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ECONOMICAL FEASIBILITY OF USING URINE VERSUS STRUVITE AS FERTILISER

USING THE EXAMPLE OF GIZ IN ESCHBORN

BACHELORARBEIT IM STUDIENGANG UMWELTMANAGEMENT

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Christina Braum

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List of Abbreviations

AC	Annual costs
AFAKE	Accumulation factor for individual payment
Ca	Calcium
DFAKE	Discounting factor for individual payment
DFAKR	Discounting factor for steady rows of cost
DPC	Dynamic project costs
GIZ	Gesellschaft für Internationale Zusammenarbeit GmbH
IBC tank	Water tank, 1 m^3
IK	Investment costs
IKR	Reinvestment costs
K	Potassium
KFAKR	Annuity factor
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft
LK	Running costs
MAP	Magnesium–Ammonium–Phosphate
Mg	Magnesium
MgO	Magnesium oxide
N	Nitrogen
NPK	Multi components mineral fertiliser, containing N, P, K
P	Phosphorous
SA I	Sensitivity Analysis Increase of fertiliser prices (40%)
SA II	Sensitivity Analysis Increase of fuel prices (40%)
SA IIIa	Sensitivity Analysis Increase of distance to field (10 km)
SA IIIb	Sensitivity Analysis Increase of distance to field (30 km)
SANIRESCH	Sanitär Recycling Eschborn
Scenario *A*	Tank 1 > Vehicle > Field
Scenario *B*	Tank 1 > Pipes > Tank 2 > Vehicle > Field
Scenario *C*	Tank 1 > Vehicle > Tank 3 > Field
Scenario *a*	Stainless steel tank
Scenario *b x*	Water tanks plane
Scenario *b y*	Water tanks stacked
Tank 1	Existing tank GIZ
Tank 2	Additional tank GIZ

Tank 3	Additional tank field
TPC	Total project costs
UDT	Urine diversion toilet

1. Abstract

The research's aim was to identify the most favourable alternative of human urine and struvite usage as innovative fertilisers compared to traditional resources.

Therefore, the study has a great focus on introducing and comparing different storage and transportation scenarios. Various combinations of different scenarios and alternatives will be presented and explained with respect to their financial efficiency.

In order to compare those scenarios properly, the common comparative cost guidelines for water management infrastructure, Leitlinien zur Durchführung dynamischer Kostenvergleichsrechnung of the Länderarbeitsgemeinschaft Wasser, LAWA, was conducted. Finally, all alternatives can be likened based on their total project costs.

As a result, one alternative for using urine turned out to be the most favourable option. This alternative based on the idea to transport the urine quarterly from GIZ to the chosen field, near Eschborn, where storage tanks with the overall size of 30 m³ are available. The transport occurs with the help of a hired farmer, his tractor and his manure barrel. As well as the urine's application is performed by a farmer and his equipment.

2. Introduction

2.1 Thesis' Intention

The idea of recycling has already captured the waste sector in many parts of the world and should become an integral part of our everyday life in the wastewater sector in the near future. The *re–use* of human excreta and household wastewater in agriculture build the foundation pillar for thoughtful wastewater usage. Therefore, soil fertility is achieved, water resources are preserved and the operation of a biogas system is possible. As a result, the increase of recirculation systems causes sustainable development in sanitation and agriculture (v. Münch et al., 2009).

The fact that „phosphate rock is a non–renewable resource“ (Cordell, 2010) and simultaneously „together with nitrogen and potassium, […] an essential plant nutrient“ (Cordell, 2010) is one of the main reasons why the agricultural reuse of the possible phosphorus–rich fertilisers, urine and struvite, should be urged. As compared with water and oil scarcity, the phosphorus scarcity is quite similar. However, there is the important difference that “phosphorus is a far less tangible resource” (Cordell, 2010) because of “no direct or visible uses of phosphorus in society” (Cordell, 2010). Furthermore, the shifting phosphorus price does not have an immediate impact on food prices –thus no direct impact on consumers– as opposed to the raw oil price, directly and daily noticeable for everybody at the petrol pump (Cordell, 2010).

Nonetheless, we have to face the fact that the conventional phosphorus origins will run dry sooner or later. According to the international journal *Nature,* “Phosphate rock deposits should last for between 300 and 400 years” (Nature, 2010). The Soil Association, however, states that “the supply of phosphorus from mined phosphate rock could “peak” as soon as 2033” (Soil Association, 2010). Cordell et al. (2009), whereas, citing Steen, Smith and Gunther, talks about 50–100 years emanating from “the present rate of consumption”, until the sources are exhausted. Additionally, Rosemarin (2010) mentions different years and time spans to describe the phosphor’s depletion by citing Steen: 60–130 years, Smil: 80 years, Smit et al.: 96–100 years, Vaccari: 90 years, Fixen: 93 years. As these statements can only be acknowledged as prognoses or ideas, no facts, there is no chance to identify a *true* and absolute point of time so far.

Nevertheless, it could be seen as a fact that the consumption of phosphate fertilisers increases, especially in developing countries.

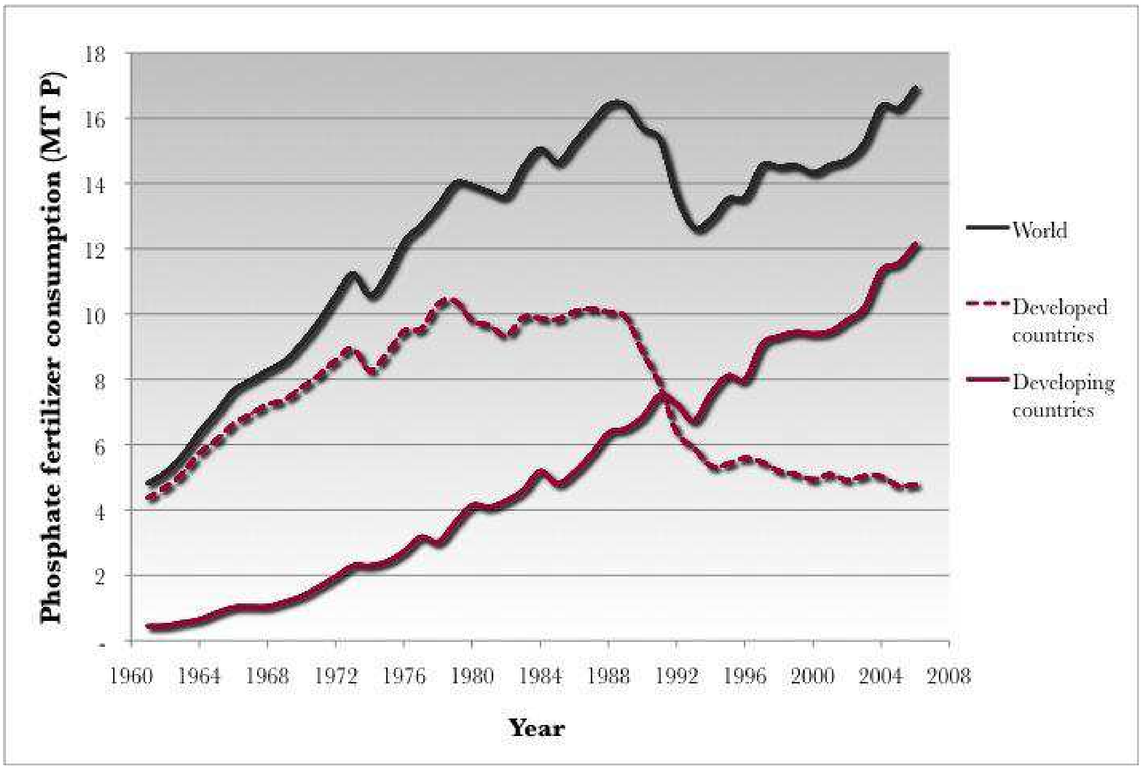

Figure 1 Fertilizer Consumption is Increasing in the Developing Countries (Rosemarin, 2010; adapted from FAOstat)

However, no matter when these resources will become scarce, the phosphorus and fertiliser prices and alternative phosphorus sources will be an important issue for farmers in a direct and for everybody in an indirect way. Based on the knowledge of the fertiliser price's increase this is particularly relevant.

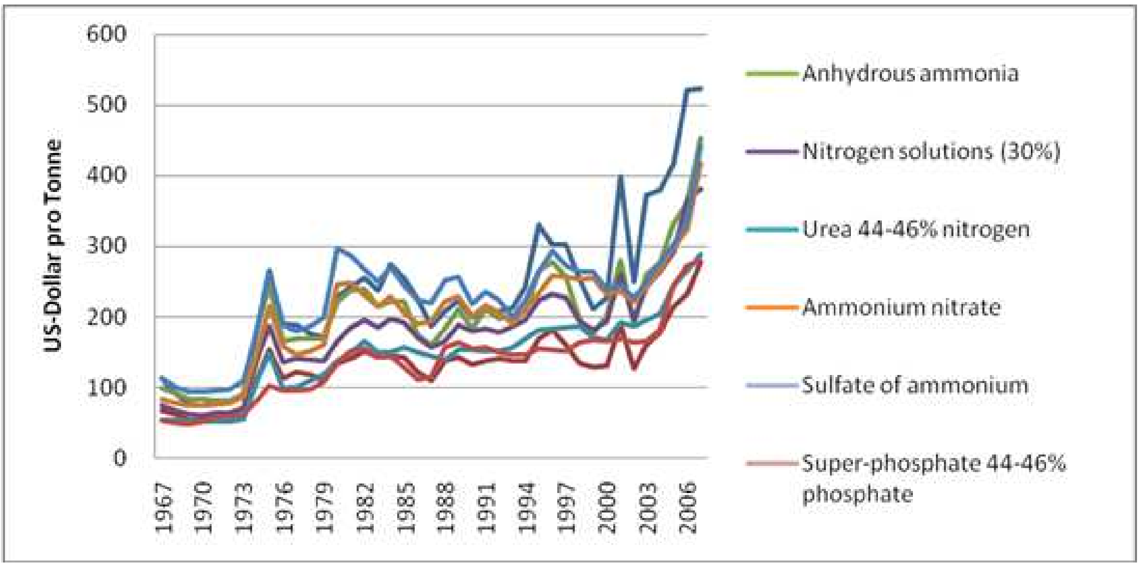

Figure 2 Customer prices for fertilisers in the United States of America from 1967–2008 (Feiereisen, in preparation; adapted from data given by USDA, 2010)

See that there are already a number of studies dealing with the questions why? and how? to gain phosphorus from different origins by closing the loop, the reuse of human excreta, in our everyday life, this thesis mainly addresses the next essential steps: the storage and transportation of the possible alternative fertilisers, urine and MAP, from the spot of emergence to the application's place. Concerning urine's and MAP's faculties to act as fertilisers, the author referred to existing studies (Simons and Clemens, 2003; Vinnerås and Jönnson, 2007). For example, Larsen and Lienert (2007) recorded "that urine-based products are suitable for use as fertilizers and are generally comparable to artificial fertilizers".

Without considering the whole chain of procedures, it is not possible to appraise the urine's and MAP's economic value. Nevertheless, this is the determining crux to make a comparison between conventional multi components mineral fertiliser, NPK, and the regarded alternatives.

In order to indentify an alternative to common mineral fertilisers that is economically interesting as well, it is absolutely essential to conduct an economic feasibility study.

2.2 Questions & Hypotheses

2.2.1 Research Questions

What are the important differences between the use of urine and the use of MAP as fertiliser? A comparison of the different logistics for storage and transportation is necessary, these are the crucial points:

- The attended logistics chain for urine use
    - The equipment needed in addition: storage possibilities, additional fertilisers
    - The possible complexity of storage, transportation and application, because of the massive volume
- The attended logistics chain for MAP use
    - The equipment needed in addition: technical plants, reactor, internal transportation of urine, starting materials for the reaction, additional fertilisers
    - The possible simplification of storage, transportation and application, because of the volume's reduction compared to urine

Under which conditions is the urine and MAP storage and transportation economically feasible?

- Different storage possibilities
- Different transportation vehicles
- Different distances of transportation

2.2.2 Research Hypotheses

The expectations are that the handling of urine, its storage, transportation and application, is complicated and therefore expensive with respect to the great mass that need to be managed. Otherwise, the equipment needed in addition is more expensive for the use of MAP, whereas a whole treatment plant has to be purchased to obtain the urine–based product struvite and the associated mass' reduction.

So, it is expected that the investment and maintenance costs in case of MAP precipitation are higher than the costs for using the untreated urine. Moreover, it is expected that the storage and transportation costs for struvite are less because of the smaller volume in contrast to urine.

The expectations are that preferably big stocks and therefore rarely transportations with big vehicles leading to minimal expenses. It is expected that the urine's transportation of more than 30–40 kilometres is uneconomic (Johannson and Nykvist, 2001), so that the occurrence of local users has to be given. Otherwise, the MAP's transportation might become economic starting from 30–40 kilometres.

3. Background

3.1 Urine

In this concrete example the urine collection takes place in Eschborn, near Frankfurt am Main, in the main building, house 1, at the Eschborn's site of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH within the SANIRESCH project. Since 2006, there is an installation of 50, now reduced to 38, urine–diversion flush toilets; UDTs; and 23 waterless urinals situated in 10 floors in the central section of the building (Winker and Hartmann, 2010).

Figure 3 Roediger Vacuum urine–diversion flush toilet and Keramag urinal (flickr, 2011)

The UDTs; constructed by Roediger Vacuum, consist of two separated bowls to divide urine and brownwater. Used in a correct way, a valve, located below the urinal bowl, allows gaining the undiluted urine. The valve is opened by sitting down whereby flush water will be provided in the urine pipe system. Additionally, there is the possibility to choose between a 1 to 3 litre and a 6 litre flush (Winker and Hartmann, 2010).

The urinals, constructed by Keramag, are made of an odour sealing rubber tube the urine has to pass and a sieve as a trap for foreign particles such as pubic hair, for example. They are working waterless (Winker and Hartmann, 2010).

According to Winker and Hartmann (2010) 400 people per working day produce approximately 40 m^3 per year which are collected in house 1's basement in four polyethylene tanks of 2.5 m^3 each. To achieve the pure urine, the implementation of two different pipeline systems for urine and brownwater was necessary (Winker and Hartmann, 2010).

Emptying the tank is achieved by pumping the urine via an outlet located nearby one of the basement gates (Winker and Hartmann, 2010).

Until now, the existing in–house sanitary installations have been described which were considered in Andrés Lazo Páez's master thesis "Economic feasibility study of the new sanitation system in Building 1 in the GTZ headquarters". His thesis discussed an economic feasibility study, which compares an ecosan, UDT's and waterless urinals together, with a conventional sanitation system. This study has been built on his results and continues the cost analysis with a new focus on transportation and storage. To be more precise, this work's cost intake starts directly following his previous findings.

3.2 MAP

Since May 2010, a Magnesium–Ammonium–Phosphate, MAP, precipitation reactor, designed and constructed by Huber SE, has been arranged in the basement. This reactor is invested with a treatment capacity of 400 litre urine per day, up to 50 litres per cycle, and is able to produce MAP by adding magnesium oxide (Winker and Tettenborn, 2011). MAP is also known as struvite, a white powder that contains the urines' nutrient phosphor, but in a far higher concentrated form compared to the untreated urine.

Figure 4 Magnesium–Ammonium–Phosphate precipitation reactor (flickr, 2011)

The reactor possesses a screw which is located on the top and transports the required magnesium oxide bags inside. In there, the added urine, containing ammonium and phosphate, and the magnesium oxide meet and the mixture is stirred. This is where the reaction takes place, “the phosphates and part of the ammonium are precipitated due to a chemical reaction” (Huber SE, 2010), after about 3 hours –sedimentation phase– MAP crystals form (Huber SE, 2010). These crystals “can be separated and recovered easily from the liquid phase by settling and subsequent drying” (Winker and Tettenborn, 2011)
Here magnesium ions, ammonium and phosphate react to struvite.

Simplified equation: $Mg^{2+}+NH_4+PO_4^{3-}\rightarrow MgNH_4PO_4$

Figure 5 Magnesium–Ammonium–Phosphate (flickr, 2011)

Afterwards, five filter bags are automatically filled with the MAP concentrated urine, approximately five litres, and the urine surplus, approximately 25 litres, in a rotating mode in different filter bags (Winker et al., 2011).

At the moment the reactor “is filled with 30 l of urine per cycle” (Winker and Tettenborn, 2011), “9 g magnesium oxide is added to each cycle” (Winker and Tettenborn, 2011) and it produces about 0.8 gram MAP per litre urine which correlates to approximately 30 kilogram MAP per year.

The MAP remains in the filter bags, whereas the precipitated water, which dropped out of the bags, is collected beneath them and added to sewage. This water still contains a high ammonium rate and therefore should be treated prospectively at the best case. Afterwards, the filter bags remain three days in a drying box, fixed in frames (Winker et al., 2011). A separate outlet for dripping liquid is given at the boxes' bottom. Afterwards, about one kilogram “of paste–like MAP can be taken out of each filter bag” (Winker and Tettenborn, 2011). The next step is to dry the filter bags and MAP approximately four days in a drying oven with about 40℃ (Winker et al., 2011). The dried MAP’s composition based on Winker and Tettenborn (2011) is:

- 110 g P/kg
- 42 g N/kg
- 100 g Mg/kg

It is free of the “pharmaceutical residues contained in urine” (Winker and Tettenborn, 2011).

4. Material & Methods

4.1 Primary and Secondary Data

This research is based on both primary and secondary data. On one hand most of the figures that were used to conduct the analysis belong to primary data. In order to provide proper data for this piece of work, various offers had to be invited and compared for every single factor. Finally, the author decided to choose the arithmetic mean of all requested offers –if they were sort of similar and therefore comparable– as it was decided to be the most realistic presentation of all data. On the other hand, secondary data was adapted for the cost comparative method

4.2 Limitations

Furthermore, there were several limitations that the author had to face during the analysis. First of all, not all figures were provided by primary or secondary sources. Although most of the expenses were developed with respect to real numbers, some assumptions had to be made. Moreover, it has to be stated that the results of this specific analysis cannot be adapted for other countries or regions universally. Most of the figures, however, only need to be changed slightly in order to use this method globally.

4.3 Scenarios

The first step is to create different possible transportation and storage scenarios for urine and MAP:

The urine transportation scenarios are marked with *capital letters*.

- Urine Transportation Scenario *A*:
  - Tank 1 → Vehicle → Field

Figure 6 Urine transportation scenario A (flickr, remondis industrie service, flickr, 2011)

- Urine Transportation Scenario *B*:
  - Tank 1 → Pipes → Tank 2 → Vehicle → Field

Figure 7 Urine transportation scenario B (flickr, directindustry, stallkamp, remondis industrie service, flickr, 2011)

- Urine Transportation Scenario *C*:
  - Tank 1 → Vehicle → Tank 3 → Field

Figure 8 Urine transportation scenario C (flickr, remondis industrie service, stallkamp, flickr, 2011)

With reference to urine transportation scenario A the existing tank, tank 1, covering 10 m³ remains as the only storage facility for the arising urine. It is regularly emptied by an adequate vehicle, so that the content can be transported to the chosen field. Unfortunately, scenario A had to be scraped at an early stage of the process as a consequence of the following reasons:

- Tank 1 ought to be emptied every three months
- 10 m³ urine accumulate per collection

As the main fertilisation usually is in spring, it would be inefficient to cultivate the land quarterly. With 10 m³ urine which is sufficient for the fertilisation of approximately ¼ hectare the running costs and the time effort for the application would be too expensive for the farmer. Nonetheless, scenario A is represented within the calculations and results, acting as an additional comparative value.

Urine transportation scenario B includes an additional storage possibility, tank 2, measuring approximately 30 m³. It is located nearby Eschborns' GIZ headquarters and is coupled with tank 1. With respect to storage scenario *a*, see following paragraph, they are coupled thanks to an overflow pipe. Nevertheless, in terms of storage scenario *b*, see following paragraph, the urine is pumped out of tank 1 three–monthly, with the assistance of a hosepipe and a pump. The urine is transported from tank 2 to the chosen field about once a year.

In urine transportation scenario C there is a further opportunity to store the urine, tank 3, with approximately 30 m³. The third tank is located nearby the field. Tank 1's emptying occurs every three months by a corresponding vehicle.

Due to the second storage facility, the farmer is independent regarding the urine's application in scenario B and C.

Table 1 Overview of the possible types for urine transportation and its costs for scenario C

Options:	Possibilities of access:	Costs per year (€):
Suction vehicle, 10 m³	• Buying[1] o New o Used • Renting[2]	 153,760 74,412 2,614
Tractor with manure barrel, 12 m³	• Buying[1] o New o Used • Renting[2]	 54,527 33,304 1,265
Forwarding company	• Placing an order	2,773
Farmer, 12 m³	• Possession of farmer[3]	156

Each variant in table 1 has been calculated with approximately 10 and 30 m³ sized vehicles.

The urine storage scenarios are marked with the *small letters a and b* and its sub scenarios with the *small letters x and y*.

- Urine Storage Scenario *a*:
    - Stainless steel tank, approximately 30 m³

Figure 9 Stainless steel tank (devosagri, 2011)

[1] Investment costs plus running costs (running costs vehicle, salary driver, fuel costs etc.) per year
[2] Rental plus running costs (salary driver, fuel costs etc.) per year
[3] Calculation based on Landwirtschaftskammer Nordrhein–Westfalen (2010)

- Urine Storage Scenario *b*:
  - 30 Water tanks (IBC tanks), approximately 1 m³
    - Plane *x*
    - Stacked *y*

Figure 10 Water tank (regenwassertanks-wn, 2011)

Urine storage scenario a contains a stainless steel tank, approximately 30 m^3, which occupies about 16 m^2 space.

IBC tanks are intended for urine storage scenario b. If 30 of these tanks can be used, the same volume as in urine storage scenario a is given. Arranged evenly, they occupy 36 m^2; stacked, in contrast, the needed space is halved.

Due to the MAP scenario's clearness, there is no need for a comparable code like the one used for urine.

- MAP Transportation and Storage Scenario:
  - Rain Barrel → Vehicle → Field

Figure 11 MAP transportation scenario (cgi.ebay, pauls-wunderwords.blogspot, hufgard, 2011)

The MAP transportation and storage scenario provides a rain barrel, covering

120 l, and is located close to the MAP reactor in the reactor chamber. The barrel is transported to the field annually.

Table 2 Overview of the possible types for MAP transportation and its costs

Options:	Possibilities of access:	Costs per year (€):
Truck	• Buying[4]	
	o New	12,859
	o Used	5,446
	• Renting[5]	114
Forwarding company	• Placing an order	50
Farmer	• Possession of farmer[6]	39

By combining all kinds of scenarios several alternatives emerge:

Table 3 Urine alternatives of all different transportation and storage scenarios, carrying segments framed red, transportation and storage scenarios framed blue

URINE Alternatives		Tank 1 > Vehicle > Field	Tank 1 > Pipes > Tank 2 > Vehicle > Field			Tank 1 > Vehicle > Tank 3 > Field		
			Stainless Steel Tank	IBC Tanks		Stainless Steel Tank	IBC Tanks	
				plane	stacked		plane	stacked
GTZ's new suction vehicle	30 m³	A I	B a I	B b x I	B b y I	C a I	C b x I	C b y I
	10 m³	A II	B a II	B b x II	B b y II	C a II	C b x II	C b y II
GTZ's used suction vehicle	30 m³	A III	B a III	B b x III	B b y III	C a III	C b x III	C b y III
	10 m³	A IV	B a IV	B b x IV	B b y IV	C a IV	C b x IV	C b y IV
GTZ's new tractor with new manure barrel	20 m³	A V	B a V	B b x V	B b y V	C a V	C b x V	C b y V
	12 m³	A VI	B a VI	B b x VI	B b y VI	C a VI	C b x VI	C b y VI
GTZ's used tractor with used manure barrel	20 m³	A VII	B a VII	B b x VII	B b y VII	C a VII	C b x VII	C b y VII
	12 m³	A VIII	B a VIII	B b x VIII	B b y VIII	C a VIII	C b x VIII	C b y VIII
Renting a suction vehicle	10 m³	A IX	B a IX	B b x IX	B b y IX	C a IX	C b x IX	C b y IX
Renting a tractor with manure barrel	20 m³	A X	B a X	B b x X	B b y X	C a X	C b x X	C b y X
	12 m³	A XI	B a XI	B b x XI	B b y XI	C a XI	C b x XI	C b y XI
Forwarding company		A XII	B a XII	B b x XII	B b y XII	C a XII	C b x XII	C b y XII
Farmer	20 m³	A XIII	B a XIII	B b x XIII	B b y XIII	C a XIII	C b x XIII	C b y XIII
	12 m³	A XIV	B a XIV	B b x XIV	B b y XIV	C a XIV	C b x XIV	C b y XIV

In table 3, the blue frames clarify the different urine transportation scenarios *A*,

[4] Investment costs plus running costs (running costs vehicle, salary driver, fuel costs etc.) per year
[5] Rental plus running costs (salary driver, fuel costs etc.) per year
[6] Calculation based on Landwirtschaftskammer Nordrhein–Westfalen (2010)

B and *C* including the two storage scenarios for scenario *B* and *C*. The upper red frame, carrying segment 1, shows the possibilities of buying a suction vehicle and a tractor with manure barrel, both new and used. The one in the middle, carrying segment 2, frames the renting opportunities of a suction vehicle and a tractor with manure barrel. Whilst the one lowered, carrying segment 3, shows the case that someone, a forwarding company or a farmer, is hired to transport the urine.

Table 4 MAP alternatives of all transportation and storage scenarios, carrying segments framed red, transportation and storage scenario framed blue

MAP Alternatives		Rain Barrel > Vehicle > Field
GTZ's new truck		I
GTZ's used truck		II
Renting a truck		III
Forwarding company		IV
Farmer		V

In table 4 the definition of the frames' colour corresponds with table 3, although in this case the scenarios and possibilities of access are reduced.

4.4 Methodology

According to Vahs and Schäfer–Kunz (2007), there are various methods that can be used for evaluating specific investment activities (Vahs and Schäfer–Kunz, 2007). They basically differentiate between static and dynamic approaches whereas both techniques do only consider monetary factors and no qualitative data. For this study it was essential to identify the alternative which requires the *lowest costs in total*. Therefore, the cost comparison method was applied in order to compare the costs of the different scenarios and conditions. Although the cost comparison method theoretically belongs to the static approaches with respect to the definition by Vahs and Schäfer–Kunz (2007) some changing, and hence, dynamic factors were added as well in order to develop a more flexible and relevant calculation. Further, it can be stated there was a general orientation towards the “Leitlinien zur Durchführung dynamischer Kostenvergleichsrechnungen” (Länderarbeitsgemeinschaft Wasser (LAWA), 2005) which was adapted for this study’s purposes. The LAWA method was highly recommended by Dr.–Ing. Martina Winker, program officer at the sustainable sanitation–ecosan program within GIZ and also SANIRESCH’s project coordinator.

The cost comparison method has basically three limiting conditions. Firstly, there is a normative objective which has to be set in advance and, further, has to be achieved irrespectively of any circumstances or issues (LAWA, 2005). For example, transporting urine or MAP to a certain field would be the main target in this case. Secondly, an equality of benefits such as usability or utility has to be given as well. This means that all alternatives have to provide the same possible outcomes (LAWA, 2005). Thirdly, there has to be an equivalence of all negative consequences which cannot be evaluated in terms of money (LAWA, 2005). Hence, all alternatives would produce, for example, the same amount of noise or air pollution. As a result, due to this specific method all alternatives will be equally comparable with respect to their total costs. Therefore, this approach can be declared as a relative advantage. Consequently, the return on investment cannot be determined properly as the beneficial part of it isn’t reviewed at all (LAWA, 2005).

Some important parameters which are assumed concerning the calculations:

- Lifetime of the project: 50 years (LAWA, 2005)
- Real interest rate: 3% per year (LAWA, 2005)
- Reference year: 2010
- Duration of every component depending on its specific lifetime

Further conditions:

- Full supply of soil is aspired

- Nutrient content soil: level C[7] (Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL), 2009)
- Distance from urine occurrence to urine application: 2,3[8] km

The following table will explain the five basic steps in order to conduct a comparative cost method based on the LAWA construct. The detailed calculation and approach will be explained afterwards.

Table 5 Basic steps and explanation of the cost comparison method according to LAWA

<table>
<tr><td><u>Basic steps of the cost comparison:</u></td><td><u>Explanation:</u></td></tr>
<tr><td>1. Costing</td><td>• First of all, all costs need to be divided in investment costs (IK), running costs (LK) and reinvestment cost (IKR).
• These costs can either be concrete or assumed, mostly depending on the temporal status of the whole project.</td></tr>
<tr><td>2. Conditioning costs regarding financial mathematics</td><td>• In order to compare their values, all costs have to be weighted/measured temporally to the reference year as they might show up in different project stages.
• Alternatives might vary a lot as they either have high investment costs and low running costs or vice versa.
• Based on the two previous factors all expenses need to be edited by the following calculation parameters:</td></tr>
<tr><td colspan="2">IK: Accumulation: cash value IK (€)=nominal value IK (€)*AFAKE (i;n) (1)
Discounting: cash value IK (€)=nominal value IK (€)*DFAKE (i;n) (2)
AFAKE (i;n)=(1+i)^n=q^n (3)
DFAKE (i;n)=1/(1+i)^n=1/q^n (4)
i=interest rate (%); n=time frame (years)</td></tr>
<tr><td colspan="2">IKR :cash value IKR (€)=nominal value IKR (€)*DFAKE (i;n) (5)
DFAKE (i;n)=1/(1+i)^n=1/q^n (6)
i=interest rate (%); after n years a reinvestment is coming due</td></tr>
<tr><td colspan="2">LK: cash value LK (€)=nominal value LK/a (€/a)*DFAKR (i;n) (7)
DFAKR (i;n)=((1+i)^n-1)/(i*(1+i)^n)=(q^n-1)/((q-1)*q^n) (8)
i=interest rate (%); n=time frame (years)</td></tr>
<tr><td>3. Cost comparison</td><td>• In order to find the best alternative, there are two different methods that can be conducted:</td></tr>
<tr><td colspan="2">Total Project costs (TPC) (€)=cash value IK (€)+cash value IKR (€)+cash value LK (€) (9)</td></tr>
</table>

[7] C=fertilisation for conservation
[8] A factor which will be varied in the sensitivity analysis

Annual costs (AC) (€/a)=TPC (€)*KFAKR (i;n) (10) KFAKR (i;n)=(i*(1+i)^n)/((1+i)^n*1)=((q-1)*q^n)/(q^n*1) (11) i=interest rate (%); n=time frame (years)	
$TPC_{Alternative\ 1}$ (€)–$TPC_{Alternative\ 2}$ (€)=saving of costs (12) $AC_{Alternative\ 1}$ (€/a)–$AC_{Alternative\ 2}$ (€/a)=saving of costs (13)	
4. Sensitivity analysis and investigation of critical values	• Alternatives are linked to risks and instability factors due to their complexity and long-term orientation, e.g. uncertainty concerning prospective progresses, unforeseeable development of interest rates, changes in petrol prices • Therefore, by changing the initial data/factors, the sensitive analyses examines the stability of the most favourable alternative • It is based on critical factors that have to be determined; these could change the advantage of one or various alternatives as a consequence.
Dynamic Project Costs (€/quantity unit)=Annual costs (€)/Annual effort (m^3/a or kg/a) (14)	
5. Overall assessment and interpretation of the results	• All calculated results and additional arguments that are essential for the decision-making progress have to be considered. • Together, they all provide an idea or proposal which has to be understood as the basis for the finally chosen alternative.

(self–constructed, based on LAWA, 2005)

As mentioned in Point 1 in table 5, all expenses had to be defined based on the different scenarios that were developed in advance. Further, all costs had to be obtained by various sources through phone interviews and email communication. Moreover, additional information such as durability or consumption rates of different resources had to be figured out as well. In general, it can be stated that the majority of the required factors and data was provided by companies and professionals working in that specific economic field.

Schmidt Kommunalfahrzeuge, for example, a firm that distributes suction vehicles among other things, was contacted with respect to the whole transportation process. The data concerning the MAP reactor and its operating was provided by Huber SE. In the calculations was made us of the costs for the special version of the MAP reactor arranged in the GIZ and the more expensive version of filter bags, simultaneously the costs of a simpler model and the missing features compared to the special version and the price for the cheaper filter bags are mentioned in the Excel–file. With respect to the fact that the Huber SE's maintenance worker approaches several clients during one tour, a number of 200 kilometres was figured out.

Nevertheless, own calculations had to be conducted as well in order to gain all the necessary information:

- Google maps was used to identify the distance between the Eschborns' GIZ headquarter and a certain field and to works out the average size of different fields surrounding the city of Eschborn
- How often the driver of the transport vehicle has latency time during one transportation day is defined in the Excel–file *Cost Analysis* in the sheet *General Assumptions and Abbreviations*. In the following, an example why latency time comes up: The urine, within urine transportation scenario *B*, is transported to the fields with a 30 m³ suction vehicle and the farmer applies it with the help of a 10 m³ manure barrel. Therefore the suction vehicle driver has to wait two *times*, until his vehicle is completely emptied and he is able to drive back to GIZ. Waiting two *times* means he has to wait the time required for the application of two 10 m³ manure barrels. These cells needs to be varied manually, if there would be changes concerning the size of urine tanks or transportation vehicles.
- MAP's specific gravity was calculated by the determined factors weight and volume
- The electricity costs for the reactor were conducted by finding out the reactor's electricity consumption and multiplying it with the current electricity costs per kWh in Eschborn
- The maximal number of rain barrels (120 l) per truck was calculated with the help of the truck's maximal cargo load

In rare cases own assumptions needed to act as dummies as it was not possible to find out facts.

In the following table the most relevant prices are shown:

Table 6 Overview of the most relevant prices

Item	Costs (€)
New suction vehicle, 30 m³	333,200
Used suction vehicle, 30 m³	205,000

Costs of renting a suction vehicle/day, 10 m³	600
Costs of forwarding company/day	662
Stainless steel tank, 30 m³	10,134
IBC tank, 1 m³	60
MAP reactor	23,000
Maintenance work reactor chamber/year	25,300

After obtaining all information, they had to be ascribed to either investment costs or running costs. Investment costs that can also be defined as either acquisition or production costs are responsible for single *initial* investments concerning purchases, developments or renewals (LAWA, 2005). They further have to be divided in the following groups according to LAWA (2005):

- Expenses for land utilisation
- Expenses for previous achievements, for example project development
- Construction and development expenses
- Reinvestment costs, for example replacement invest for components, of which the duration periods are shorter than the project's lifetime

Expenses for operation, maintenance and monitoring of the construction are called running costs. All investments concerning the replacement of components could also be charged as running costs if they become due before reaching the limit of five years. They could be separated, based on the LAWA (2005) method, into:

- Staff costs
- Material costs
- Energy costs

Investment and running costs need to be updated based on the current price level of each calculation's base year. In other words they have to be correlated to the reference year's price level (LAWA, 2005). However, this is not necessary in this concrete case, as all expenses are obtained within the reference year.

In Point 2, as already brought up in table 5, it is aspired to attain a comparison in terms of expenses' values which accrue at different times during the project. This is achieved by the parameters interest rate and time frame. In this piece of work, the interest rate is 3%, while the time frame is set up with 50 years, both recommended by LAWA and adapted from André Lazo Páez's master thesis. The used term for the nominal value within the reference date is cash value. As a result, the nominal values which emerge before or after the reference date need to be accumulated and discounted respectively, according to the above mentioned calculations (1), (2), (5) and (7) (LAWA, 2005).

As referred to Point 3 in table 5, there are two different ways for the comparison of costs, one considering the total project costs and the other measuring annual costs. With the assistance of the first one, total project costs (9), an addition of all investment, running and reinvestment costs proceeds and the whole project time is considered as well. Annual costs (10), the second approach, are the total project costs with respect to an annual point of view. To identify the saving of costs in detail, the differences of the alternative's results have to be formed (LAWA, 2005).

Concerning Point 4 in table 5, it is a fact that the sensitivity analysis constitutes a necessary component in every operations research for a water management scheme, as planning unavoidably contains uncertainties concerning the project's impact and the calculation's approach. In other words, reactions are identified based on total project costs and annual costs if different assumptions, for example interest rates, time frame, quantities and prices, would alter (LAWA, 2005). The table below shows how the different factors are varied:

Table 7 Overview of the varied factors in the sensitivity analysis

Varied factors:	Variation rate:
Fertiliser prices	Increase of 40%, *SA I*
Fuel prices	Increase of 40%, *SA II*
Distance between the urine's and MAP's amount and the area of utilisation	Increase up to 10, *SA IIIa*, and 30[9] kilometres, *SA IIIb*

A critical value would be identified if total project costs and annual costs of the original most affordable alternative emerge comparable to an unfavourable alternative after the value's modification. Their identification provides clearance referred to risks whilst examining the results' resilience (LAWA, 2005).

[9] If there would be chosen a distance farther than 30 kilometres, there would occur several logistical problems if the transportation vehicle needs to drive the tour GIZ to field and back to GIZ more than one time

A cost comparison method refers to given alternatives, which are designed for specific performances concerning quantity. If the regarded performances based on assumptions, it is recommended to conduct a sensitivity analysis referring to possible impacts on cost efficiency. With respect to LAWA (2005), qualified means is the dynamic project costs (14), which describe the average production costs per afforded quantity unit.

As a final work step the summarising results' assessment is necessary, see Point 5 in table 5. Several aspects which are not appraisable in terms of costs are factored in this assessment. Thus, the suggestion for the decision–making could be worded. For that reason, the comparative alternative's cost structure needs to be discussed based on a comparison of investment and running costs. This is the basis for the comparison of the different total project costs and annual costs. Furthermore, a conclusion concerning the sensitivity analysis and, consequently, the project risks which are relevant to costs needs to be done. With reference to the durability of water infrastructure projects the potential of risk and uncertainty's appraisal is essential (LAWA, 2005).

In case several alternatives have similar costs, the decision–making could be shifted to potential differences in project performance, for example availability and reliability of project components. If the proposed alternative differs from the most affordable one, the crucial factors have to be pointed out and explained solidly (LAWA, 2005).

4.5 Agricultural Part and Fertiliser's Comparison

Emanating from a fertilisation for conservation (Düngeverordnung, 2009) and based on a supposed soil status of level C (KTBL, 2009), it is necessary to substitute the removed nutrients. The main fertiliser application is due in March or April. Summer wheat was chosen as the crop for calculation in this thesis. Within the SANIRESCH project urine has already been applied successfully to this crop in 2010. Consequently, the factors for the fertiliser requirements are chosen with respect to the wheat's demand. Based on KTBL (2009), the following parameters are assumed for the standard crop:

- Harvest of 80 dt/ha
- Nutrient's removal:

- N: 1.81 kg/dt
- P: 0.35 kg/dt
- K: 0.50 kg/dt
- Mg: 0.12 kg/dt

In combination with this data and the given analysis results concerning the urine and MAP composition, the fertiliser demand[10] is calculated within the Excel–file in sheet *Annex1 fertiliser amount*. These calculations are conducted for urine, MAP and NPK. In order to create a comparative value, fertilisation with NPK, and to be able to determine the cost efficiency of urine and MAP it is necessary to reveal these three scenarios:

- Fertilisation of urine plus additional fertilisers
- Fertilisation of MAP plus additional fertilisers
- Fertilisation of NPK plus additional fertilisers

Raiffeisen in Sulzbach was contacted with respect to the expenses for NPK and additional fertilisers. Due to the fact that additional fertilisers are needed in all cases, a second application of fertiliser is required. With other words, the field has to be frequented twice.

The values for the composition of urine and MAP are chosen based on the current analysis results of the SANIRESCH project partners. Too differing values are cancelled, these finding use are averaged.

The application of urine is done by a liquid manure barrel, 10 m³, and a spreader, 1500 litre, for the pourable fertiliser. This size is chosen regarding the average field size of 2.7 hectare. The arising costs for the fertiliser application are assumed with reference to Landwirtschaftskammer Nordrhein–Westfalen (2010).

4.6 Excel–File *Cost Analysis*

An interactive excel file was developed which can be used for any location in Germany and with larger adaptations, regarding transportation costs and so

[10] Ancillary fertilisation with N-, P-, K-, Ca-, Mg–fertiliser, in the case of the main fertiliser (urine, MAP, NPK) does not cover the entire demand

forth, also worldwide. The excel sheet performed the required calculations as was used for the sensitivity analysis as well.

In the following a summarised manual is shown that gives an overview of the constructed Excel–file and several explanations about it.

Factsheet Germany is the basic data sheet which contains all of the received costs, data and information. For instance, the investment costs for a stainless steel tank, its running costs, its durability and therefore its reinvestment costs and the time needed for a trip from GIZ to the chosen field and back to GIZ are listed. General data is listed in the sheet *General Assumptions and Abbreviations* as well. Several factors like the number of days per month are determined and auxiliary calculations and abbreviations are deposited.
The yellow marked input in these two sheets can be modified manually. In this way it is possible to adapt the constructed calculations to different projects, circumstances, requirements, price levels, etc. This is necessary with respect to the fact that this piece of work and its calculation's base –such as costs, salaries, distances and so forth– are conform to the given example of GIZ. This means, for example, that if someone has to change the size of the stainless steel tank, it might be essential to adapt its price, too. Moreover, there are a few cells, marked blue, that need to be varied manually according to the changes of the input.

Within the other sheets costs are conditioned based on the information given in table 5 with respect to the LAWA method (2005), resulting in the sheet *Investment Costs and Running Costs and Reinvestment Costs*. The outcome, in the form of total project costs, annual costs and dynamic project costs, are presented in the sheet *Total Project Costs and Annual Costs and Dynamic Project Costs.*

5. Results & Discussion

In this part, the main economic analysis' results of the urine's and MAP's transportation and storage alternatives, using the example of GIZ, are presented. A comparison of the different alternative's investment costs, reinvestment costs and running costs is conducted. Hence in the following step an overarching cost comparison is possible. The sensitivity analysis' outcome is introduced in the ensuing section.

In the following, the codes and abbreviations described in chapter *4.3* and *4.4* will be applied.

5.1 Investment, Reinvestment and Running Costs

From now on urine transportation scenario *A* is not regarded any longer due to the fact that it needed to be scraped, see chapter *4.3*.

The presented tables and figures based on the calculations conducted within the Excel–file *Cost Analysis*. Investment, reinvestment and running costs are already referred to 50 years, the project's time frame, according to the calculations presented in chapter *4.4* in table 5.

The table below shows all alternatives within urine transportation scenario *B*, including the two storage scenarios, separated in investment, running and reinvestment costs:

Table 8 Overview of the costs of all alternatives in urine scenario B, itemised to investment cost (IK), running costs (LK) and reinvestment costs (IKR), carrying segments framed red, IK, LK and IKR framed green; for more explanation see chapter 4.3 and 4.4

Urine Tank 1 > Pipes > Tank 2 > Vehicle > Field Costs (€)		IK			LK			IKR		
		Stainless Steel Tank	IBC Tanks		Stainless Steel Tank	IBC Tanks		Stainless Steel Tank	IBC Tanks	
			plane	stacked		plane	stacked		plane	stacked
GIZ's new suction vehicle	30 m³	362,749	354,060	345,060	7,720	12,094	12,094	804,169	808,998	808,998
	10 m³	183,059	174,370	165,370	8,521	12,895	12,895	370,492	375,321	375,321
GIZ's used suction vehicle	30 m³	234,549	225,860	216,860	7,720	12,094	12,094	413,344	418,173	418,173
	10 m³	103,711	95,023	86,023	8,521	12,895	12,895	149,535	154,364	154,364
GIZ's new tractor with new manure barrel	20 m³	103,549	94,860	85,860	6,271	10,646	10,646	141,774	146,603	146,603
	12 m³	83,882	75,193	66,193	7,434	11,808	11,808	102,120	106,949	106,949
GIZ's used tractor with used manure barrel	20 m³	73,443	64,754	55,754	6,271	10,646	10,646	84,493	89,322	89,322
	12 m³	62,659	53,970	44,970	7,434	11,808	11,808	62,749	67,578	67,578
Renting a suction vehicle	10 m³	29,549	20,860	11,860	22,957	27,331	27,331	0	4,829	4,829
Renting a tractor with manure barrel	20 m³	29,549	20,860	11,860	16,786	21,161	21,161	0	4,829	4,829
	12 m³	29,549	20,860	11,860	17,170	21,544	21,544	0	4,829	4,829
Forwarding company		29,549	20,860	11,860	22,864	27,238	27,238	0	4,829	4,829
Farmer	20 m³	29,549	20,860	11,860	5,578	9,952	9,952	0	4,829	4,829
	12 m³	29,549	20,860	11,860	7,177	11,551	11,551	0	4,829	4,829

Considering investment costs, all alternatives with stacked IBC tanks, *B b y*, are more favourable compared to the ones with the tanks arranged plane, *B b x*. This is attributed to minor land consumption. Running costs and reinvestment costs are equivalent for the alternatives in *B b x* and *B b y*, the additional purchase reflects approximately 24% higher investment costs for *B b x*.

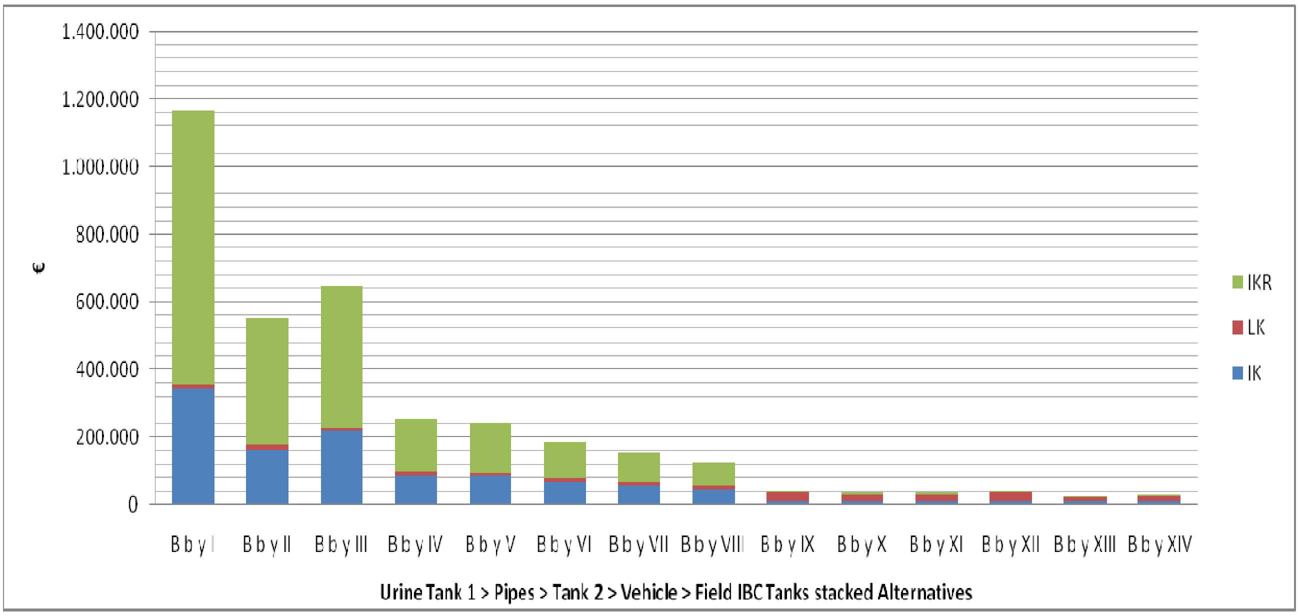

Figure 12 Investment costs (IK), running costs (LK) and reinvestment costs (IKR) for urine scenario B b y, for more explanation see chapter 4.3 and 4.4

The alternatives with a stainless steel tank, *B a*, are most expensive. They have the highest investment costs in scenario *B*, 35% higher compared to the alternative *B b y*. However, the alternatives of *B a*'s reinvestment costs are the most favourable in scenario *B*, based on the long durability of 50 years of the stainless steel tank. As a consequence, there would be no need for a reinvestment within the project's time frame of 50 years. Therefore, the reinvestment costs in carrying segment 2 and 3 reach the total of 0 Euro. The running costs of the alternatives *B a* are the cheapest in this scenario as well. The reason is that flushing the pipe to the stainless steel tank once a year causes minor costs in comparison to pumping the urine via a hosepipe to the IBC tanks quarterly.

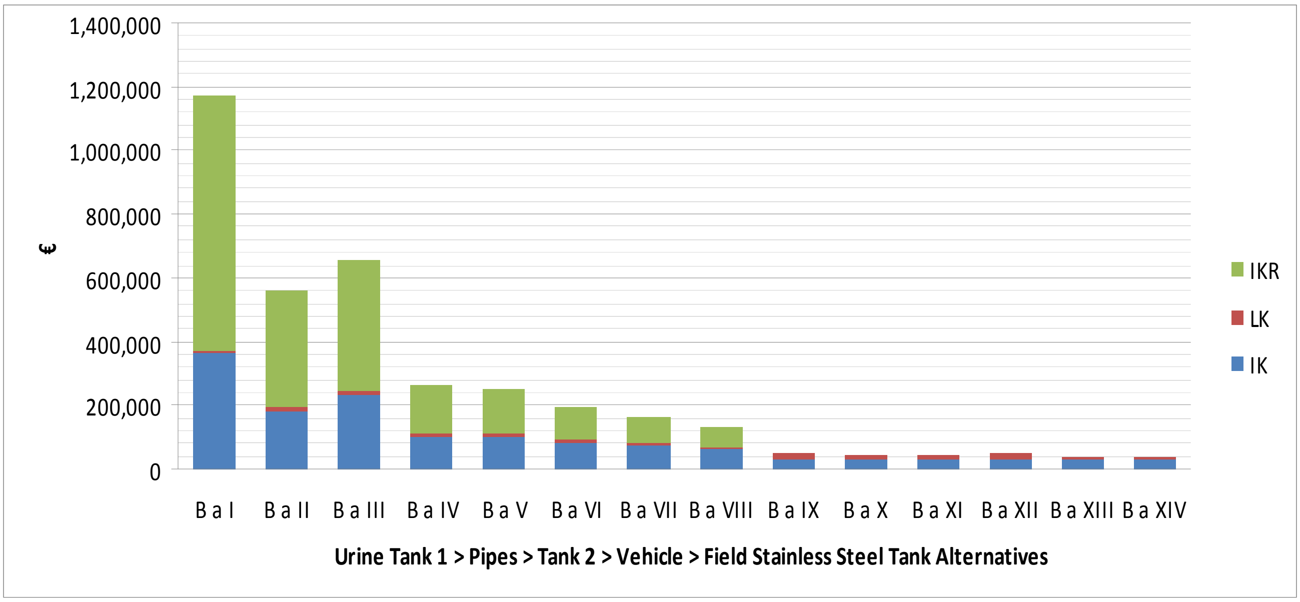

Figure 13 Investment costs (IK), running costs (LK) and reinvestment costs (IKR) for urine scenario B a, for more explanation see chapter 4.3 and 4.4

Considering all alternatives in transportation scenario *B*, including the two storage scenarios *a* and *b*, the following overarching results could be determined:

- Investment costs
  - are most expensive in carrying segment 1, due to the purchase of a vehicle
  - are equal in carrying segments 2 and 3 and 50%–75% lower than the most favourable alternative in carrying segment 1 based on the fact that only tank 2 needs to be purchased, no vehicle
- Reinvestment costs
  - are most expensive in carrying segment 1, see point investment costs above
  - are equal in carrying segments 2 and 3 and 93%–100% lower than the most favourable alternative in carrying segment 1, see the upper point, investment costs
- Running costs
  - are most expensive in carrying segment 2 due to the fees for

renting vehicles

- o are higher in carrying segment 3 than in segment 1 as hiring a forwarding company, belonging to segment 3, is quite expensive; costs in segment 1 and for a farmer, the other part of segment 3, are comparable

The following table identifies all alternatives within urine transportation scenario *C*, including the two storage scenarios, separated in investment, running and reinvestment costs:

Table 9 Overview of the costs of all alternatives in urine scenario C, itemised to investment cost (IK), running costs (LK) and reinvestment costs (IKR), carrying segments framed red, IK, LK and IKR framed green; for more explanation see chapter 4.3 and 4.4

Urine Tank 1 > Vehicle > Tank 3 > Field Costs (€)		IK			LK			IKR		
		Stainless Steel Tank	IBC Tanks		Stainless Steel Tank	IBC Tanks		Stainless Steel Tank	IBC Tanks	
			plane	stacked		plane	stacked		plane	stacked
GIZ's new suction vehicle	30 m³	343,495	335,955	335,775	5,810	5,810	5,810	804,169	808,998	808,998
	10 m³	163,805	156,265	156,085	5,810	5,810	5,810	370,492	375,321	375,321
GIZ's used suction vehicle	30 m³	215,295	207,755	207,575	5,810	5,810	5,810	413,344	418,173	418,173
	10 m³	84,457	76,918	76,738	5,810	5,810	5,810	149,535	154,364	154,364
GIZ's new tractor with new manure barrel	20 m³	84,295	76,755	76,575	4,789	4,789	4,789	141,774	146,603	146,603
	12 m³	64,628	57,088	56,908	4,786	4,786	4,786	102,120	106,949	106,949
GIZ's used tractor with used manure barrel	20 m³	54,189	46,649	46,469	4,789	4,789	4,789	84,493	89,322	89,322
	12 m³	43,405	35,865	35,685	4,786	4,786	4,786	62,749	67,578	67,578
Renting a suction vehicle	10 m³	10,295	2,755	2,575	67,883	67,883	67,883	0	4,829	4,829
Renting a tractor with manure barrel	20 m³	10,295	2,755	2,575	33,430	33,430	33,430	0	4,829	4,829
	12 m³	10,295	2,755	2,575	33,430	33,430	33,430	0	4,829	4,829
Forwarding company		10,295	2,755	2,575	72,433	72,433	72,433	0	4,829	4,829
Farmer	20 m³	10,295	2,755	2,575	3,819	3,819	3,819	0	4,829	4,829
	12 m³	10,295	2,755	2,575	3,817	3,817	3,817	0	4,829	4,829

Considering investment costs, all alternatives with stacked IBC tanks, *C b y*, are marginally favourable, than the ones with the tanks arranged plane, *C b x*. The minor difference in costs, compared to *B b x* and *B b y*, is ascribed to the low cost of land in the fields of Eschborn, as contrasted with the cost of land in Eschborn city, near to GIZ. Running costs and reinvestment costs are equivalent for the alternatives *C b x* and *C b y*. Representative for the alternatives *C b x* and *C b y*:

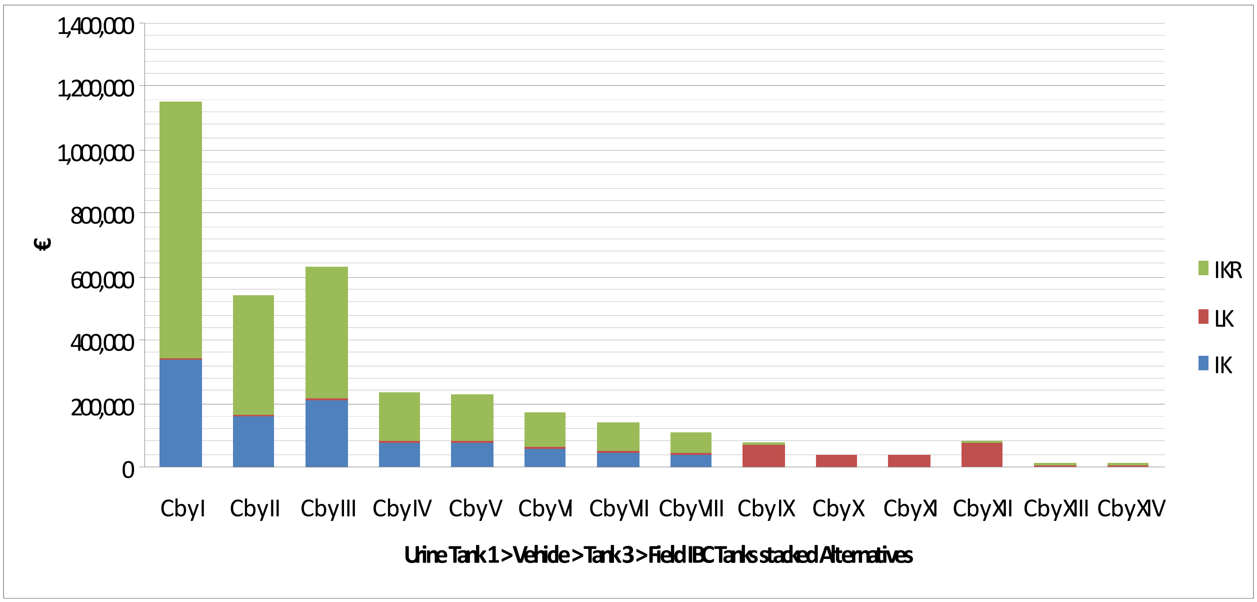

Figure 14 Investment costs (IK), running costs (LK) and reinvestment costs (IKR) for urine scenario C b y, for more explanation see chapter 4.3 and 4.4

Here, the alternatives with a stainless steel tank are the most expensive, too; 37% higher than the stacked IBC tanks. Running costs for *C a*, *C b x* and *C b y* are the same, with respect to the omission of pipes, for the stainless tank, and the omission of a hosepipe and a pump, for the IBC tanks, in transportation scenario *C.* Therefore it exists no differing extra work for the two tank types. Reinvestment costs act comparable with the alternatives of scenario *B*. They are the same for the alternatives of *C b x* and *C b y* but higher in comparison to the alternatives of *C a*. Here the reinvestment costs reach the total of 0 Euro in carrying segments 2 and 3.

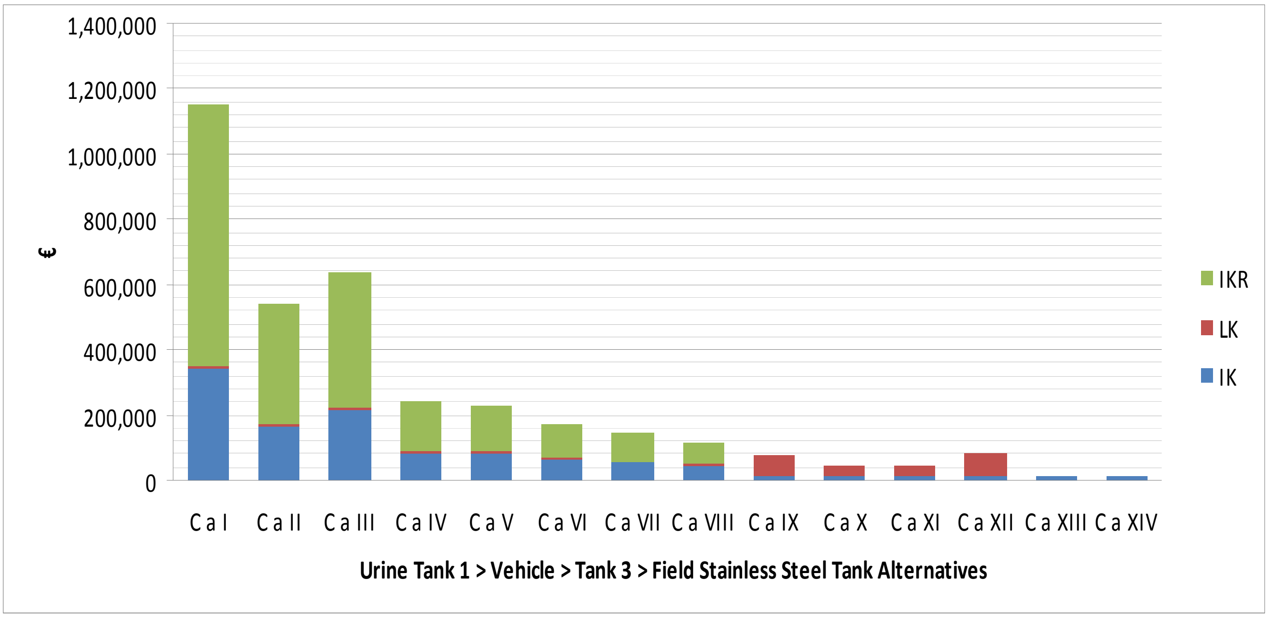

Figure 15 Investment costs (IK), running costs (LK) and reinvestment costs (IKR) for urine scenario C a, for more explanation see chapter 4.3 and 4.4

Considering all alternatives in transportation scenario *C*, including the two storage scenarios *a* and *b*, it could be determined overarching results, similar to scenario *B*. The deviance is listed here:

- Investment costs
  - are in carrying segment 2 and 3 75%–92% lower than the most favourable alternative in carrying segment 1
    - The grander range of cost, compared to scenario *B*, is caused by the occasion of the pipe's, hosepipe's and pump's purchase and the lower cost of land in scenario *C*
- Reinvestment costs
  - have no differences to scenario *B*
- Running costs
  - of the different segments going along with scenario *B*, but the range of cost is bigger
    - The costs within carrying segment 2 and the costs for a forwarding company, segment 3, are higher, due to the fact that the frequency of transportation days per year increases

- The costs within carrying segment 1 and the costs for a farmer, segment 3, are lower, referred to no extra work with pipes, hosepipes and pumps

The table below points out investment, running and reinvestment costs for all possible MAP transportation alternatives:

Table 10 Overview of the costs of all MAP alternatives, itemised to investment cost (IK), running costs (LK) and reinvestment costs (IKR), carrying segments framed red, IK, LK and IKR framed green; for more explanation see chapter 4.3 and 4.4

MAP Rain Barrel > Vehicle > Field Costs (€)		IK	LK	IKR
GIZ's new truck		47.357	492.335	65.883
GIZ's used truck		39.944	492.335	36.926
Renting a truck		34.749	488.797	16.634
Forwarding company		34.749	487.261	16.634
Farmer		34.749	486.629	16.634

Concerning the comparatively low number of MAP alternatives the overarching results' determining ensues directly:

- Investment costs
  - containing as the essential part the purchase of equipment needed in addition for the urine precipitation
  - in carrying segment 1 are moderately more expensive in comparison to carrying segments 2 and 3, due to extra purchases for transportation
  - in the segments 2 and 3 are equivalent, because of no additional purchases for transportation
- Reinvestment costs

- o are the most expensive in carrying segment 1, the most favourable alternative in segment 1 is 55% higher than the alternatives in carrying segments 2 and 3, in consequence of the same reasons as in the point investment costs

- Running costs
    - o are by far the major item
    - o containing as the essential part costs for a maintenance worker and the needed filter bags
    - o the different carrying segments are hardly reflected

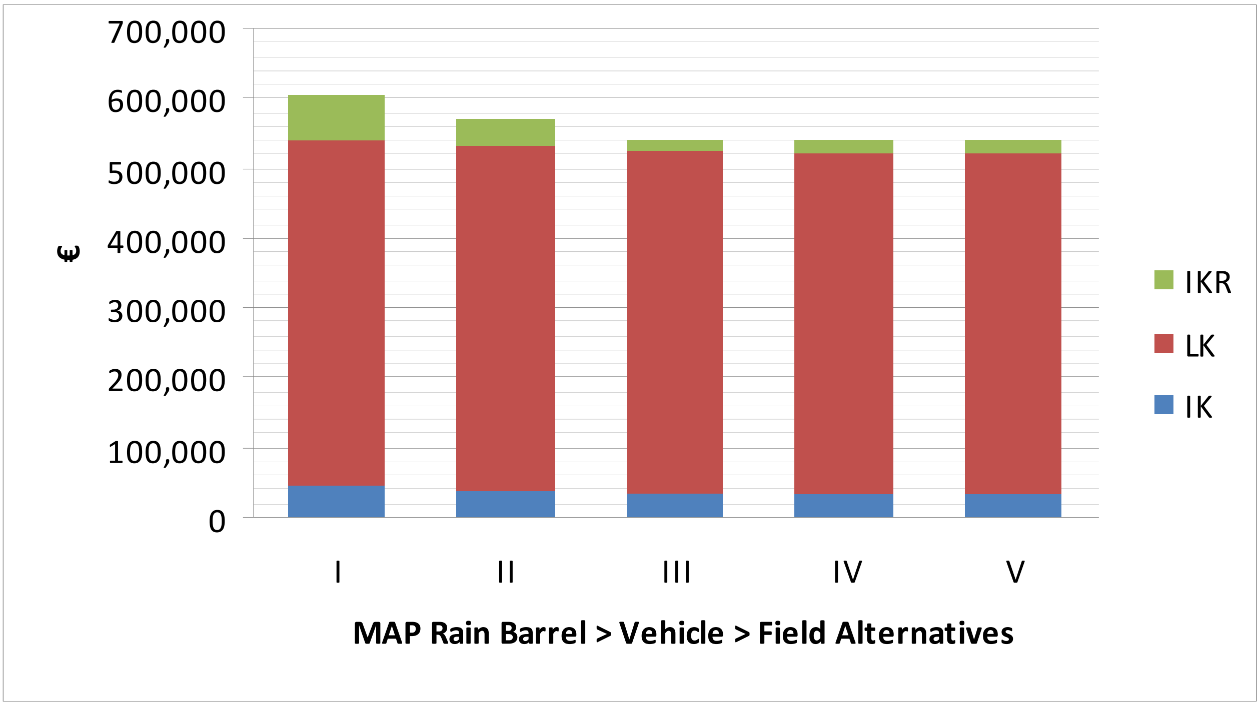

Figure 16 Investment costs (IK), running costs (LK) and reinvestment costs (IKR) for MAP alternatives, for more explanation see chapter 4.3 and 4.4

Concerning these results, always considering the most favourable alternative, it could be stated for the comparison of urine and MAP, that:

- Investment costs
    - o are far more favourable for urine
- Reinvestment costs

- o are far more favourable for urine
- Running costs
  - o are far more favourable for urine

Therefore, the hypothesis ‘it is expected that the investment and maintenance costs in case of MAP precipitation are higher than the costs for using the untreated urine’, see chapter *2.2.2*, is confirmed.

For examining the second hypothesis ‘it is expected that the storage and transportation costs for struvite are less because of the smaller volume in contrast to urine’, see chapter *2.2.2*, it is necessary to have a more precise look at the running costs for urine’s and MAP’s transportation:

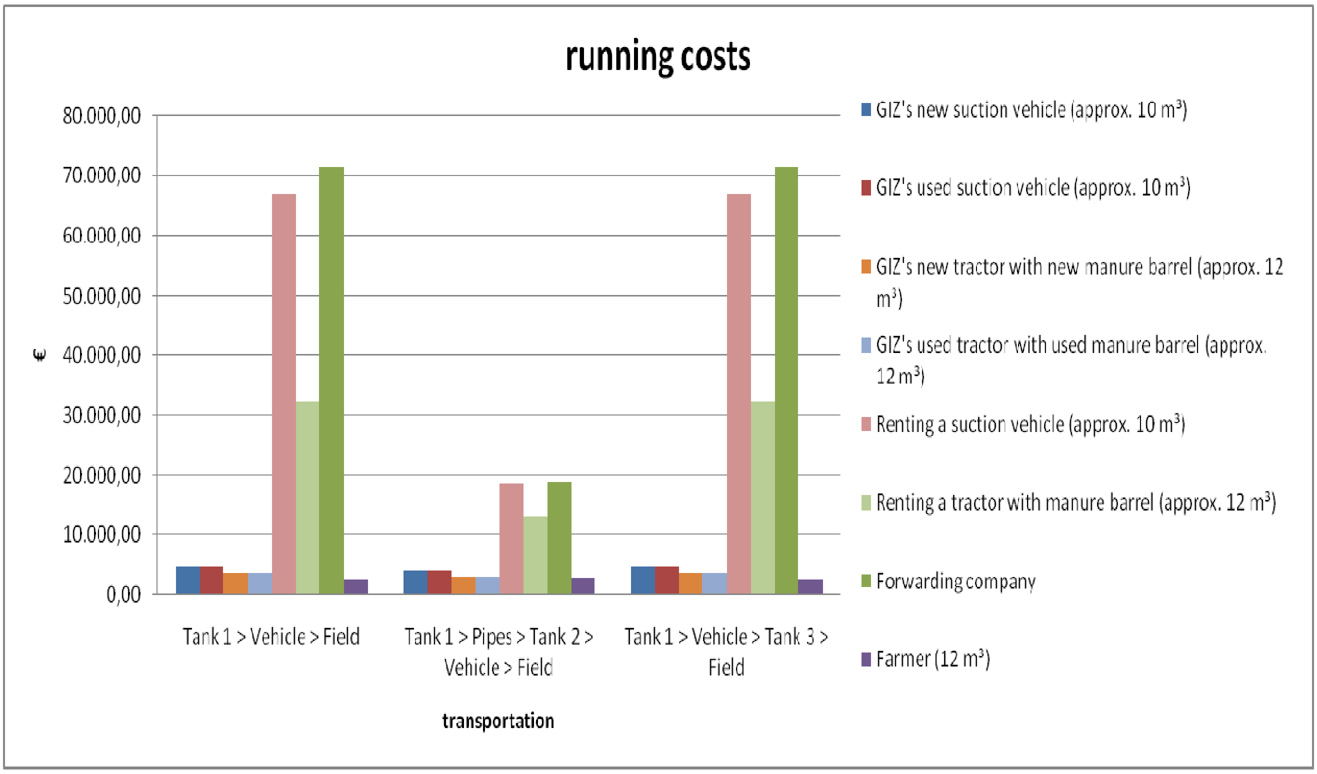

Figure 17 Running costs for the transportation of urine with the help of small vehicles for scenario A, B and C, for more explanation see chapter 4.3 and 4.4

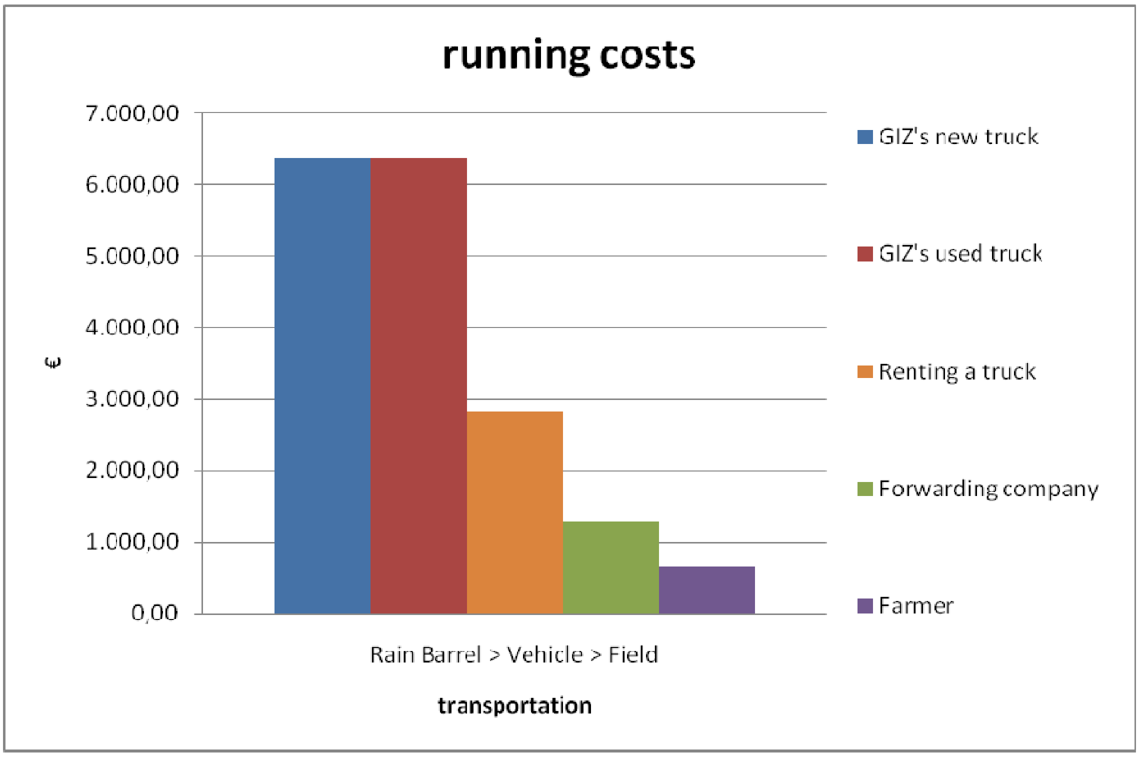

Figure 18 Running costs for the transportation of MAP, for more explanation see chapter 4.3 and 4.4

As it is already vague shown in the charts, MAP's more favourable transportation alternative is preferable to the urine's one.

- Urine: 2,900 Euro
- MAP: 655 Euro

The running costs referred to the whole project with its time frame of 50 years. As there do not exist running costs for the storage of MAP at all, the second hypothesis is confirmed.

5.2 Total Project Costs, Annual Costs and Dynamic Project Costs

This chapter shows the results of the comparative cost method based on the LAWA guidelines.

Although urine transportation scenario *A* appears in the following tables, it is not regarded due to the fact that it needed to be scraped, see chapter *4.3*.

The total project costs emerged by addition, according to calculation (9), of investment, reinvestment and running costs which were already introduced in chapter *5.2.1*:

Table 11 Overview of the total project costs (TPC) for all urine alternatives, carrying segments framed red, transportation and storage scenarios framed blue and the encircled costs are showing the most expensive and the most favourable alternative ; for more explanation see chapter 4.3 and 4.4

URINE TPC (€)		Tank 1 > Vehicle > Field	Tank 1 > Pipes > Tank 2 > Vehicle > Field			Tank 1 > Vehicle > Tank 3 > Field		
			Stainless Steel Tank	IBC Tanks		Stainless Steel Tank	IBC Tanks	
				plane	stacked		plane	stacked
GIZ's new suction vehicle	30 m³	1,143,179	1,174,638	1,175,152	1,166,152	1,153,474	1,150,763	1,150,583
	10 m³	529,812	562,072	562,586	553,586	540,107	537,396	537,216
GIZ's used suction vehicle	30 m³	624,154	655,613	656,128	647,128	634,449	631,739	631,559
	10 m³	229,508	261,767	262,281	253,281	239,802	237,092	236,912
GIZ's new tractor with new manure barrel	20 m³	220,563	251,594	252,109	243,109	230,858	228,147	227,967
	12 m³	161,239	193,436	193,951	184,951	171,534	168,823	168,643
GIZ's used tractor with used manure barrel	20 m³	133,175	164,207	164,721	155,721	143,470	140,759	140,579
	12 m³	100,645	132,842	133,356	124,356	110,939	108,229	108,049
Renting a suction vehicle	10 m³	67,883	52,505	53,020	44,020	78,178	75,467	75,287
Renting a tractor with manure barrel	20 m³	33,430	46,335	46,850	37,850	43,724	41,014	40,834
	12 m³	33,430	46,719	47,233	38,233	43,724	41,014	40,834
Forwarding company		72,433	52,412	52,927	43,927	82,728	80,017	79,837
Farmer	20 m³	3,819	35,127	35,641	26,641	14,114	11,404	11,224
	12 m³	3,817	36,726	37,240	28,240	14,111	11,401	11,221

According to table 11, the range of costs between the most expensive and the most favourable alternative is very wide: from total project costs of 11,221 Euro for stacked IBC tanks in the fields, scenario *C b y* –including a farmer collecting the urine with the help of his tractor and a 12 m³ manure barrel–, up to total project costs of 1,174,638 Euro for a stainless steel tank next to GIZ, scenario *B a* –transporting the urine with a new 30 m³ suction vehicle, belonging to GIZ. For all alternatives costs decrease from carrying segment 1 to segment 2 to segment 3, except for the forwarding company's alternatives. In terms of prices they are located between carrying segment 1 and 2.

With reference to table 11, it could be stated that scenario *C*, no matter which storage scenario is chosen, is more favourable than scenario *B*, comparing the matching alternatives. However, the alternatives renting a suction vehicle and hiring a forwarding company constitute an exception. They are more favourable within scenario *B*. The reason why the more expensive scenario here shows up as the favourable one is that the major cost component in these alternatives is the transportation of urine. The frequency of transports is with one time per year far less than four times per year, with respect to transportation scenario *C*. For both of these carrying types the costs for storage scenario *a* and *b x* are very similar as both has total project costs of approximately 53,000 Euro. The total project costs of approximately 44,000 Euro for storage scenario *b y* are more favourable, though.

In the following, a listing of the *winners*, meaning the best alternatives, is based on the information given in table 11 (total project costs rounded):

1. Farmer, 12 m³ and 20 m³, transportation and storage scenario *C b x* and *C b y*: 12,400 Euro
2. Farmer, 12 m³ and 20 m³, transportation and storage scenario *C a*: 15,200 Euro
3. Farmer, 12 m³ and 20 m³, transportation and storage scenario *B b y*: 28,500 Euro
4. Farmer, 12 m³ and 20 m³, transportation and storage scenario *B a* and *B b x*: 37,200 Euro
5. Renting a tractor with manure barrel, 12 m³ and 20 m³, transportation scenario *B* and *C*, including all storage scenarios: 43,000 Euro
6. Renting a suction vehicle and forwarding company, transportation scenario *B*, including all storage scenarios: 50,000 Euro
7. Renting a suction vehicle, transportation scenario *C*, including all storage scenarios: 76,500 Euro
8. Forwarding company, transportation scenario *C*, including all storage scenarios: 80,500 Euro

So far, all alternatives originating from carrying segments 2 and 3 are listed above, the most expensive one charging about 80,000 Euro. The most favourable alternative within carrying segment 1 with 110,000 Euro is transportation and storage scenario *C b y* with a farmer collecting the urine. It further identifies this segment as the most expensive area. Summarising carrying segment 1, it is to note:

- Buying a tractor with manure barrel is more favourable than buying a suction vehicle
- Buying a used vehicle and manure barrel is more favourable than buying a new one
- Buying a smaller vehicle and manure barrel of approximately 10 m^3 is more favourable than buying bigger ones of approximately 30 m^3

With the use of calculation (12) it is possible to define the total costs savings, in case one alternative is preferred to another.

’The expectations are that preferably big stocks and therefore rarely transportations with big vehicles leading to minimal expenses’, see chapter *2.2.2*, is the third hypothesis.
Unfortunately, the first part of the hypothesis could not be reviewed. Because of urine transportation scenario *A*, with its comparative small storage possibility, needed to be scraped, see chapter *4.3*. The storage possibilities in urine transportation scenario *B* and *C* have the same size and for MAP does only exist one storage scenario.
The second part of it could be refuted with respect to table 11. As urine transportation scenario *C*, with its four transports per year, was stated as more favourable than urine transportation scenario *B*. Nevertheless, in order to transport the urine with the help of a forwarding company or a rented suction vehicle it is vice versa. Because in these two cases the costs for the act of transportation is that high.

Within carrying segment 1 the last part of this hypothesis is disproved. However, inside segments 2 and 3 the costs for the different sized vehicles are quite similar, see table 11.

As a next step the annual costs was ascertained with the help of calculation (10):

Table 12 Overview of the annual costs (AC) for all urine alternatives, carrying segments framed red, transportation and storage scenarios framed blue and the encircled costs are showing the most expensive and the most favourable alternative; for more explanation see chapter 4.3 and 4.4

URINE AC (€/a)		Tank 1 > Vehicle > Field	Tank 1 > Pipes > Tank 2 > Vehicle > Field			Tank 1 > Vehicle > Tank 3 > Field		
			Stainless Steel Tank	IBC Tanks		Stainless Steel Tank	IBC Tanks	
				plane	stacked		plane	stacked
GIZ's new suction vehicle	30 m³	34,295	35,239	35,255	34,985	34,604	34,523	34,517
	10 m³	15,894	16,862	16,878	16,608	16,203	16,122	16,116
GIZ's used suction vehicle	30 m³	18,725	19,668	19,684	19,414	19,033	18,952	18,947
	10 m³	6,885	7,853	7,868	7,598	7,194	7,113	7,107
GIZ's new tractor with new manure barrel	20 m³	6,617	7,548	7,563	7,293	6,926	6,844	6,839
	12 m³	4,837	5,803	5,819	5,549	5,146	5,065	5,059
GIZ's used tractor with used manure barrel	20 m³	3,995	4,926	4,942	4,672	4,304	4,223	4,217
	12 m³	3,019	3,985	4,001	3,731	3,328	3,247	3,241
Renting a suction vehicle	10 m³	2,036	1,575	1,591	1,321	2,345	2,264	2,259
Renting a tractor with manure barrel	20 m³	1,003	1,390	1,405	1,135	1,312	1,230	1,225
	12 m³	1,003	1,402	1,417	1,147	1,312	1,230	1,225
Forwarding company		2,173	1,572	1,588	1,318	2,482	2,401	2,395
Farmer	20 m³	115	1,054	1,069	799	423	342	337
	12 m³	114	1,102	1,117	847	423	342	337

All alternatives that are shown in table 12 are based on the total project costs with respect to an annual point of view. The relation of the different alternatives stays the same as it is already explained for the total project costs. The average annual saving of costs could be identified with the help of calculation (13), in case one alternative is preferred to another.

Finally, the dynamic project costs were determined with use of calculation (14):

Table 13 Overview of the dynamic project costs (DPC) for all urine alternatives, carrying segments framed red, transportation and storage scenarios framed blue and the encircled costs are showing the most expensive and the most favourable alternative; for more explanation see chapter 4.3 and 4.4

URINE DPC (€/m³)		Tank 1 > Vehicle > Field	Tank 1 > Pipes > Tank 2 > Vehicle > Field			Tank 1 > Vehicle > Tank 3 > Field		
			Stainless Steel Tank	IBC Tanks		Stainless Steel Tank	IBC Tanks	
				plane	stacked		plane	stacked
GIZ's new suction vehicle	30 m³	817	840	840	833	824	822	822
	10 m³	379	402	402	396	386	384	384
GIZ's used suction vehicle	30 m³	446	469	469	463	453	452	451
	10 m³	164	187	187	181	171	169	169
GIZ's new tractor with new manure barrel	20 m³	158	180	180	174	165	163	163
	12 m³	115	138	139	132	123	121	121
GIZ's used tractor with used manure barrel	20 m³	95	117	118	111	103	101	100
	12 m³	72	95	95	89	79	77	77
Renting a suction vehicle	10 m³	49	38	38	31	56	54	54
Renting a tractor with manure barrel	20 m³	24	33	33	27	31	29	29
	12 m³	24	33	34	27	31	29	29
Forwarding company		52	37	38	31	59	57	57
Farmer	20 m³	3	25	25	19	10	8	8
	12 m³	3	26	27	20	10	8	8

Also in this case, the relation of the different alternatives remains constant. With this analytical tool it is possible to evaluate the cost efficiency of the differing alternatives in terms of effort. For the most favourable alternative 9 Euro per m³ urine accrue. This value originates in the urine's transportation, its storage and the application of it.

The same procedure was conducted for the MAP alternatives.

According to calculation (9), an addition of investment, reinvestment and running costs which are already introduced in chapter *5.2.1* proceeds in the following total project costs:

Table 14 Overview of the total project costs (TPC) of all MAP alternatives, carrying segments framed red, transportation and storage scenario framed blue and the encircled costs are showing the most expensive and the most favourable alternative; for more explanation see chapter 4.3 and 4.4

MAP TPC (€)		Rain Barrel > Vehicle > Field
GIZ's new truck		605,575
GIZ's used truck		569,206
Renting a truck		540,180
Forwarding company		538,644
Farmer		538,011

With respect to table 14, it can be stated that the total project costs of the different MAP alternatives are quite homogeneous compared to the urine alternatives. The different carrying segments and the fact if a new or a used vehicle is bought do not affect in the same way as in the case of urine. This is a result of the disproportional size of the costs for a maintenance worker and the needed filter bags to keep the precipitation progress running. Consequently, the other items hardly carry weight.

The annual costs were ascertained by calculation (10):

Table 15 Overview of the annual costs (AC) of all MAP alternatives, carrying segments framed red, transportation and storage scenario framed blue and the encircled costs are showing the most expensive and the most favourable alternative ; for more explanation see chapter 4.3 and 4.4

MAP AC (€/a)		Rain Barrel > Vehicle > Field
GIZ's new truck		18,167
GIZ's used truck		17,076
Renting a truck		16,205
Forwarding company		16,159
Farmer		16,140

The annual costs are shown in table 15. They are based on the costs for the whole project, broken down into an annual consideration.

As an additional analytical tool, the dynamic project costs were determined with use of calculation (14):

Table 16 Overview of the dynamic project costs (DPC) of all MAP alternatives, carrying segments framed red, transportation and storage scenario framed blue and the encircled costs are showing the most expensive and the most favourable alternative ; for more explanation see chapter 4.3 and 4.4

MAP DPC (€/kg)		Rain Barrel > Vehicle > Field
GIZ's new truck		541
GIZ's used truck		509
Renting a truck		483
Forwarding company		481
Farmer		481

With the information given in table 16 it is possible to evaluate the cost efficiency of the differing alternatives, in terms of effort. Also in this case, the costs stay quite homogeneous. 684 Euro per kg MAP accrue for the most favourable alternative. This value originates in MAP's production, its storage, transportation and its application.

The dynamic project costs are chosen as means for the cost comparison of urine and MAP. As it is not convincing to compare the costs for one m³ urine and one kg MAP, there is the need to accomplish a certain level. This level is said to be the accruing costs for the fertilisation[11] of one hectare per year. In the following, the performance contained in the dynamic project costs for urine and MAP is listed:

- Urine
    - Storage
    - Transportation
    - Application
    - Application of additional fertilisers

[11] Based on the conditions determined in chapter *4.5*

- MAP
    - Production of MAP, thus urine precipitation
    - Storage
    - Transportation
    - Application
    - Application of additional fertilisers

The amount of urine and MAP needed to be applied per hectare and year:

- Urine: 62 m³
- MAP: 164 kg

This results in the total asset of 558 Euro for urine and 112,176 Euro for MAP to supply one hectare of summer wheat during one year. As a matter of fact, the most favourable alternatives for urine and MAP are used and the outcomes are based on the given example GIZ with its existing conditions. Certainly, it needed to be regarded that in case of MAP the purchase and maintenance of the whole precipitation plant is considered. As opposed to this, the in–house installations required for urine separation are taken for granted, due to the reason mentioned in chapter *3.1*.

In order to gain a standard value costs for NPK application were calculated in the sheet NPK application scenario. The scenario implicates the case that instead of urine and MAP, NPK is used to fertilise the appropriate area. Not mentioned are NPK's storage and transportation, but the current shop price for NPK and the fertiliser needed in addition, moreover, the costs for the application flow in. These costs result in 122 Euro to supply one hectare of summer wheat during one year.

5.3 Sensitivity Analysis

The fertiliser prices' increase of 40%, *SA I*, has no remarkable effect to the total project costs of urine and MAP. Representative for urine shown in figure 17:

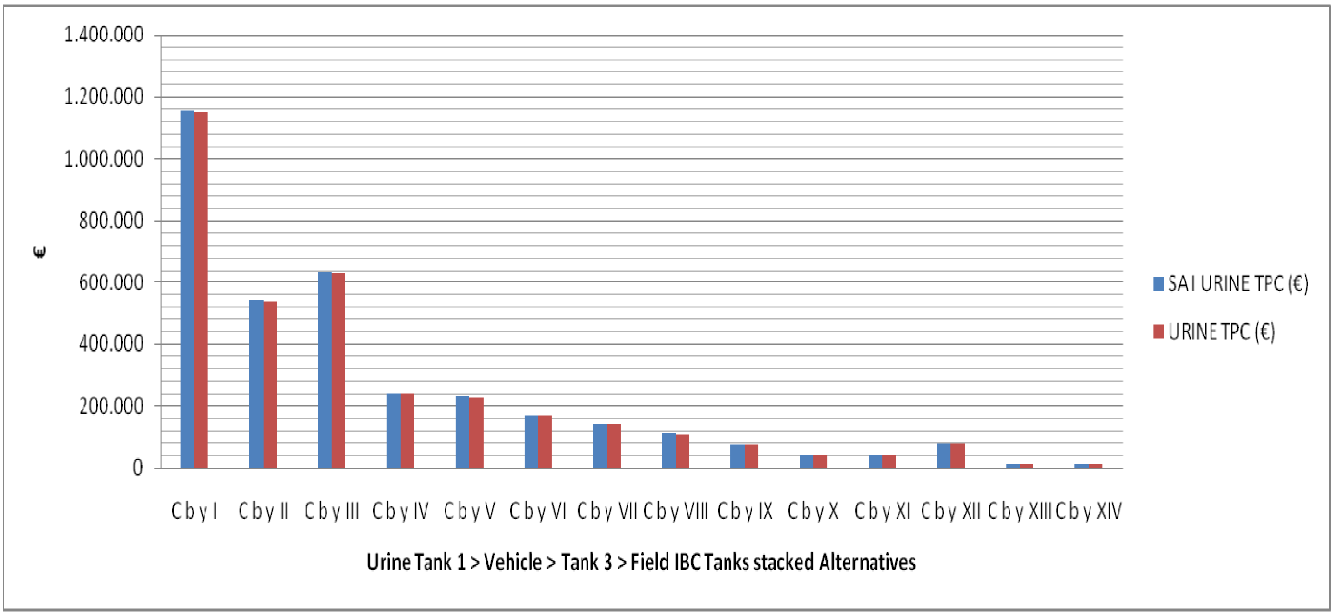

Figure 19 Increasing of fertiliser prices, 40% (SA I) for all urine alternatives within scenario C b y, for more explanation see chapter 4.3 and 4.4

The fuel prices' increase of 40%, *SA II*, behaves similarly, here clarified by MAP:

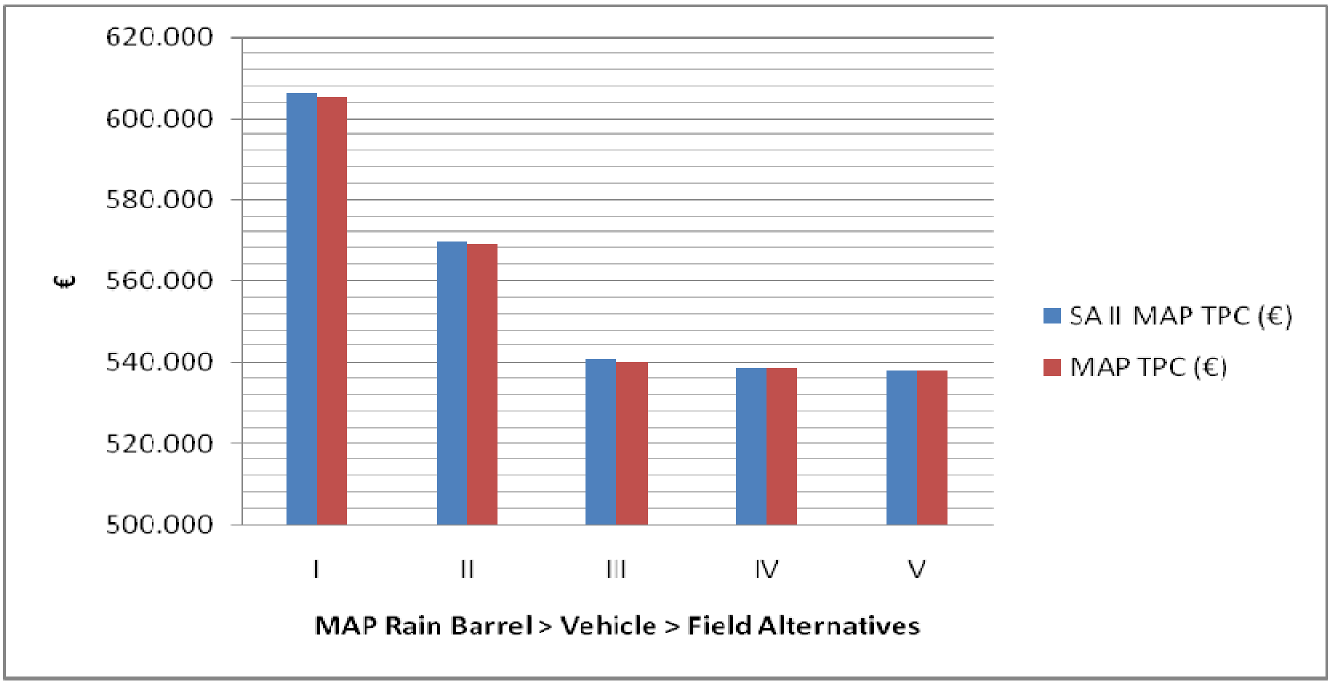

Figure 20 Increasing of fuel prices, 40% (SA II) for all MAP alternatives, for more explanation see chapter 4.3 and 4.4

By the rise of the distance to the fields from 2.3 kilometres to 10 kilometres, *SA IIIa*, an effect shows up for MAP only. The MAP alternatives I–III became more expensive:

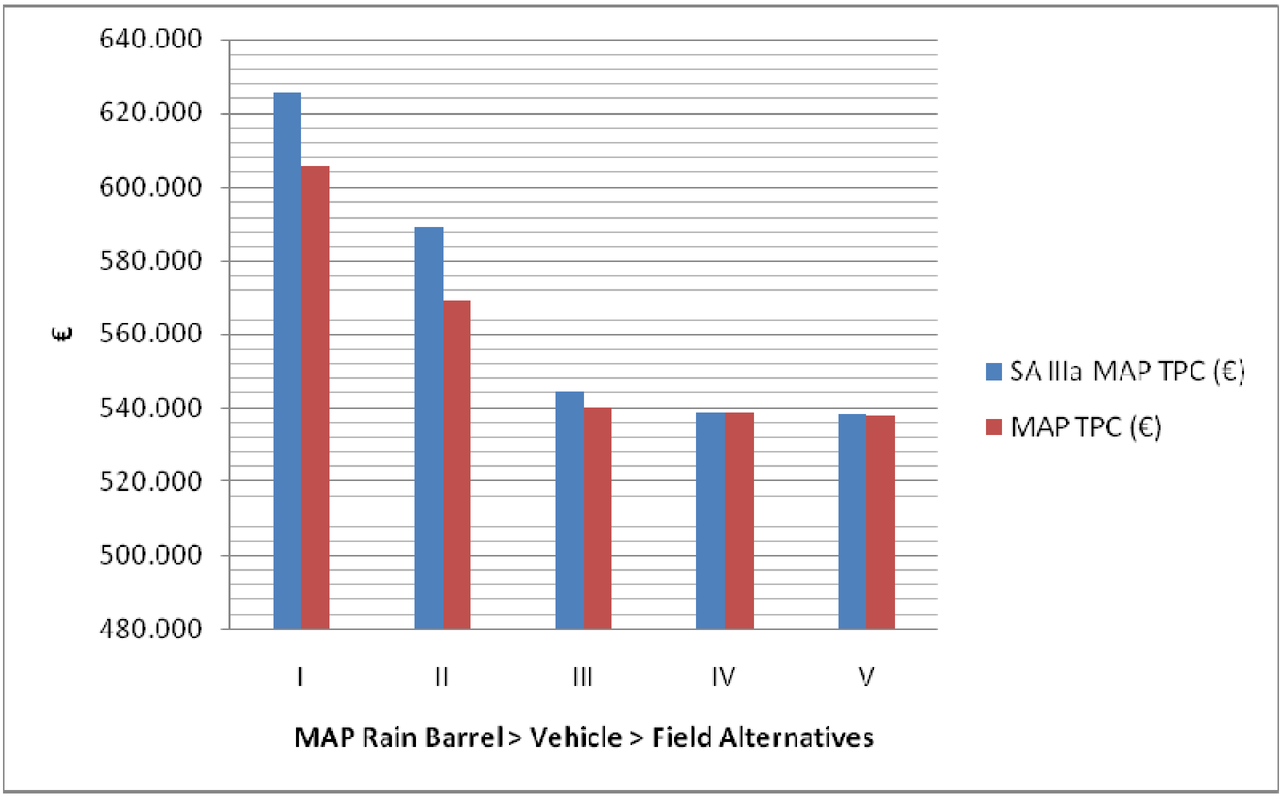

Figure 21 Increasing of the distance to field up to 10 km (SA IIIa) for all MAP alternatives, for more explanation see chapter 4.3 and 4.4

By the rise of the distance to the fields from 2.3 kilometres to 30 kilometres, *SA IIIb*, an effect shows up for urine and MAP. The urine alternatives became slightly more expensive, the MAP alternatives I–III showed up as noticeable more expensive:

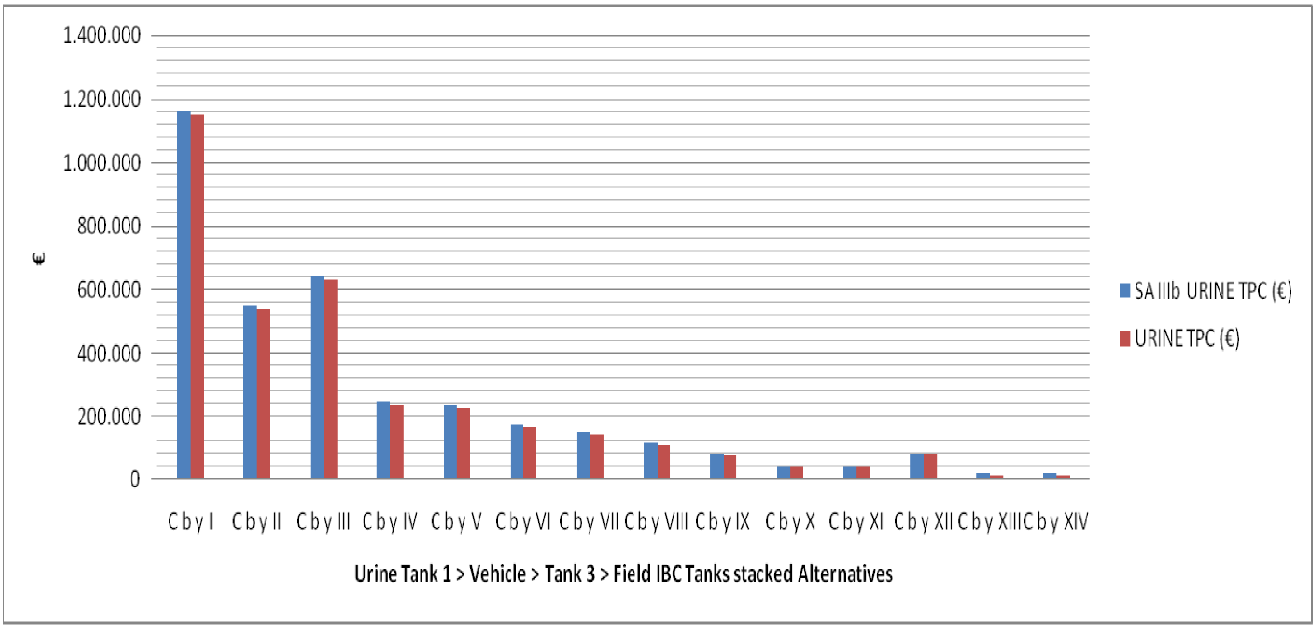

Figure 22 Increasing of the distance to field up to 30 km (SA IIIb) for all urine alternatives within scenario C b y, for more explanation see chapter 4.3 and 4.4

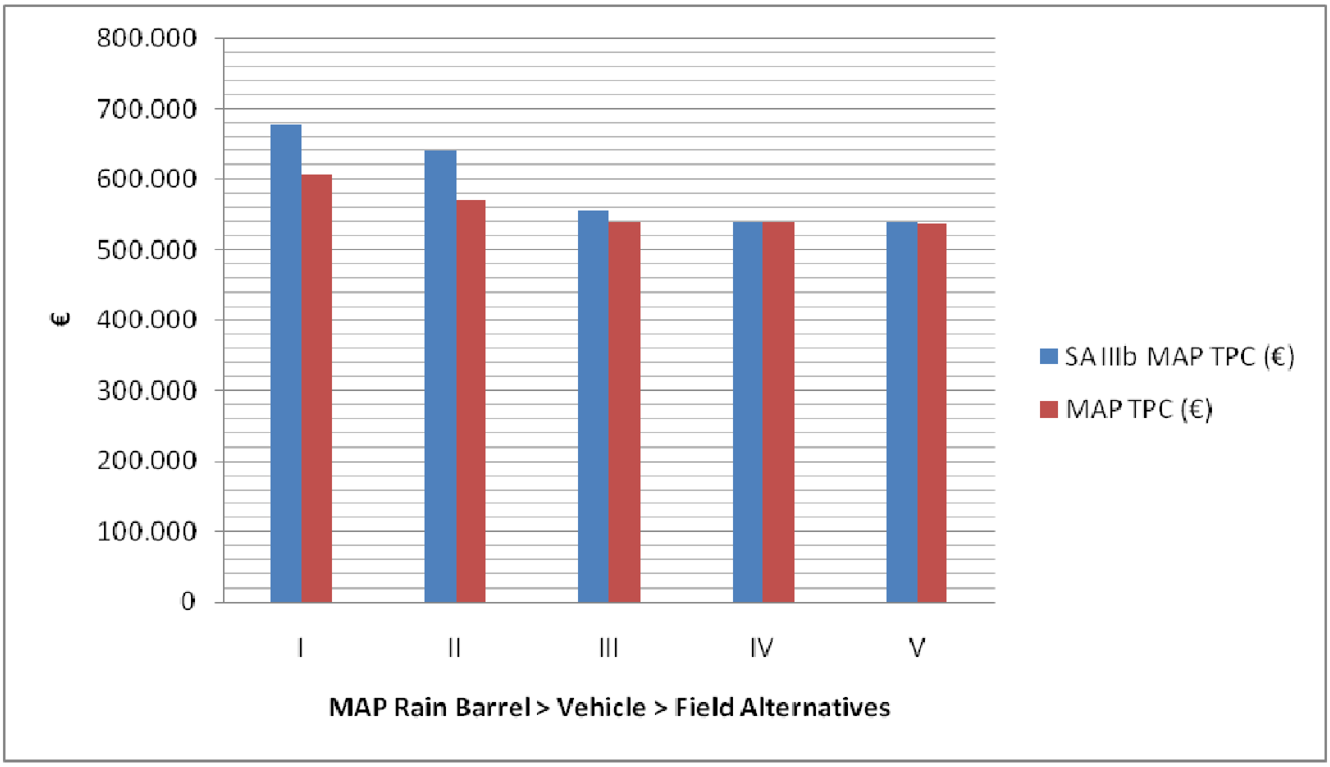

Figure 23 Increasing of the distance to field up to 30 km (SA IIIb) for all MAP alternatives, for more explanation see chapter 4.3 and 4.4

In the sequel of this sensitivity analysis no critical values within the calculations could be investigated. These show up in order to a reversal of the relations between the different alternatives' costs, but that is not the fact in this case.

Now, the last hypothesis 'It is expected that the urine's transportation of more than 30–40 kilometres is uneconomic (Johannson and Nykvist, 2001), so that the occurrence of local users has to be given. Otherwise, the MAP's transportation might become economic starting from 30–40 kilometres', see chapter *2.2.2*, needs to be verified.

As shown in figure 22, the distance's increasing causes an escalation of the total project costs for the different urine alternatives within scenario *C b y*. It is expected that this effect would strengthen through further increase of the distance. Nevertheless, the created calculation construct within the Excel–file is not yet designed for a transportation of more than about 30 kilometres. Due to the fact that some costs, for instance these for the forwarding company, are based on day rate. But up from a certain distance an eight–hour day will be not enough to convey the whole urine. Anyway, the first part of this hypothesis could be seen as confirmed.

Unfortunately, figures 21 and 23 present the same effect for MAP. Therefore, the second part of the hypothesis is refuted.

6. Conclusion

As a result, urine transportation turns out to be more favourable than MAP with respect to their economical factors and efficiency. To be more precise scenario *C* can be identified as the best transportation alternative, embracing, regarding the prices, quite similar storage possibilities. However, option *C b y* can be presented as the most fortunate alternative, requiring total project costs of 11,221 Euro. It comprises a quarterly transportation of urine from GIZ to the fields surrounding Eschborn, where it is filled in stacked IBC tanks, with an overall size of 30 m^3.

Given the example of GIZ, it has to acknowledged that the usage of both, urine and MAP, as fertilisers shows less economic efficiency than the usage of regular multi components fertilisers, see *5.2*. Nevertheless, as the study was based on the assumption that phosphor is supposed to vanish as a future source and, consequently, does not occur as a relevant option, this result would not have any impact on the decision making process choosing between the urine and MAP usage.

Last but not least, it is intended to provide the reader with some input for further studies.

First of all, it would be essential to analyse the adaptability of this case's calculation for other countries, especially for developing countries. It can be assumed that due to cheaper costs for workers and vehicles, urine and MAP usage might be more beneficial than the usage of traditional multi components fertiliser. Among other things, salaries and material for the precipitation reactor's operation might decline. Therefore, this strong amount of running costs would decrease significantly. In addition, costs for decreasing sources such as phosphor and, moreover, regular fertilisers might have a positive impact on prospective calculations and scenarios as well. This kind of development should be monitored and controlled on a regular basis in order to generate the latest results for effective analyses and decision processes.

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9. Appendix

Table	Located in the Excel File *Cost Analysis:*
Table 1	Based on calculations in sheet *URINE transportation scenarios small vehicles*
Table 2	Based on calculations in sheet *MAP transportation scenarios*
Table 3	Sheet *Total Project Costs and Annual Costs and Reinvestment Costs*
Table 4	Sheet *Total Project Costs and Annual Costs and Reinvestment Costs*
Table 6	Based on sheet *Factsheet Germany*
Table 7	Based on sheet *Sensitivity Analysis*
Table 8	Sheet *Investment Costs and Running Costs and Reinvestment Costs*
Table 9	Sheet *Investment Costs and Running Costs and Reinvestment Costs*
Table 10	Sheet *Investment Costs and Running Costs and Reinvestment Costs*
Table 11	Sheet *Total Project Costs and Annual Costs and Reinvestment Costs*
Table 12	Sheet *Total Project Costs and Annual Costs and Reinvestment Costs*
Table 13	Sheet *Total Project Costs and Annual Costs and Reinvestment Costs*
Table 14	Sheet *Total Project Costs and Annual Costs and Reinvestment Costs*
Table 15	Sheet *Total Project Costs and Annual Costs and Reinvestment Costs*
Table 16	Sheet *Total Project Costs and Annual Costs and Reinvestment Costs*

Figure	Located in the Excel File *Cost Analysis:*
Figure 12	Sheet *Investment Costs and Running Costs and Reinvestment Costs*
Figure 13	Sheet *Investment Costs and Running Costs and Reinvestment Costs*
Figure 14	Sheet *Investment Costs and Running Costs and Reinvestment Costs*
Figure 15	Sheet *Investment Costs and Running Costs and Reinvestment Costs*
Figure 16	Sheet *Investment Costs and Running Costs and Reinvestment Costs*
Figure 17	Sheet *URINE transportation scenarios small vehicles*
Figure 18	Sheet *MAP transportation scenarios*

Figure 19	Sheet *Sensitivity Analysis*
Figure 20	Sheet *Sensitivity Analysis*
Figure 21	Sheet *Sensitivity Analysis*
Figure 22	Sheet *Sensitivity Analysis*
Figure 23	Sheet *Sensitivity Analysis*