable, followed by the scenarios that assumed biannual harvesting of worms, with a growth from 5 to 12 kg/m2. These scenarios were profitable even under increased labour requirements, disposal costs for vermicompost, as well as under increased processing, transport and selling costs. The least profitable scenarios were the scenarios that assumed no harvesting of the worms, except for the scenario with a greatly reduced worm biomass price.

This report shows a positive business case for processing pig faeces on site by individual pig farmers. However, due to limitations regarding availability of data, certain assumptions had to be made. Therefore more practical experience and larger scale tests are necessary to validate certain assumptions. Especially regarding worm growth and labour requirements.

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Annex 1 Vermicomposting of pig manure

To support the assumptions made in this report, some real life experiments were executed with vermicomposting of pig manure. The aim of the experiments was to get a better understanding of the breakdown and conversion of the pig manure into vermicompost.

Experimental set-up
Two different pig manures were collected, pig manure solids (PMS), directly collected from the stable floor which results in minimal additional urine in the PMS. The second pig manure is collected freshly from the dunghill (PD). The pig manure was mixed in the stable with urine and straw.

Figure 1 a. The pig manure solids (PMS) collected from van Beek SPF pigs (Lelystad). b. Pig feces mixed with urine and straw collected from ten Have pigs (Beerta) c. The vermicompost end product from the PMS substrate.

The experiments were conducted at WormsSystems, Oostwold the Netherlands. Both types of manure were spread out over the barn floor and left to decompose in the air for two weeks, with regular turning of the manure. The PD still contained to much ammonia for the worms to grow, and this manure was discarded. The PMS was left to decompose for a total of 4 weeks, before the experiment was started.

The experiment was conducted in duplicate. Two trays (60x40x12) each containing 4.5 kg of PMS were placed in a climate cell with a temperature of 12°C. 250g of *Dendrobena veneta* were added to each tray, together with 1L of water. After two days, another 750g of *D. veneta* were added, together with 0.5L of water making a total of 1 kg worms in 6 kg of moist substrate. The worms were left to feed for 24 days. The amount of starting substrate was weighed, as was the amount of vermicompost and compostworms at the end of the experiment.

Samples of the vermicompost of both trays, together with the starting substrate were sent for analyses (Eurofins, Wageningen). The vermicompost analyses contained fertilizing value and heavy metal analyses. Samples of the compostworms at the start and end of the experiment were sent for analyses to Agrolab, Germany for Weender and heavy metal analyses

The substrate breakdown in percentages is calculated in the following way in either dry of fresh matter and where the start substrate is the composted PMS;

$$Substrate\ breakdown\ percentage = \frac{(End\ weight\ of\ the\ substrate\ (g) - starting\ weight\ of\ the\ substrate(g))}{starting\ weight\ of\ the\ substrate\ (g)} * 100\%$$

SUBSTRATE	Dry matter g/kg	Organic matter g/kg DM	Ash g/kg DM	Nitrogen g/kg DM	C/N ratio g/kg	NH3-N g/kg DM	N-org g/kg DM	Phosphor g/kg DM	P2O5 g/kg DM	Potassium g/kg DM
PMS fresh	411	833	167	30.0	12	3.0	27.0	17.5	40.2	11.4
PMS COMPOSTED	303	825	175	30.1	12	3.7	26.5	18.2	41.8	9.9
PMS end, tray 1 vermicompost	339	736	264	30.2	11	1.2	29.0	22.0	50.4	13.5
PMS end, tray 2 vermicompost	347	739	261	31.2	10	0.6	30.7	21.3	48.7	10.9
Cattle Slurry (Samenstelling organische meststoffen, n.d.)	**92**	**772**	**43**	**43**		**21**	**23**		**16**	

Results

The substrates were completely eaten by the worms at the end of the experiment. The dry and fresh matter breakdown of vermicomposting of the substrates is shown in the table below. The .

Table 1 *Breakdown percentages of the substrates, calculated from the start and end weights of the substrates and vermicompost.*

	Breakdown of substrate fresh matter (%)	Breakdown of substrate dry matter (%)	Breakdown of substrate organic dry matter (%)
PMS end tray 1 vermicompost	-31.3%	-14.5	-23.7
PMS end tray 2 vermicompost	-28.9%	-9.4	-18.8

The breakdown of fresh matter is around 30% for each of the duplicates. On a dry matter base, the breakdown percentage is lower, which could be caused by water evaporation in the trays. The breakdown of the organic matter is therefore a better parameter to determine the breakdown of the substrates. The breakdown percentage of the organic matter (DM based) is around 20%.

The two tables on the next page show the fertilizer values of the fresh pig manure, the composted pig manure and the vermicompost of the pig manure (in duplicate), the heavy metals analyses were also conducted on the compostworms, at the start and the end of the experiments. The dry matter content decreases during composting. Organic matter decreases only slightly during the composting period, whereas vermicomposting decreases the organic matter content from 824 g/kg to 736 g/kg or 739 g/kg in the duplicate. The ash content rises, probably due to rearing of the compostworms, converting organic matter into non digestible end products. To reflect better on the fertilizer values, the values of cattle slurry are also presented in Table 2 below. Cattle slurry is often used in the Netherlands as fertilizer on grassland or fields. The organic matter content is with 772 g/kg DM comparable to the organic matter content of vermicompost. The total nitrogen content of vermicompost is slightly lower (30.2 and 31.2 g.kg DM) than the total nitrogen content of cattle slurry (43 g/kg), whereas the N in cattle slurry is mainly mineral-N, the nitrogen in vermicompost from pig manure is mostly organic-N. The phosphate content is higher in the vermicompost, which could be due to using only solid parts of pig manure for vermicomposting (the solids have a known higher content of phosphor). The kali content of the vermicompost is lower (16.1 and 13.9 g/kg DM) when compared to the kali content of the cattle slurry (58 g/kg DM). The vermicompost of the solid pig manure is suitable as a fertilizer for plots with a lower need of K and N, but a higher need of P.

Since compostworms are fed on pig manure in this experiment, it is likely that the vermicompost will also be labeled as manure. For manure, there are no thresholds of heavy metals when it is used as fertilizer on the fields. However, to still get a feeling about the heavy metal content, the threshold of compost is presented in

Table 3 below. The heavy metal analyses in the vermicompost show that all heavy metals are present below the threshold for compost (RVO, 2015), except for zinc and copper. However, zinc and copper thresholds are set very low in the Netherlands, even lower than the EU standard. Secondly, farmers don't see higher concentrations of zinc and copper as an issue. The concentration of zinc and copper also increased in the compostworms, it is known that they can accumulate heavy metals. The increase of zinc and copper could also be due to evaporation of the water, resulting in a higher concentration in the dry

SUBSTRATE	Dry matter g/kg	Organic matter g/kg DM	Ash g/kg DM	Nitrogen g/kg DM	C/N ratio g/kg	NH3-N g/kg DM	N-org g/kg DM	Phosphor g/kg DM	P2O5 g/kg DM	Potassium g/kg DM
PMS fresh	411	833	167	30.0	12	3.0	27.0	17.5	40.2	11.4
PMS COMPOSTED	303	825	175	30.1	12	3.7	26.5	18.2	41.8	9.9
PMS end, tray 1 vermicompost	339	736	264	30.2	11	1.2	29.0	22.0	50.4	13.5
PMS end, tray 2 vermicompost	347	739	261	31.2	10	0.6	30.7	21.3	48.7	10.9
Cattle Slurry (Samenstelling organische meststoffen, n.d.)	**92**	**772**	**43**	**43**		**21**	**23**		**16**	

matter. The zinc and copper concentrations where already above the threshold in the starting substrate. If the vermicompost is sold as compost, the initial heavy metal content of the starting substrate needs to be taken into account. The compostworms, next to zinc and copper, also slightly accumulated cadmium, nickel and arsenic, whereas chrome and lead concentrations dropped.

The compostworms were also analyzed on their heavy metal content. To place these values in perspective, the max values of heavy metals in animal feed of animal origin are also presented in

Table 3 below. Take into account, that compostworms fed on animal manure are not allowed and regulated as animal feed yet, so this is just hypothetical as for now. The heavy metals that should be carefully watched in animal feed are lead, cadmium and arsenic. The worms do not exceed the limits set for lead and cadmium, but they do exceed the limit for arsenic (4.33 and 5.11 mg/kg DM whereas 2.3 g/kg DM is allowed). However, there are exceptions possible to exceed the limits, for example some additives to animal feed, presence of flocculants or presence of trace elements.

Table 2 *Fertilizer values of the fresh substrate, the composted and the vermicompost at the end of the test.*

SUBSTRATE	Dry matter g/kg	Organic matter g/kg DM	Ash g/kg DM	Nitrogen g/kg DM	C/N ratio g/kg	NH3-N g/kg DM	N-org g/kg DM	Phosphor g/kg DM	P2O5 g/kg DM	Potassium g/kg DM	K2O g/kg DM	Magnesium g/kg DM	MgO g/kg DM	Sodium g/kg DM	Na2O g/kg DM
PMS fresh	411	833	167	30.0	12	3.0	27.0	17.5	40.2	11.4	13.7	10.7	17.7	1.9	2.6
PMS COMPOSTED	303	825	175	30.1	12	3.7	26.5	18.2	41.8	9.9	11.9	11.9	19.7	2.0	2.7
PMS end, tray 1 vermicompost	339	736	264	30.2	11	1.2	29.0	22.0	50.4	13.5	16.1	13.2	22.0	2.6	3.5
PMS end, tray 2 vermicompost	347	739	261	31.2	10	0.6	30.7	21.3	48.7	10.9	13.9	12.9	21.5	2.6	3.4
Cattle Slurry (Samenstelling organische meststoffen, n.d.)	**92**	**772**	**43**	**43**		**21**	**23**		**16**		**59**		**13**		**8**

Table 3 *Heavy metal analyses of all samples taken during the experiment. The following samples were taken, pig manure solids starting substrate, pig manure solids composted, vermicompost in tray 1 and vermicompost in tray 2. The compost worms were also analysed on heavy metal content at the start and the end of the experiment.*

Sample name	Chrome (Cr) mg/kg DM	Nickel (Ni) mg/kg DM	Copper (Cu) mg/kg DM	Zinc (Zn) mg/kg DM	Lead (Pb) mg/kg DM	Cadmium (Cd) mg/kg DM	Mercury (Hg) mg/kg DM	Arsenic (As) mg/kg DM
Start PMS substrate	4.9	5.3	108	739	<6.8	0.35	<0.04	<1.2
PMS composted substrate	5.9	5.2	129	846	<6.7	0.34	<0.04	<1.2
PMS end, tray 1 vermicompost	7.9	7.5	149	978	<6.5	0.46	<0.04	<1.1
PMS end, tray 2 vermicompost	8.3	7.6	144	934	<6.5	0.49	<0.04	<1.1
Max value of heavy metals per kg DM compost	50	20	90	290	100	1	0.3	15
Start compostworms	1.59	0.73	10.70	115.00	1.75	1.90	0.02	6.89
End test Tray 1 compostworms	0.93	1.91	37.80	178.00	0.85	2.10	0.02	4.33
End test Tray 2 compostworms	0.97	1.29	34.90	175.00	1.21	2.30	0.02	5.11
Max value of heavy metals in animal feed of animal origin Barroso, J. M. (2013)					**11.4**	**2.3**		**2.3**

To explore the potential of nature to improve the quality of life

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