GREEN CHAINS

Adaptive Logistics in Circular Economy

rijksuniversiteit groningen

DINALOG Dutch Institute for Advanced Logistics

gasunie

GasTerra

HOLTHAUSEN GROUP

GRONINGEN SEAPORTS

DNV·GL

Hanzehogeschool Groningen University of Applied Sciences

Green goods

N-TRA ENERGIETRANSITIE

In memoriam prof. dr. ir. Gerard (Gerhard Pieter Jan) Dijkema

INDEX

Photo front cover: https://www.leasingo.de/biogasanlagen-leasingvergleich

1.PREFACE

This booklet describes the context and the end results of the ADAPNER project. This NWO project was granted in 2015 within the call Vital Logistics, initiated by the Topsector TKI-Dinalog.

You will find in succeeding chapters detailed descriptions of the introduction to the project, a summary of the research results performed by the PhD's in the project, infographics of the studied green chains topics, and descriptions of the interactive ADAPNER version of a serious sustainability game developed earlier. The last chapter contains an outlook to further study and pilot studies foreseen. Last but not least, the results of several master theses have found a place in this booklet. The other appendices list contributions of the related project partners, the reference list of publications and a detailed version of the infographic.

The project results show that the multidisciplinary approach worked well around the green chains concept: on the one hand running such a project is not easy, on the other hand the intensive collaboration and better understanding of the fields of related research groups within the University of Groningen benefits cross-fertilization of knowledge.

It is a pity that due to the corona crisis, the end of this project could not be accompanied by a conference where we planned to physically meet and interact with participants on the results of the project. At least we can share this booklet with you together with the hope to have an opportunity at a next sustainability event to meet in reality.

Happy reading!

Hans Wortmann
Project leader ADAPNER
Rijksuniversiteit Groningen

2.OVERVIEW OF THE PROJECT ADAPNER

How it started

At the end of the year 2014 George Huitema engaged with the entrepreneur Stefan Holthausen at an LTO meeting, and they talked about biogas and green gas. Stefan explained that biogas could be transported in large cylinders on trucks, and his company had experience with all kind of gas transport since many decades. George Huitema mentioned that academia could help in finding the right business models and the right solutions for transport problems. The context was the high expectations of the government regarding the role of green gas: a growth from the 1% share of gas consumption in 2015 to 10% in 2030 was expected.

At the 2015 new year reception of Energy Valley, George met Gerard Dijkema, who was moving from Delft to Groningen to become full professor in energy modelling. They knew each other already from the EDGAR program on Gas Research. They had joint academic interest in the phenomenon of *growth* of the infrastructure needed for biogas and green gas. Apparently, the means of transportation and storage would have to adapt several times in the years to come, for the government expectations to turn into reality. In their conversation the plan arose to write a proposal on the interface of logistics and sustainability for the open NWO call Vital Logistics by TKI Dinalog, the research funding body for logistics in The Netherlands.

Hans Wortmann was involved as the person most equipped to take leadership for such a project. The program required the involvement of companies, and Gasunie, GasTerra and Holthausen were quite happy to oblige and join research on Adaptive Logistics in the Circular Economy. The proposal was granted and the project took off in 2015. Two PhD students were hired, Jan-Eise Fokkema with a background in logistics and with great interest in modelling and Dieu Linh Hoang, with a background in sustainability and great interest in the nutrient flows around farming.

How it went on

In many respects, the project journey looked like a roller coaster, both on a personal level and in content. At the personal level, we had a dramatic event when Gerard Dijkema passed away after the first year of the project. We remember him as a visionary colleague who was taken away much too early. Fortunately, Sanderine Nonhebel could take his place in the project in due time and took over the supervision of Dieu Linh Hoang. We also had nice events to celebrate. In February 2019, Linh gave birth to a beautiful daughter.

The company members of the steering committee, from GasTerra, Gasunie and Holthausen were quite supportive, in providing feedback to the PhD students but also in providing topics and internships for master students. From GasTerra we had continuous support from Gerard Martinus. From Gasunie we started with Rob de Wolf, who handed over his duty later to Tineke van der Meij. When Tineke decided to start her own business, Kees Alberts took over the steering committee role and continued to open doors to knowledgeable people in Gasunie. René Brons represented Holthausen in the early years of the project and although his time to participate in the project was clearly limited, we were happy to see him back aboard at the end of the project. We decided to hire Tineke van der Meij as project manager in the last years of the project and Frank Pierie as postdoc. They contributed much to the final results of the project, including this booklet. Hans Wortmann got severely ill in 2019, and we are grateful to George Huitema who took over his duties in the last year, but is now recovering. Martin Land, who had the role of daily supervisor for Jan Eise Fokkema as PhD student, also turned out to be supportive in having master students involved in the project. Some of these master students' projects are highlighted later in this booklet.

Dynamic project content

Also, the content of the project was very dynamic, with a surprise every few months. First of all, we learned a lot about the farmers' considerations in creating biogas. Farmers need biomass to be mixed with manure in order to produce biogas. Many farmers have to buy additional biomass on the market, which causes biomass transport form different locations. Moreover, biomass supply is not only seasonal but can also be of quite different quality. Polluted biomass results in polluted digestate which cannot be used for fertilization anymore. For all these reasons, it is difficult to apply logistics principles which are applicable elsewhere. Nevertheless, Jan Eise Fokkema wrote an interesting paper on how farms in a region could co-operate to transport biogas by truck to a centralized upgrading facility which transforms biogas into green gas.

Also, we found out that the time investment in running a biogas system is large. Dairy farming is already time intensive, which makes biogas production on dairy farms not easy to implement. Sanderine Nonhebel gave a very convincing pitch to a workshop with industry on this issue.

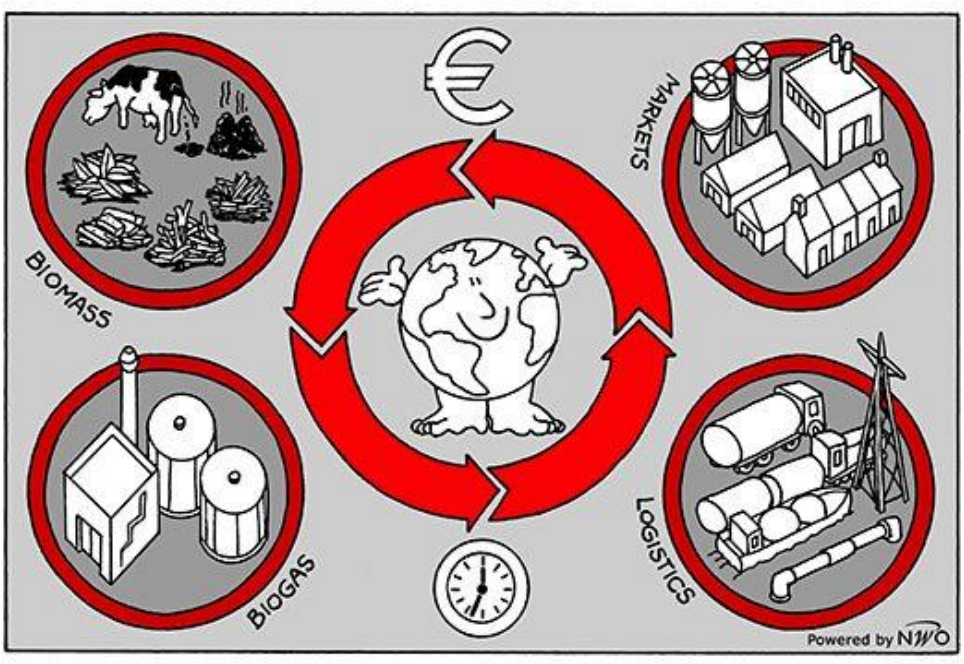
During our project the nitrogen emissions from farms became a hot topic in society. Dieu Linh Hoang studied the nitrogen emissions related to nitrogen emissions on dairy farms. It was shown that biogas production on a dairy farm increased when a digestor was implemented. Further there are strong indications that use of digestate instead of manure to fertilize soils is leading to a decline in soil organic matter. All these issues show that biogas production on dairy farms is interfering with the present agricultural practices and these issues should be solved, before biogas production on dairy farms can take place at large scales. This implies that we need other sources than manure to reach a production of 2BCM by 2030.

While studying biogas, the dynamic world of renewable energy and the circular economy crossed our path, with the promising role of hydrogen for storing converted electrical energy in particular. For farmers, the investment to have windmills on their land and solar panels on roofs is competing with an investment to produce biogas. However, local supply of renewable electrical energy is never in balance with local demand, and therefore conversion and storage of energy is an option. The other option is the current and continued grid connection. Here, hydrogen is likely to play a key role in the future. Accordingly, Jan Eise Fokkema started to investigate trade-offs between investments in renewable electricity generation, conversion to hydrogen and storage of hydrogen. The companies in the ADAPNER consortium started to see the role of hydrogen. Studies in generation, transport and storage of hydrogen were requested from many master students, leading to useful insights and as mentioned earlier, new surprises every few months.

Finally, biogas, green gas, hydrogen and sustainable farming cannot be seen in isolation. Frank Pierie did a wonderful job in distinguishing these topics and putting them together in his research and a serious game. The key element of the game is not the separate topics by themselves, but the interrelationships between them.

Target group

The results of this project are very interesting for all parties participating in the green chain around production, consumption and logistics of biogas, biomass and other green energy options. The issues we study are highly relevant, not only for logistics providers in the biogas industry, but for the entire biogas business ecosystem and society in general.



Drawing from Dinalog website, ADAPNER project page.

3. SUMMARY RESULTS ADAPNER RESEARCH

The ADAPNER project proposal

In 2015, the ADAPNER project (Project number 438-15-519) was awarded with a grant under the Vital Logistics call of NWO. This call was initiated by TKI-Dinalog and fits within the Topsector Logistics Roadmap. ADAPNER stands for *Adaptive Logistics in Circular Economy*.

Alignment with the Topsector Logistics Roadmap.

The ADAPNER project contributes to the theme Cross Chain Control Centres of the logistics roadmap by further development of collaboration and co-operation mechanisms, in particular in the biogas/biomass supply chain. Moreover, ADAPNER contributes to the add-on value of chain control services in Cross Chain Control Centres by finding optimal configurations leading to transparency in costs and cost savings.

Scope of the ADAPNER project proposal

Within a Circular Economy, three interdependent cyclic systems emerge around: biological nutrients, technical nutrients and energy capture. Biomass plays a pivotal role as biological nutrient and as feedstock for biogas. Biogas is currently not economically viable in the Netherlands without subsidies. This state of affairs is related to logistics costs. Transport of biomass, of biogas and of digestate is too expensive to warrant a viable circular economy around biogas. Crucial within a circular economy is a well-developed logistical system enabling the transport of all kind of value streams and hence, the reusability of resources. The ADAPNER project will focus on achieving economic viability by new technologies and by new organizational forms.

Project team ADAPNER

The project team consists of the University of Groningen (RUG) with members of the Faculty Economics and Business (FEB), members of the Faculty of Science and Engineering (FSE) and the industry partners Gasunie, GasTerra and Holthausen.
The research work is done by two PhD researchers and one postdoc. In the case studies MSc students are involved; these are supervised and coached by researchers and industry partners involved.

ADAPNER Research

The research of the ADAPNER project is split up in two PhD studies each dealing with a different perspective on the ADAPNER scope. Below a short summary for each study is given. More details can be found in the published articles, given presentations and finally their upcoming PhD theses (see Appendix E). The last years the two research topics were brought together by means of the Green Chain concept, as illustrated in Chapter 4 and Appendix D.

A. Energy Logistics

Given the research domain of ADAPNER to study adaptive logistics in the circular economy this PhD study focuses on Energy logistics as follows.

Objective
The original objective was “Determining optimised adaptable and sustainable configurations for different distribution alternatives regarding biomass and biogas in a circular economy”. During the project, it was decided to expand the scope to include also other energy forms than biogas, e.g. solar and wind as energy sources and green hydrogen as energy carrier.

Research and research topics
This research focusses on the **business case of biogas** with the following different applications:

- local purposes (heating);
- power generation;
- upgrading biogas to green gas, for feed in in gas network.

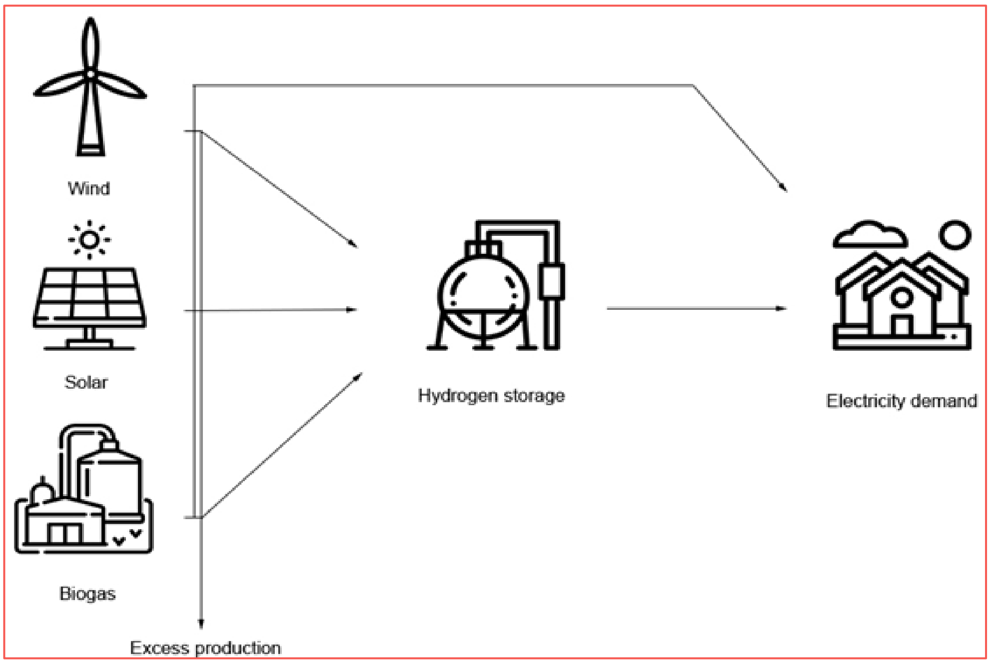
In particular the **logistic optimisation for transporting biogas** to (regional/central) upgrading facilities is studied for the following flows:

- flow of manure to digesters;
- flow of other biomass to digesters;

Together with the **optimisation of energy sourcing, transport and storage**:

- Sourcing by solar and wind
- Applications of hydrogen for transport and storage

In the related research (Part B on Nutrient Cycles) the effects of biogas production are studied on the nitrogen-cycle and carbon-cycle and balancing different nutrients for agricultural crops.



Relations between the different research topics in Study A. Energy Logistics.

Jan Eise Fokkema, PhD

In four research projects, we examine how renewable energy infrastructure - from a logistics perspective - can be developed effectively in rural areas. The focus lies on modeling and simulating energy flows and storage of hydrogen and biogas.

1. Efficient distribution of biogas using trucks and tube trailers

In this research project, we investigate optimal route planning decisions of tube trailers that pick-up biogas at decentralized farms and deliver these to green gas upgrading facilities for injection into a gas grid. We assume that cylinders are filled at each farm and are exchanged with empty cylinders and take into account the biogas storage levels at each farm.

TAKE AWAY

- *The most efficient schedules can be realized when the storage capacity at each farm is larger than or equal to the truck capacity.*
- *The most efficient schedules are those in which the least possible number of farm visits are combined in a single tour. Increasing truck capacity reduces travel times.*

2. The optimal mix between solar, wind and bioenergy to minimize storage requirements

In this study, we focus on how different combinations of solar, wind, and bioenergy at a small rural scale can help in minimizing total storage requirements. The supply-driven profiles of these renewable energy sources do not match well with local electricity demand. Research questions: What are optimal combinations of solar, wind, and bioenergy to minimize storage requirements? Which sources can best be used for peak-shaving combined with other sources?

TAKE AWAY

- *The optimal mix between wind, solar and biogas to minimize storage requirements is strongly dependent on the amount of total installed production capacity in which constant energy sources are given the largest share in combination with a smaller share of wind energy.*
- *Constant energy sources such as biogas are important in reducing total storage requirements.*
- *When the total production capacity is limited, but storage is available, wind energy is best-suited to supply the peaks in electricity demand.*

3. Solving (local) grid congestion problems of solar parks using seasonal hydrogen storage

In this study, we investigate how hydrogen storage can help in reducing local electricity grid congestion problems throughout the year which can be caused by a peak supply of solar energy. We take into account uncertainty in electricity prices, local electricity demand, and solar energy production. We assume that batteries are used to smooth intra-day fluctuations

whereas hydrogen is used to store differences between days as a result of seasonal differences in supply and demand.
Research questions: Given the uncertainty in demand, production, and prices, how much should be sold, bought, or stored each day depending on the prevailing electricity prices, solar production level, and the amount remaining in storage? How are congestion levels and electrolyzer utilization levels affected by solar production capacity, distribution capacity of the electricity grid, and storage capacity?

TAKE AWAY

- *Even though a low electrolyzer capacity has better utilization levels, hydrogen storage is more cost-effective when the electrolyzer capacity is larger and has a lower utilization rate.*
- *For a low distribution capacity of the electricity grid, it is most efficient to keep sufficient storage levels to prevent local shortages in the winter. Congestion is then mostly caused by buying electricity in the winter.*
- *For a larger (but still limited) distribution capacity, congestion is caused by both buying in winter and selling in summer.*

4. Current research: Investing in hydrogen storage or electricity distribution capacity?

In this study, we examine to what extent it is sensible to invest in hydrogen storage or expansion of the electricity distribution capacity. We assume that the electricity grid has a limited capacity in which the supply of a solar park causes congestion issues. We take into account both electricity and heat demand.
Research topics: Taking into account local electricity prices and a market for solving congestion problems, we compare costs and revenues from storage with costs and revenues of investing in distribution capacity expansion. Furthermore, we examine how capacities of electrolyzers and storage of hydrogen affect the distribution between investments in storage and distribution capacity.

Preliminary conclusions from student research: cost of storage is of the same order of magnitude as cost of electrolysis. Hydrogen for seasonal storage is not economically feasible; for shorter/ intermediate storage periods an additional battery -before- the electrolyzer is advisable to flatten the production rates with the electrolyzer.

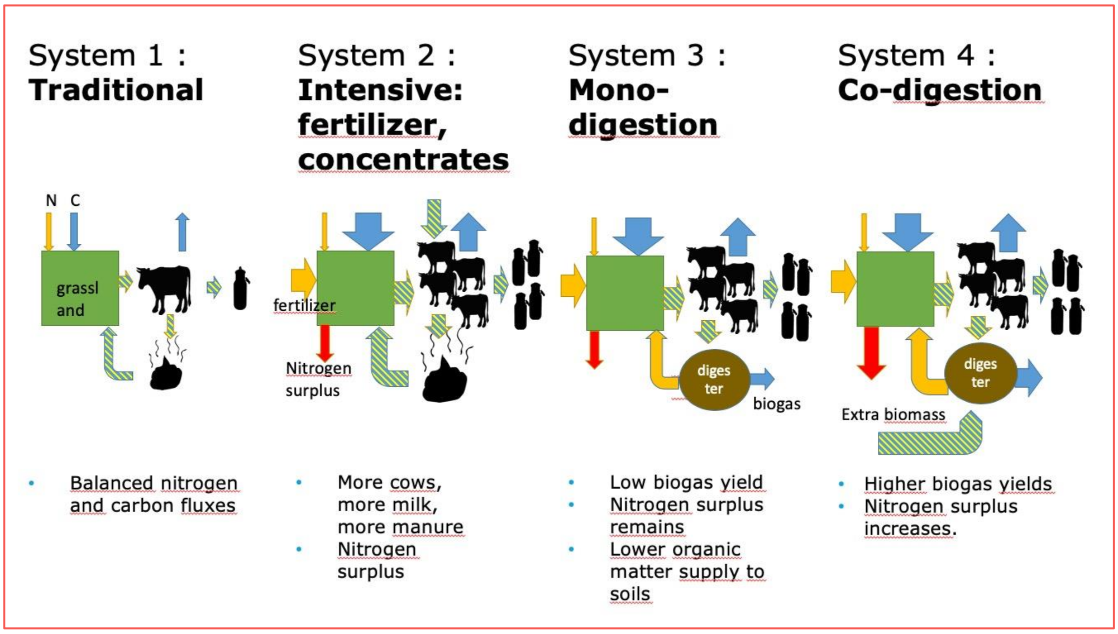
Jan Eise Fokkema, MSc

B. Nutrient Cycles

Objective
Determine the influence of different biogas production systems on the nitrogen and carbon cycle on a dairy farm. Compare the different types of biomass and competing use of the biomass.

Background
This research focusses on biogas production from manure on Dutch dairy farms. The total amount of manure in the Netherlands is large and converting it into biogas may generate about 10 % of the present natural gas consumption. Biogas is considered to be an environmentally friendly energy source, as a waste stream (manure) is used for energy production. Dairy farming has a large environmental impact. Three quarters of the national methane and ammonia emissions are caused by this sector and a lot of attention is paid to reducing these emissions and large investments are needed to make this happen.

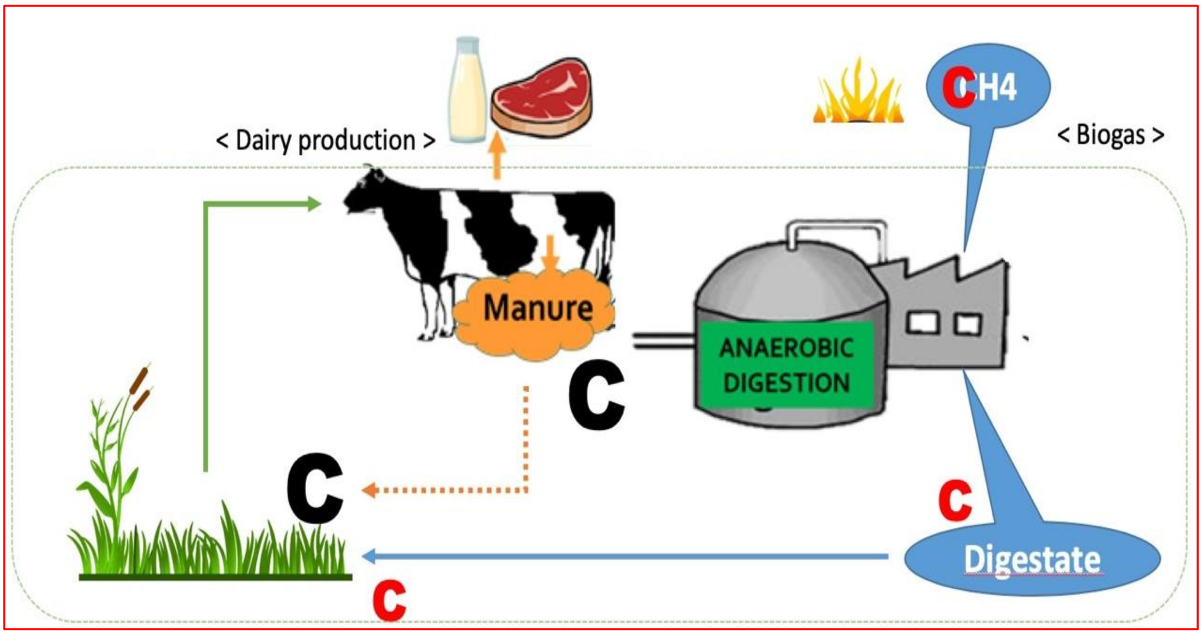
The introduction of a biogas production unit (digestor) on a farm will affect existing processes. It is essential these changes are not increasing the present environmental problems even further. When the production of biogas is going to lead to extra methane or ammonia emissions it is not likely that farmers will invest in such an installation. In this project we analyse the environmental impacts of installing a biogas system on Dutch farms. We compare nitrogen cycle and carbon cycle on a Dutch farm with and without a digestor. As farms differ we study impacts of implementing a biogas production unit in different types of farms such as an organic farm and a large 'normal' one.



Overview of the different systems studied.

A farmer has a number of cows which produce milk and manure. The milk is sold and the manure remains on the farm. The manure is used to fertilize the grasslands that produce the feed for the cows. Additionally, artificial fertilizer is used and extra feed (concentrates) is supplied to the cows. The nitrogen emissions in this system mainly occur in the fields and from the stables and the methane emissions are related to the digestion system of the cows and to the manure handling. When a digestor is implemented this system changes. Manure is now fed to the digestor where biogas is produced. The remainder from this process (digestate) is applied to the soil as fertilizer. The biogas production from cow manure is relatively low and by adding other biomass (silage maize for instance) the biogas production of the system can be improved a lot. This so-called co-digestion makes the system more economical feasible.
Digestate has another composition than manure: it contains far less carbon, as this is converted into methane in the digestor. In case a co-digestion system is used, the nitrogen content of the digestate is higher than the nitrogen content of the manure.

The research done in this project mainly involves the work of a PhD candidate, the MSc projects related to this subject were supervised by her and a share of the student work is incorporated in the papers and the final PhD thesis.



Dieu Linh Hoang, PhD

In this PhD project, we studied the impact of biogas production on the nitrogen and carbon flows on current Dutch dairy farms. Substance flow analysis (SFA) was chosen as the main methodology. This means that we made models where we quantified the in- and outflows of the concerned substances relating to the current dairy farming practice and studied the changes of these flows caused by the addition of biogas production.

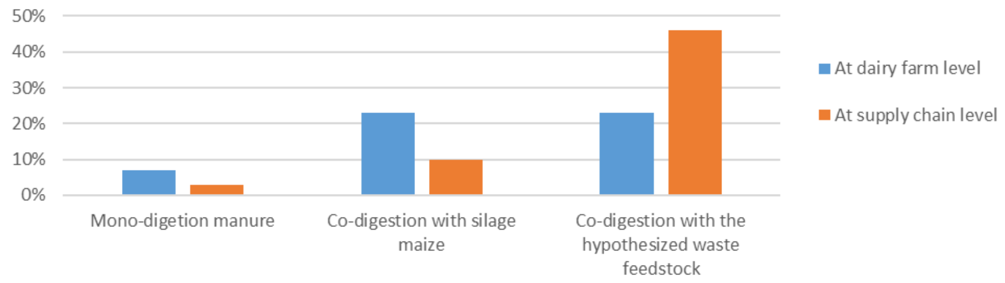
In the first project, the impact of biogas production on nitrogen emissions was studied. We aim to provide insights into the relation between the energy yield and the nitrogen emissions of the common types of anaerobic digestion based on the involvement of biogas feedstock, and what this relation means to certain stakeholders. Three biogas production scenarios were included. The first scenario is biogas production from manure alone which has a low biogas output. The second scenario is the co-digestion of manure with silage maize, a virgin crop, which has a high biogas output. The third scenario is also co-digestion but the additional feedstock is a plant-based waste stream which has similar characteristics as silage maize. This scenario is added to take into account the environmental costs of crop production for co-digestion. Waste streams are often seen as having no environmental impact for their generation.

In this research, we consider two groups of stakeholders. First are the dairy farmers who directly earn money from the amount of biogas produced and are impacted by the emissions on their own farms. Second are biogas policy makers who are responsible for the biogas production and its environmental cost at the national level. To the latter stakeholder, the considered emissions extent beyond the dairy farms into the supply chain which includes farms producing the additional feedstock.

Our result points out significant trade-offs between energy production and nitrogen emissions in biogas production. At the dairy farm level, regardless of the type of additional feedstock, gaseous nitrogen emissions increase by about 25%. At the supply chain level, silage maize, the virgin feedstock, adds nearly 50% more nitrogen emissions while the waste feedstock only adds 10%. In contrast, there is little impact of manure mono-digestion to nitrogen emissions at all levels.

TAKE AWAY

- *Mono-digestion of manure has little impact on nitrogen emissions but its biogas output is low.*
- *Co-digestion options can considerably increase biogas output but will also increase the nitrogen emissions.*
- *Co-digestion from waste can help extract more biogas with less nitrogen emissions trade-off; however, availability of waste feedstock for biogas can be limited in practice.*



Additional nitrogen emissions caused by biogas production on the current Dutch dairy farming practice in comparison with no biogas scenario

In another project, we investigated the impact of biogas production on the carbon flows on a conventional Dutch dairy farm. We aim to describe the quantitative potentials of biogas production on mitigating methane emissions and on lowering the addition of carbon to the soil of the dairy farm. To do this, the baseline of no biogas production and the scenario of mono-digesting manure were considered. Our result shows that 75% of the methane emissions of a dairy farm is from enteric fermentation and 25% is from manure. This means that only one-fourth of the farm's methane emissions is saved by installing a biogas production facility. On the other hand, the extraction of biogas leads to a reduction of 30% of carbon content of the manure and a reduction of 16% of total carbon addition to the soil of the dairy farm. Considering the role of the carbon addition to the soil health, this reduction may have negative impacts on cropping which is one of the main activities of dairy farms.

TAKE AWAY

- *Even with biogas production, three-fourth of the methane emissions on a dairy farm cannot be avoided*
- *Biogas production from only manure leads to a considerable reduction of soil carbon availability on dairy farms which might have negative impacts on the main activities of the farms.*

To conclude, our research shows that there are trade-offs related to carbon and nitrogen flows of biogas production. The awareness of these trade-offs and limitations can support practitioners to make decisions related to future biogas production.

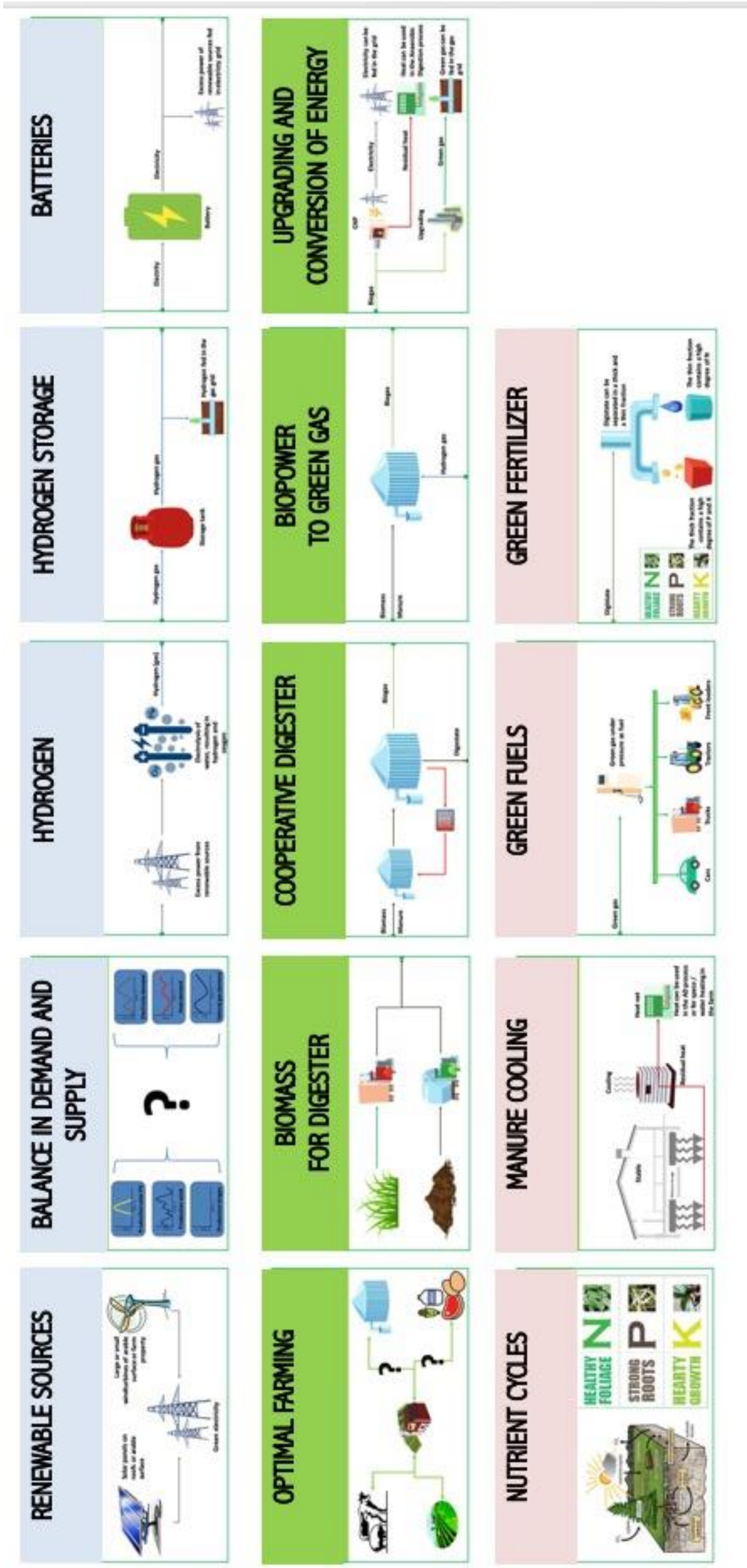
Dieu Linh Hoang, MSc

4. GREEN CHAINS

In the last year of the ADAPNER project we focused on integrating the insights and knowledge obtained from both the research lines (energy and nutrients) by applying them to a combined case. In this case, a cooperative of both dairy farmers and arable farmers in an agricultural region, share biomass, energy and nutrients to achieve a more sustainable circular farming cooperation.

To gain insight in the complexity of the aforementioned case, we divided the biogas production chain into individual components representing research topics in the ADAPNER project. Visualizing the combination of individual components helped us to understand the complexity of the system reseached in the ADAPNER project. Furthermore, it showed how the different parts of the research are connected. See pictures below.

We concluded that we could distinguish three interconnecting chains: an energy & storage chain, a digestion chain and a circularity chain. In the next pages we give an overview of the green chains, in appendix D the complete chains are depicted in more detail.


RENEWABLE SOURCES
BALANCE IN DEMAND AND SUPPLY
HYDROGEN
HYDROGEN STORAGE
BATTERIES
OPTIMAL FARMING
BIOMASS FOR DIGESTER
COOPERATIVE DIGESTER
BIOPOWER TO GREEN GAS
UPGRADING AND CONVERSION OF ENERGY
NUTRIENT CYCLES
MANURE COOLING
GREEN FUELS
GREEN FERTILIZER
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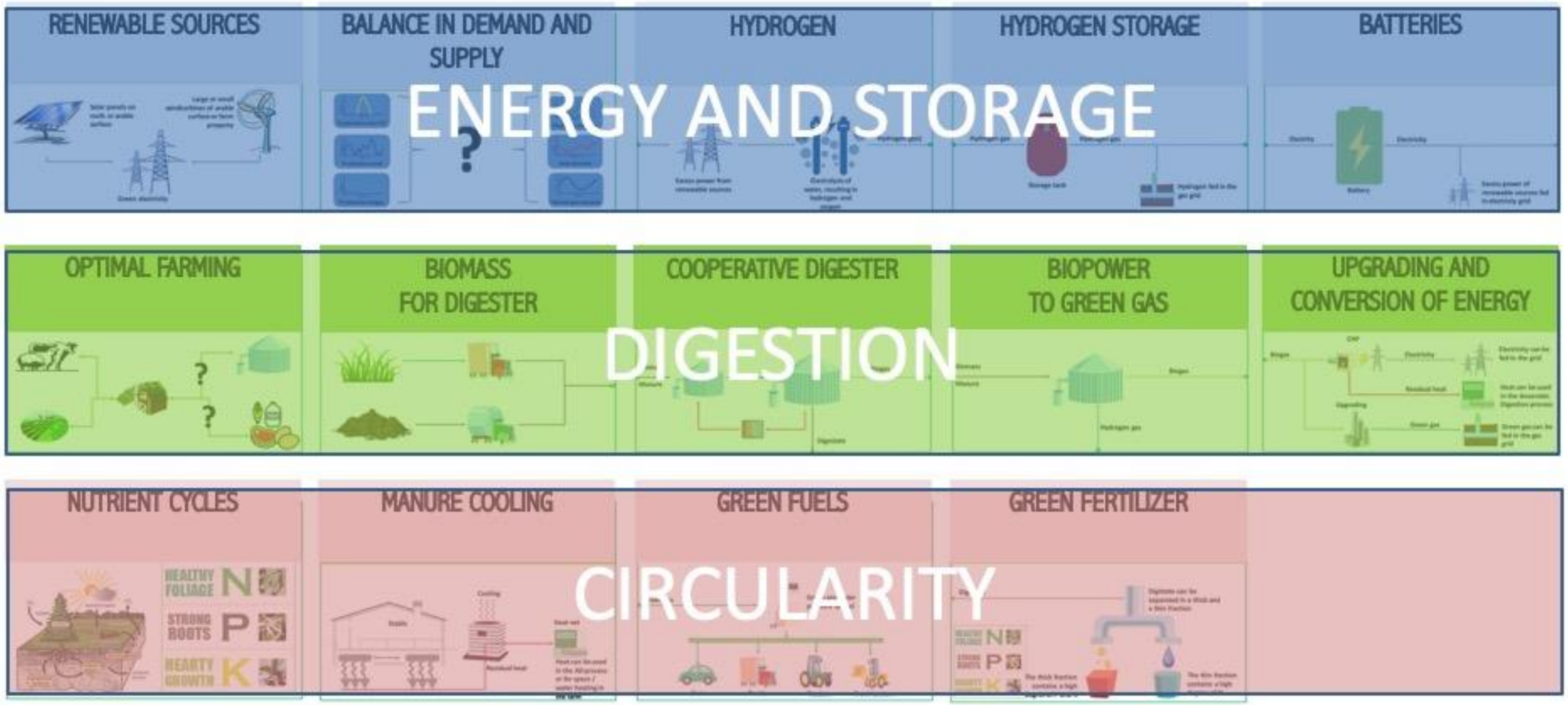
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MANURE COOLING
GREEN FUELS
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STRONG ROOTS P
HEARTY GROWTH K

Several workshops with project team ADAPNER and consortium partners. Trying out the Biomass game concept and the Green Chains infographic. Serious work and having fun

The lively discussions with the research group and steering committee resulted in some interesting insight but also some contradictions for the proposed case. A selection of the key findings from the PhD research, sorted according to these three ‘chains’, offer insights into the issues discussed.

Energy and Storage

The most efficient logistic schedules can be realized when the storage capacity at each farm is larger than or equal to the truck capacity and the least possible number of farm visits are combined in a single tour.

When the total production capacity is limited, but storage is available, wind energy is best-suited to supply the peaks in electricity demand.

Constant energy sources such as biogas are important in reducing total storage requirements.

Even though a low electrolyzer capacity has better utilization levels, hydrogen storage is more cost-effective when the electrolyzer capacity is larger and has a lower utilization rate.

For a low distribution capacity of the electricity grid, it is most efficient to keep sufficient storage levels to prevent local shortages in the winter. Congestion in this case is predominantly caused by buying electricity in the winter. For a larger (but still limited) distribution capacity, congestion is caused by both buying in winter and selling in summer.

Digestion

Mono-digestion of manure has little impact on nitrogen emissions, but its biogas output is low.

Co-digestion options can considerably increase biogas output but will also increase the nitrogen emissions.

Co-digestion from waste can help extract more biogas with less nitrogen emissions trade-off; however, availability of waste feedstock for biogas can be limited in practice.

Circularity

Even with biogas production, three-fourth of the methane emissions on a dairy farm cannot be avoided

Biogas production from only manure leads to a considerable reduction of soil carbon availability on dairy farms, which might have negative impacts on the main activities of dairy farms.

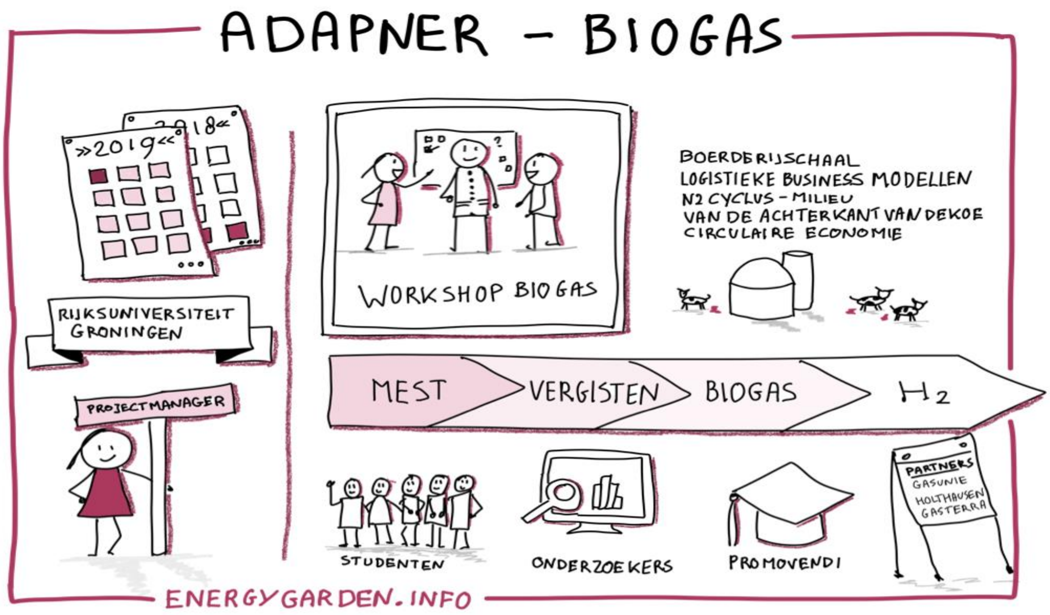
Three workshops with researchers, students and business partners from outside the project ADAPNER and one public symposium.

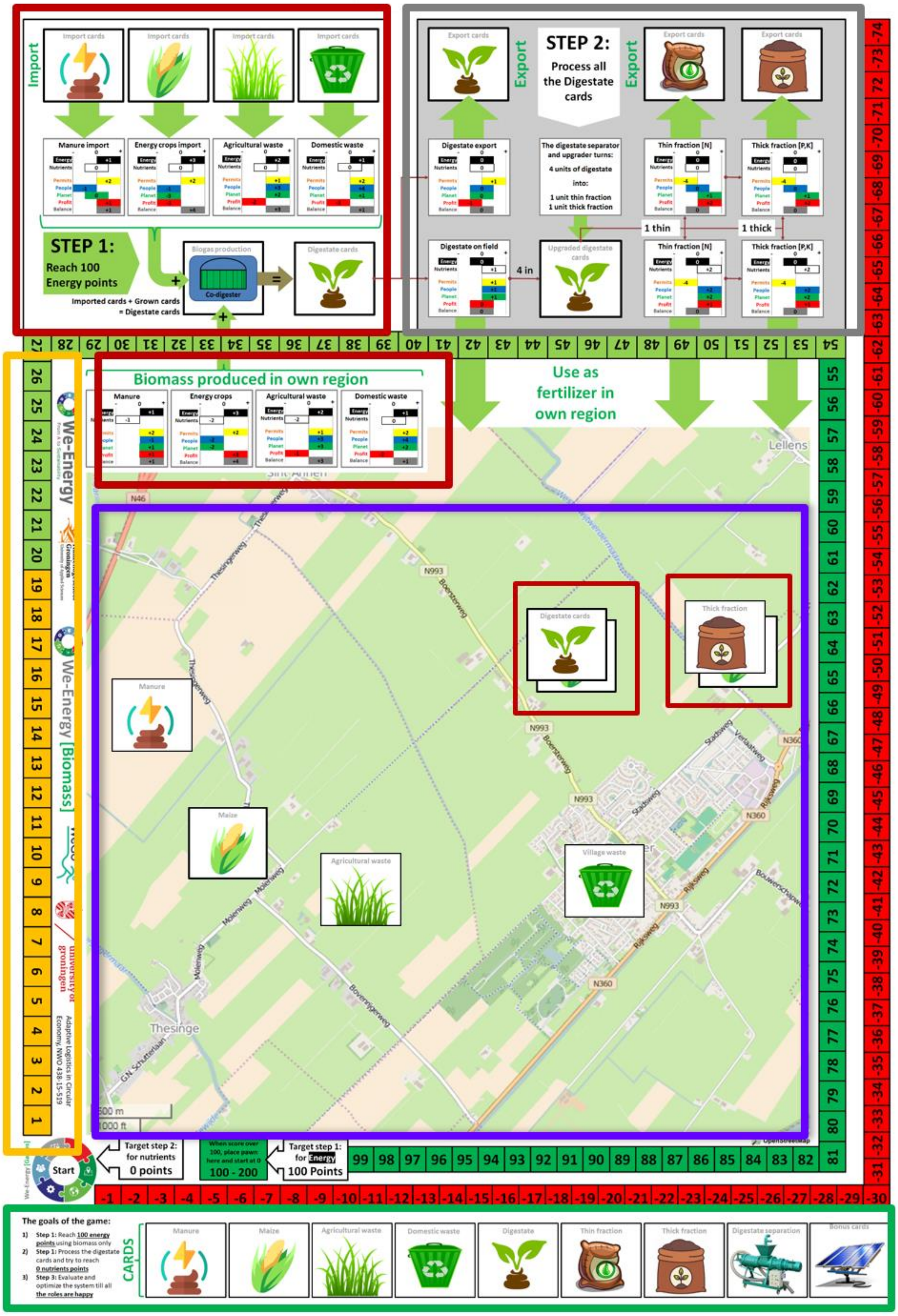
5. WORKSHOPS

We organized several workshops during the course of the ADAPNER project.

- In 2017 a workshop in which PHD students and researchers of both University of Groningen and Hanze University of Applied Sciences gave presentations on their biogas related research. The business partners of the project were also invited. In the discussion after the presentations it became clear that validation of the academic models with real live cases would be interesting.
- In 2018 two of the business partners, N.V. Nederlandse Gasunie and GasTerra BV organized a green gas workshop, to show the business side of biogas and green gas. Researchers and several students of the University of Groningen and Hanze University of Applied Sciences attended.
- In 2019 a third workshop was organized at the research location of DNVGL in Groningen. This time, in addition to a presentation from the ADAPNER team, also Bioclear Earth, Stercore and a representative of 'Stichting Duurzaam Dearsum', a small agricultural community, gave a presentation. The afternoon was finalized with a tour of a torrefaction installation and a workshop resulting in an advice for the community of Dearsum.

Furthermore, we presented a poster on the project at the public Transfuture festival in June 2019 at EnTranCe, the renewable energy living lab in Groningen.
As spin off of these encounters with businesses, several student thesis projects followed.





The full explanation, the map and the cards can be downloaded here:

www.wegosustainable.nl/adapner-game

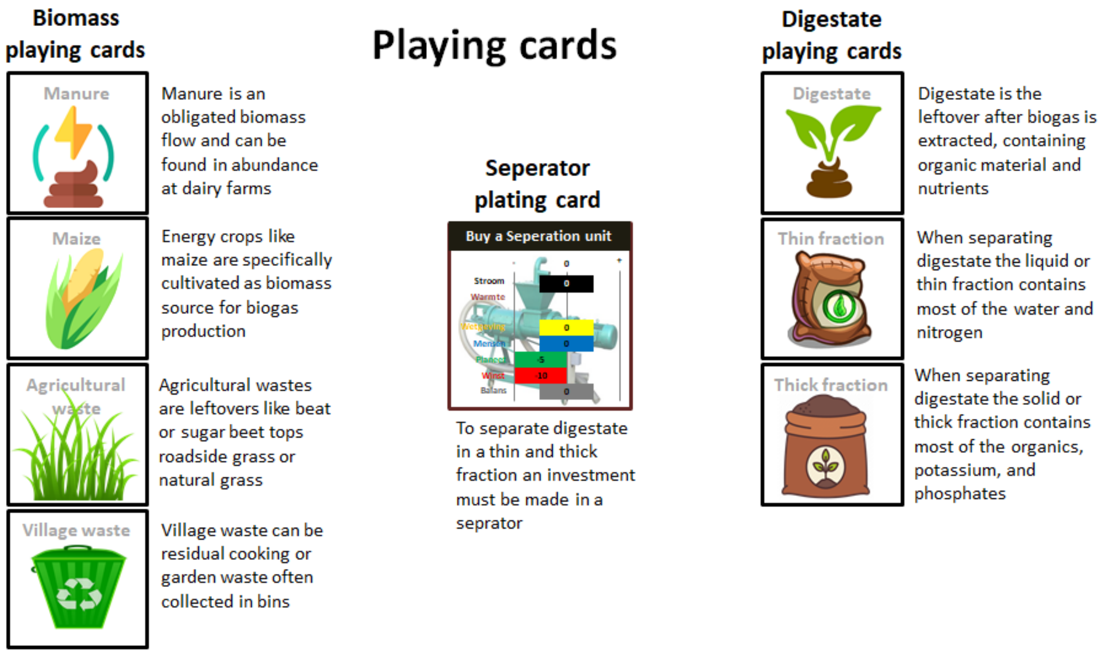
6. BIOGAS GAME

In the course of the project we developed an ADAPNER biogas game. It is based on the WE-energy Game, and is extended with results and insights from the research on Energy Logistics and Nutrients in the ADAPNER project.

The ADAPNER biogas game is the We-Energy game with a twist where a biomass scenario for a village can be devised providing all the required energy solely using biomass. During this quest there will be discussions to make and hurdles to overcome. You as a representative of the village must decide to go green or cheap or to have energy all the time every time or maybe even all of them. But whatever you do you must keep the stakeholders happy. So, your mission is to make a sustainable village run on local or imported biomass.

The game is based on the research done within the ADAPNER project combined with the serious gaming knowledge of the We-Energy game. However, a small footnote in advance; the game is based on research but the points in the game do not directly represent outcomes in the real world as every region or project differs and many impacts or consequences are combined in one representative single score. The scores should be regarded as an indication.

Within this game *balance* is the key, as was also discovered in the ADAPNER project. Where biogas can be a versatile and flexible energy carrier, it does require large amounts of biomass feedstock and with it (agricultural) space. Besides biogas the Anaerobic Digestion process also produces another (by)product called digestate, which contains the undigested organic material, water, and nutrients. These will also need to be used or processed in one form or another. Digestate, can be used as low-quality fertilizer, comparable to manure, however, there is a limit to how much nutrients land requires which is similar to the amount extracted. Furthermore, the process must be profitable and preferably good for the planet, the local inhabitance and the energy grid.



The sources of biomass and by-product available in the game.

A balance needs to be found between the elements and actors. The main elements of the game are listed below.

- For all the players the main goal is to reach a 100% renewable village by supplying enough energy using Anaerobic Digestion and managing the byproducts. To achieve this some additional hurdles must be overcome.
- The game can be played with up to 7 players per playing map. Each player has a different role: energy, nutrients, people, planet, profit, balance, permits. The first 2 roles are ADAPNER additions to the previously designed We-Energy game.
- The players will divide the roles of the game between themselves, where every player represent one of the roles. Each role has also an individual target to achieve.
- Three rounds will be played where the players: firstly, will need to supply the electricity in the village; secondly, will need to manage the digestate or byproduct of the process; and finally, optimize the system to satisfy all roles in the game.

7. OUTLOOK

The aim of the ADAPNER project is to bring up results for stakeholders in the green gas supply chain by giving insights into which biomass/biogas configurations may evolve, who may consume and produce what and where, and by sharing knowledge on development of novel logistics business models and organizations to serve a circular economy.

Achieving sustainability through Circular Economy not only provides new business opportunities, it is one of the developments that may radically transform business. Achieving steps towards a Circular Economy, however is uncharted territory. One must deal with legacy systems, institutions and organizations, while anticipating the effect of known and unknown developments. Overarching is the question which strategy – if not transition path – can our society develop to escape the lock-in of linear production and consumption, from resource to waste, and shift to a Circular Economy. The utilization of the knowledge acquired in the project can not only add value for the stakeholders involved in the biogas business ecosystem, but also for the society in general as already stated above.

The ADAPNER research has delivered new insights on how decentralized the agricultural and (bio-) energy sector can arrange their logistics and business concepts.

Based on the study and results of ADAPNER project the following topics for further research are proposed. It has become clear that the original ADAPNER ambitions on large green gas volumes originating from dairy farms are not realistic in view of the environmental impacts of such systems, or indeed of farming in itself. Thus, we think that the gas industry, the agricultural sector, academia and environmentalists can and should work together to see how this might still materialize. The outcome should respect boundary conditions such as minimal environmental impact, care for animal welfare, but also the global food requirements.

In particular we propose to broaden the scope of research to include the circular economy.

For the energy field this implies enlarging the scope from biogas, and green gas to include also renewable sources of energy and to include the energy carrier hydrogen as a means for transport and storage. For the farms, it means reduction of the use of artificial fertilizers, reduction of the use of imported livestock feed and an increased attention to recycling biomass materials on the farm itself. The production of energy on the farm, might improve the feasibility of circular farming (kringloop landbouw).

Challenges and opportunities for the logistics of supply chains in a circular economy

- What are the evolutionary growth paths for an adaptive infrastructure of biomass in the circular economy? Explore how the supply network and the logistics co-evolve – how does or can we adapt biomass logistics, and how does adaptable logistics shape the underlying biomass transport network?
- How do you optimize an adaptive biomass infrastructure/network in which multiple stakeholders are involved? Which parties should collaborate in co-operatives, where could supply chain co-operation be useful, and where are markets needed?

- How costs and yields are being calculated and divided over the stakeholders in the ecosystem? Especially, when supply of biomass and destination of digestate is seen from a circularity perspective.

Challenges and opportunities for the sustainable farm

- The challenges in the food production system are large. It is rather likely that in the coming decade large changes in Dutch agriculture and livestock keeping will take place. The changes provide the opportunity to integrate the energy production and food production on Dutch farms (both arable as livestock keeping). However, to do so it is essential that agricultural and energy specialists work together to develop such systems.
- On a larger scale also an evolution towards a circular/biobased economy is to be expected. This may mean that a larger need for biobased materials will emerge. The future availability of biomass for biogas production will be affected by this transition and should be taken into consideration.
- Our research showed that biogas production results in extra emissions of nitrogen. It seems that the choice of biomass used as source for biogas production has a large impact on the magnitude of the emissions. For future biogas production we should look for biomass sources with low nitrogen emissions.

Challenges and opportunities for Serious Gaming Approach

- The serious gaming approach is used for communicating the complexities of multi commodity systems to stakeholders. The ADAPNER biogas game (based on the We-Energy game for a specific village with a biogas scenario) could be expanded by looking at the nitrogen emissions and the carbon in the soil.
- Further development of the game should also pay attention to the value of the digestate, this is the by-product of biogas production. In the present game it can only be used as green fertilizer and it turns out that local use is not always possible.
- Serious gaming can be further developed for communicating complicated problems and systems, as researched in the ADAPNER project, to the general public. This can help to increase the understanding of topics surrounding the energy transition in the general public. Understanding is a prerequisite and precursor for willingness to change.

APPENDICES

A. Project Team ADAPNER

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5) Hanze University of Applied Sciences, Centre of Expertise Energy

B. Partners

N.V. NEDERLANDSE GASUNIE

Gasunie aims at contributing to the energy transition, accelerating the transition to carbon neutrality by 2050. Important steps to accelerate the energy transition are development and sharing of knowledge, and further research on promising techniques that could contribute to carbon neutrality. More and more it becomes clear that an integrated approach to electricity, gas and heat provides best chances to achieve carbon neutrality. One of the strong aspects of ADAPNER is its integrated approach. Where individual projects within ADAPNER study specific aspects related to biomass, biogas or hydrogen within a circular economy, there is a clear interlinkage between the projects within ADAPNER, thus covering and combining various aspects along the value chain.

Gasunie welcomed the opportunity to be involved in several Master students' research projects. One Project provided valuable insights how developments of future energy systems impact operational decisions on future hydrogen infrastructure. Another increased our understanding of how operating local, national and international energy systems interact with each other.

With ADAPNER, the Rijksuniversiteit Groningen successfully links science with business, resulting in not only scientifically sound research papers, but also in practically usable results.

Gasunie is a leading European energy infrastructure company whose core activities are gas transport and gas storage. We serve the public interest and facilitate the energy transition by providing integrated infrastructure services. We focus on value creation for our shareholder(s) and other stakeholders and apply the highest safety and business standards used in the sector. We believe in a sustainable future with a balanced energy mix and a lasting role for diversified gas. We believe that we serve our customers best with innovative gas and related infrastructure solutions

Kees Alberts, Senior Advisor Strategy, N.V. Nederlandse Gasunie

GASTERRA

The ADAPNER project from the onset had interesting elements for gas trading company GasTerra. For us, it entailed a multidisciplinary approach to the production of biogas or, after upgrading, green gas. Whereas in our view these are essential energy carriers in the carbon neutral energy system of the future, we are increasingly aware of the fact that sustainable production of biogas involves more than a carbon budget and economics. There are logistical issues, and there are other environmental footprints.

In GasTerra's view, green gas plays an essential role in the reduction of Dutch CO2-emissions. It has the major advantage that it can be introduced in the existing gas infrastructure without any modifications to it, and therefore, it is possible to reduce emissions in places where no other realistic alternative for natural gas exists.

GasTerra could provide the research partners with information on the functioning of the energy markets, and particularly on the role of flexibility in those markets. We welcomed the opportunity to be deeply involved in one of the Master students' research into the role of local storage, and felt that we could contribute regularly to the discussions in the project team.

Whereas GasTerra started out with a clear focus on biogas, we were quickly taken along the more essential strong point of the project. This is the awareness that there is a need for organic growth from current to future configurations. The attention paid to adaptability paid out, as the research opened up for and incorporated many elements that during the project became central in societal discussions, such as nitrogen emissions and the role of hydrogen in the energy system.

GasTerra is wholesale trader in natural gas and green gas. We buy gas as from domestic and foreign producers, as well as on the traded markets such as TTF. Our customer base consists of energy companies, industries, and other large gas consumers in Western Europe. GasTerra's contribution to the project was coordinated by Gerard Martinus.

Gerard Martinus, Project Leader Energy Transition

HOLTHAUSEN

Initially we started with this project to investigate possible business cases for our company regarding biogas and green gas. Our firm Holthausen is selling fossil gases for over 75 years, and we recognize the fact that fossil fuels and gases will be phased out.

Since we started as partner in the ADAPNER project in 2016, developments quickly followed one another. In parallel to the biogas strategy, we started developing a zero-emission strategy and at this moment in time (2020) that has become our focus.

The fit of our company with a biogas route turned out to be less than anticipated, partly because the government postponed biogas and green gas initiatives in her Fuel Vision (Brandstofvisie).

And then hydrogen crossed our path.

ADAPNER did help us to direct our thoughts, and I really think it contributed to our accelerated course towards zero emission. In 2020 Holthausen abandoned the green gas strategy altogether in order to focus on implementing hydrogen filling stations. We are continuously developing hydrogen business cases.

We thank all the project partners for their contribution and dedication. Although for us, as an SME, it did not lead to new products or services, it did help us along the way towards a more sustainable future.

HOLTHAUSEN GROUP

Stefan Holthausen
CEO Holthausen Groep

OTHER PARTNERS

Our desire to only distribute renewable gas in 2030 as a Distribution System Operator (DSO) is not achieved only by doing, but especially by doing the right things. Research in how this ambition can be achieved with all ecological and logistic challenges is key, that's why the graduation theses of the students within the ADAPNER project are important to us. In addition to the biogas value chain the configuration of equipment and efficient value chain in a local hydrogen application is relevant and will be used in actual project development; research taking into practice! By doing the right things.
RENDO (a DSO in the province of Drenthe and Overijssel)

N-TRA ENERGIETRANSITIE

Bastiaan Meijer, Duurzame (energie)gebiedsontwikkelaar

Groningen Seaports greatly enjoyed working with the master students, working on the (flexibility) market for hydrogen on our industrial sites. Their thesis work resulted in a wealth of new knowledge and helped us add value to our hydrogen infrastructure in future. Many thanks to Hans Wortmann and Martin Land for their inspiring guidance of these students.

GRONINGEN SEAPORTS

Henk Zwetsloot,
Manager digital innovation

C. Student Theses

In this appendix the thesis work of a selection of students is presented in more detail.
A complete list can be found at the end of this appendix.

A. NORTH SEA WIND POWER HUB CASE

THE ROLE OF HYDROGEN STORAGE FOR LARGE OFFSHORE WIND PARKS

The large-scale integration of renewable energy sources presents challenges related to balancing daily and seasonal mismatches between supply and demand. These mismatches, and insufficient transmission capacities are the main reason for the curtailment of high shares of available wind power. The production and storage of hydrogen from surplus wind power offers an attractive solution for these challenges. In this research the potential of a hydrogen infrastructure complementary to an electricity system is analyzed from a logistics perspective. For a large-scale offshore wind park the need for additional storage at the onshore and offshore side of a large transportation pipeline that connects the wind park to the mainland is examined. The results show that the pipeline, though important for day-to-day fluctuations, will not offer sufficient storage capacity to bridge seasonal differences. Furthermore, the results show that if the pipeline is sufficiently sized, additional storage is only needed at one side of the pipeline, which would limit the needed investments. Results show that the policy which determines what part of the available wind power is fed into the electricity grid and what part is converted into hydrogen has a significant influence on these seasonal storage needs. Lastly, our study shows that the capacity requirements for the electricity grid and the hydrogen infrastructure are interrelated, therefore optimal investments in the hydrogen infrastructure should be sought in the entire energy system rather than in isolation from the electricity system.

TAKE AWAY

- *The need for onshore storage will only emerge, given a sufficiently sized pipeline*
- *The hydrogen system should not be optimised in isolation from the electricity system*

Eric Dute

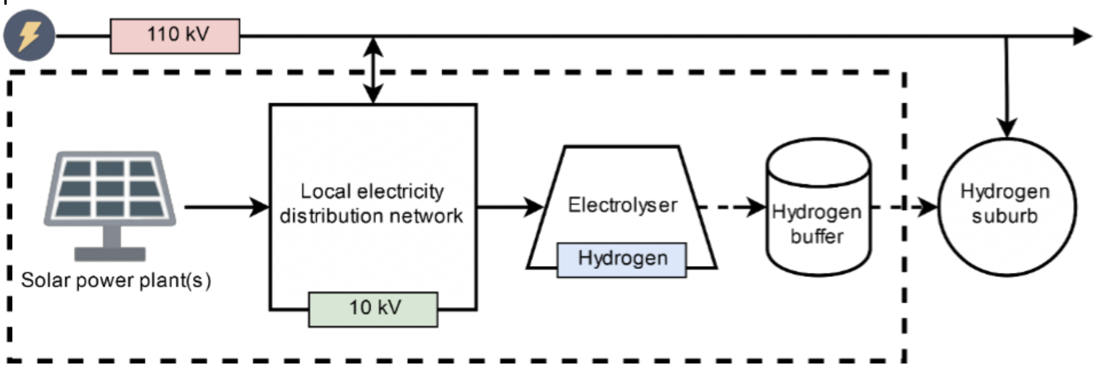
gasunie

2018 Master Thesis *North Sea wind power hub case: the role of hydrogen storage for large offshore wind parks,* University of Groningen, Faculty of Economics & Business, Operations Department; Host company N.V. Nederlandse Gasunie.
January 2019- August 2019: junior researcher ADAPNER

B. LOCAL E-GRID MANAGEMENT

MANAGING CONGESTION BY USING HYDROGEN PRODUCTION

The purpose of this study is to fill a gap in literature by analysing an innovative congestion management system, that uses electrolysis to relieve strain, caused by the increase in decentralized electricity production, from the electricity grid. By doing this from an operation management point-of-view, it is possible to zoom out of the technicalities and focus on analysing the bigger picture, based on the operations effects of different system configuration options.
For the system configuration analysis a model was developed, based on real-life data of the network operator. In this model, hourly solar production patterns, electricity demand, hydrogen demand, and electricity distribution grid constraints are used as fixed data inputs. Variables used in the simulations are: location of the electrolyser, priorities and handling of the electricity flows and solar park electricity output. The resulting scenarios are used to analyse the different possible configuration options in order to gain valuable insights and support real-life decision making.
The findings of this study show that, the location of the electrolyser in such a system is vital for relieving grid congestion. Next to that, it is shown that a mixture of electricity feedback and hydrogen production is needed to optimise the utilisation and efficiency of the electrolyser, together with the electricity load flow of the system. Finally, it is shown that the electrolyser capacity should not be determined by the highest peak in available electricity for hydrogen production. Instead of that, choosing the electrolyser capacity should go hand-in-hand with determining the optimal mix between electricity feedback and hydrogen production.



TAKE AWAY

- *Trade-off between optimised costs of this innovative congestion management system, versus the benefits of supplying houses with hydrogen, while relieving grid-congestion.*
- *Adjusting the balance between electricity feedback and hydrogen production to optimize ratio the electrolyser utilisation, efficiency and the electricity grid load flow time.*

Jelle Keizer

2019 Thesis *Local E-grid management: managing congestion by using hydrogen production*. University of Groningen, Faculty of Economics & Business, Operations Department; Host company N-tra

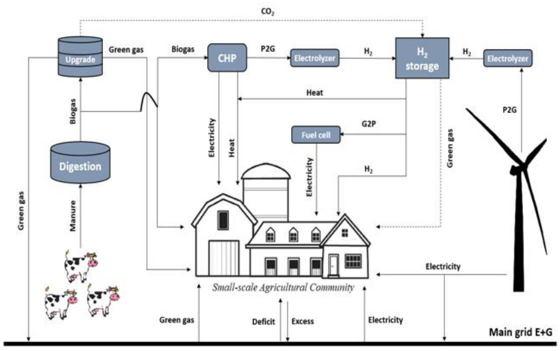
C. SELF-SUFFICIENT ENERGY SYSTEMS

A SCENARIO ANALYSIS OF KEY DESIGN DECISIONS FOR A SMALL-SCALE AGRICULTURAL COMMUNITY

Community initiatives for energy self-sufficiency are emergent, as they may benefit the individual community and contribute to the contemporary climate debate. This is also the case in the small-scale agricultural community Dearsum in the province of Friesland. This community aspires to become energy self- sufficient based on the renewable energy sources - biomass from manure and wind energy -within their community.
The main challenge is to integrate all the varying design considerations into a self-sufficient and economically viable design. Guidance hereon is lacking in the energy- and sustainability literature. Therefore, this study aims to provide guidance to communities like Dearsum and fill the existing gap in the literature, by analysing the 'key design decisions' for energy self-sufficient systems. A simulation approach is conducted, aimed at matching the supply of the renewable energy sources to the demand of a small-scale community. Inherent with this operational challenge is the application of buffers for which a grid connection, and hydrogen as an energy carrier, are applied. Based on feasible configurations of the renewables and buffer options, twelve unique scenarios are developed. Heuristics further determine the infrastructure and priorities of each scenario. These scenarios are modelled in MS-Excel on an hourly basis for a single year, yielding a performance economically and in the degree of self-sufficiency. Further experiments, altering the proportions of supply and demand, are conducted. The results show that a well-informed decision must be made on the application of biomass and wind tailored to the context-dependent demand. Balance is key. Combinations of biomass and wind with a buffer work best. Buffering through the grid is preferable, with hydrogen showing future potential. All in all, this research provides foundations for designing energy self-sufficient systems.

TAKE AWAY

- *Combinations of biomass and wind with a buffer work best*
- *Buffering through the grid is preferable, with hydrogen showing future potential*



Sander Kok

2019 Thesis: Dual Degree MSc. Operations Management *Self-sufficient energy systems: a scenario analysis of key design decisions for a small-scale community*, Dual degree University of Groningen – Newcastle University; Host organization: DNVGL and village of Dearsum

D. EFFECTS OF BIOGAS PRODUCTION ON THE CARBON CYCLE OF DAIRY FARMS

Anaerobic digestion (AD) is seen as part of a potential solution to decrease the methane emissions from dairy farms. The byproduct of anaerobic digestion is digestate, which can be used to replace manure as soil fertilizer. During anaerobic digestion, carbon is captured from the manure and therefore the digestate has a lower carbon content than animal manure. However, carbon plays an important role in maintaining soil properties such as the overall health and fertility.
The goal of this study is to gain insight in the carbon flows of a dairy farm and to study the effects of anaerobic digestion on these flows, on a farm-level. The carbon flows of a case study farm, with and without AD, were modeled using a substance flow analysis approach. The results show that the maximum reduction that can be achieved by anaerobic digestion on the farm is 24% of its total methane emissions. The results of the AD-system show that per hectare of farm land, 650 kg of carbon would be removed from the manure during the digestion. This results in a reduction in the carbon content of the digestate of 30% compared to the manure and a reduction of 16% in the total carbon input to the soil.
It can be concluded that by replacing animal manure with digestate for soil fertilization, the carbon input to the soil decreases profoundly on farm level, which might lead to long term effects on overall soil quality and the fertility of the farm lands.

TAKE AWAY

- *Biogas production reduces the carbon that is available for the soil*
- *Despite different decomposition rates, the effective organic carbon is still decreasing*
- *Main consequences: Decreasing SOC levels - less C-sequestration potential in grasslands and increased the risk of nitrogen leaching to the environment*

Brienne Wiersema

2020 Master Thesis, *System analysis of the carbon and nitrogen flows in dairy farming. A case study of the substance flows and the influence of anaerobic digestion on farm- level*. Environmental Sciences, University of Groningen

E. SELF-SUFFICIENCY AND CIRCULARITY IN THE DUTCH AGRICULTURAL SECTOR, USING AD

The agricultural sector is responsible for almost 7% of the total Dutch energy consumption and for 12% of the total Green House Gas emissions. Focus of this research is on dairy farmers producing their own energy from onsite manure using anaerobic digestion (AD), thereby improving sustainability and self-sufficiency. The level of sustainability is expressed with the use of three (sustainable impact) indicators; carbon footprint, environmental impact and cost.

This study focusses on matching the electricity demand of an average Dutch dairy farm with the biogas supply patterns of an AD system. Two different milking methods with very different demand patterns are used. Several scenario's, using different measures to increase the sustainability are developed. These measures are: addition of AD system, adding storage capacity, feeding energy back into the grid, making use of other energy sources and conversion of energy with the use of a unit.

The results indicate that a combination of the automated milking system in combination with biogas storage is the only scenario in which no additional energy is required; there is still a connection to the grid to export surplus energy.

This research shows the possibilities of matching energy demand and supply patterns with the sole use of locally obtained feedstock, thus stimulating circularity, to produce renewable energy. Thence, showing that there is potential in shaping the agricultural sector in a more circular and autarkic sector and thereby achieving the future set goals.

TAKE AWAY

- *It is possible to match energy demand and supply patterns with the sole use of locally obtained feedstock, thus stimulating circularity, to produce renewable energy.*
- *There is potential in shaping the agricultural sector towards a more circular and autarkic sector*

Tim Middelburg

2019 Master Thesis *Achieving energy self-sufficiency and circularity in the Dutch agricultural sector, using anaerobic digestion.* Environmental Sciences, University of Groningen

F. TO WHAT EXTENT CAN NITROGEN EMISSIONS BE MITIGATED ON DAIRY FARMS

Nitrogen makes up 79% of atmospheric air, however, the reactive compounds of this element, i.e. ammonia and nitrous oxide adversely affect different forms of life on Earth and have concerned humans in the past few decades. Around 86% of NH_3 and 70% of N_2O emissions in the Netherlands come from agricultural activities. Since the most recent approach of the Netherlands to reduce nitrogen emissions (PAS) has proven to be ineffective, new strategies need to be applied in order to overcome the problem of nitrogen.

The main goal of this research was to find methods that can be effective in reducing the nitrogen emissions from dairy farms; for this purpose, a number of scenarios have been developed that emit less reactive nitrogen compounds. Two scenarios with lowest amount of emissions have been introduced in the report. However, the amount of reduction achieved by some of these methods vary very greatly, some have even resulted in an increase of emissions. The characteristics of soil, i.e. pH and moisture and the surrounding environment conditions such as wind speed, temperature, precipitation and humidity are some of the parameters that affect the amount of emissions and the effectiveness of mitigating strategies.

The method that can reduce the emissions of NH_3 and N_2O with minimal controversy among different sources is artificial covering of the manure storage, which should be applied in all storage facilities of dairy farms, including the farms with an anaerobic digester installed. It should also be noted that anaerobic digestion will increase the emissions of both compounds and should not be used individually without a subsequent mitigating strategy.

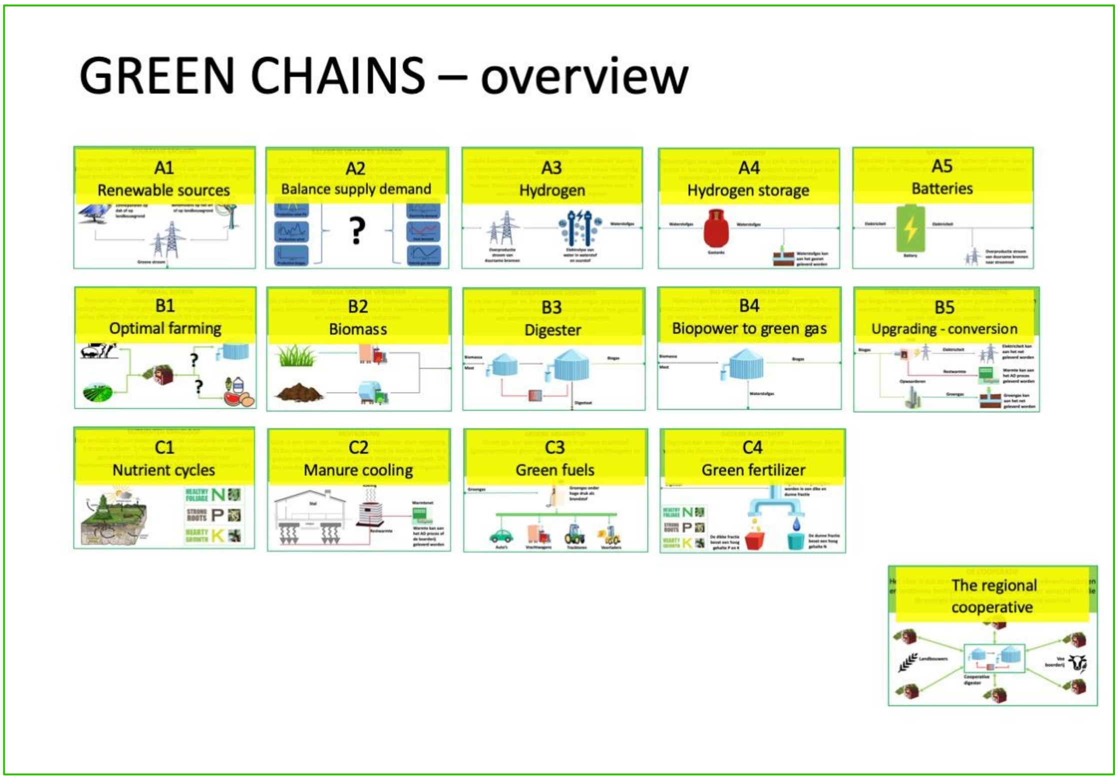
TAKE AWAY

- *It is important to include a mitigation strategy on each stage of manure management, i.e. housing facility, storage and land application.*
- *In order to reduce the nitrogen emissions, improved policies and regulations should be implemented: policies should be applied to smaller regions, i.e. provinces rather than the whole country.*

Sadaf Shoohanizad

2020 Master Thesis *To what extent can nitrogen emissions be mitigated on dairy farms: A case study using a symbiotic approach*, Sadaf Shoohanizad, Environmental Sciences, University of Groningen

G. LIST OF ALL STUDENT THESES RELATED TO ADAPNER



	THESIS	NAAM	
2016	Logistics of decentralized produced biogas to centralized upgrading facilities-Holthausen	Frank Nijborg	A1
2018	Assessing the eco-efficiency of several green gas supply chain configurations	Jasper Faber	A1
2018	A small hydrogen world: Dimensioning electrolyzer and fuel cell capacity to realize self- sufficiency	Emil Noordbruis	A3
2018	Buffering Configuration: An Essential Decision for The Biogas Supply Chain - GasTerra	Adrian Gilrandy	B4
2018	Buffer policies for hydrogen - Gasunie	Eric Dute	A4

	THESIS	NAAM	
2018	Buffer policies in reused biogas pipeline networks - Gasunie	Doeke Dijkhuizen	B4
2018	Electricity supply in Friesland with upgraded biogas and hydrogen from accumulated wind energy	Lysandros Georgos Martiko	B1
2019	Renewable gases in Future Energy Systems – Modelling Hydrogen and Biogas Storage Requirements to Balance Supply and Demand Mismatches - Gasunie	Rene Schuppert	A2
2019	Balancing cross-regional electricity grids with hydrogen: a modelling approach - Gasunie	Jorick van der Vlag	A2
2019	Local E-grid management: managing congestion by using hydrogen production - Rendo	Jelle Keizer	A5
2019	Harvesting Challenges for green biorefineries: a scenario analysis on harvesting patters in Green Biorefinery systems – Green Goods	Christiaan Hurulean	B2
2019	Self-sufficient energy systems: a scenario analysis of key design decisions for a small-scale agricultural community – DNVGL	Sander Kok	B1
2019	Defining and designing critical services for a multi-commodity energy business ecosystem which incorporates flexibility in energy – Groningen Seaports	Pieter Minnee	A1 A3
2019	Exploring a viable stand-alone flexible multi-commodity energy system in the North of the Netherlands – Groningen Seaports	Niels Radstaak	A1 A3-A4
2019	The feasibility evaluation of Dutch biogas adoption - A Case Study of Adopting Biogas in Dutch Wadden Sea Islands	Haoyue Deng	B4
2019	Achieving energy self-sufficiency and circularity in the Dutch agricultural sector,	Tim Middelburg	B3

	THESIS	NAAM	
	using anaerobic digestion. Focus on Dutch dairy farms		
2020	Utilizing excess heat from electrolysis in a district heating infrastructure. – Gasunie	Martijn Dam	A3
2020	Green hydrogen production through electrolysis: deployment of shortterm battery storage to increase electrolyzer utilization and manage buffer size - Rendo	Krijn Wermerbol	A4
2020	Hybrid heat pumps - demand side management - Rendo	Gerben Holvast	A2
2020	Certain uncertainties in the design of a hydrogen supply chain; A simulation study - Groningen Seaport	Thomas Agterhuis	A3
2020	The implications of dimensioning offshore wind supplied electrolyzers - a view on a high renewable energy supply capacity future – Groningen Seaports	Joey Nijnens	A3
2020	System analysis of the carbon and nitrogen flows in dairy farming. A case study of the substance flows and the influence of anaerobic digestion on farm-level	Brienne Wiersema	C1
2020	To what extent can nitrogen emissions be mitigated on dairy farms: A case study using a symbiotic approach	Sadaf Shoohanizad	B1
2020	Farming Cooperation: a pathway to energy self-sufficiency	Maarten Oolderink	A1/A5 B2/B5 C3

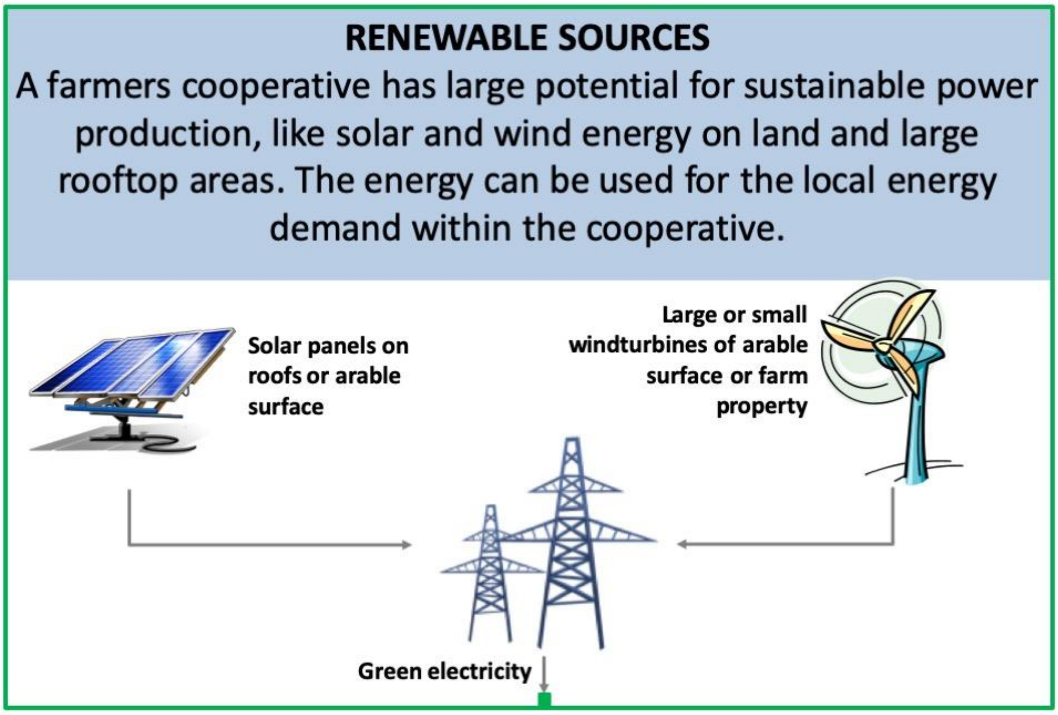
D. Infographic GREEN CHAINS

To gain insight in the complexity within the ADAPNER project, we divided the biogas production chain into individual components representing research topics. Visualizing the combination of individual components helped us to understand the complexity of the system reseached in the ADAPNER project. Furthermore, it showed how the different parts of the research are connected.

Read the texts in the top colored boxes of the pictures in this appendix sequentially to follow the story of the green chains.

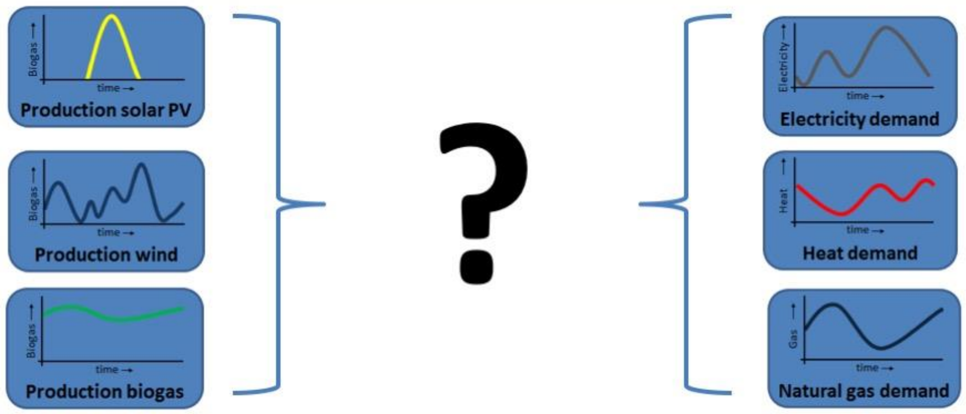
A digital copy of the infographic can be downloaded from the RUG website:

https://www.rug.nl/cope/projecten/adaptive-logistics-in-circular-economy-_adapner_



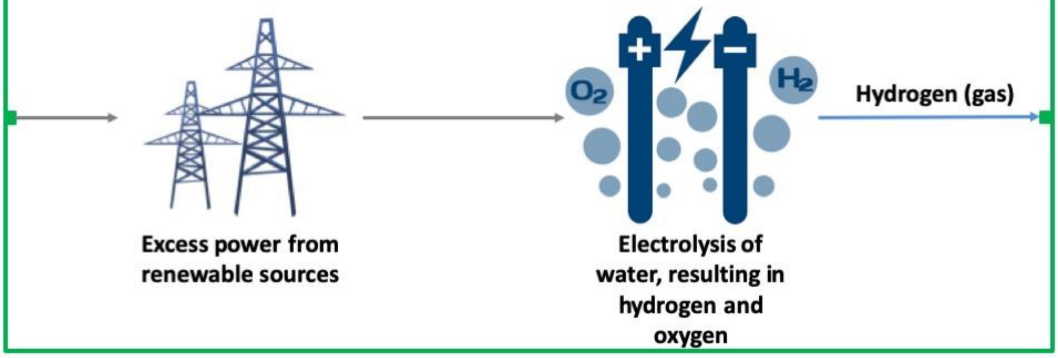
BALANCE IN DEMAND AND SUPPLY

Farm operations require different energy carriers and nutrients at different times. How can the demand and the supply be balanced for each moment in time?



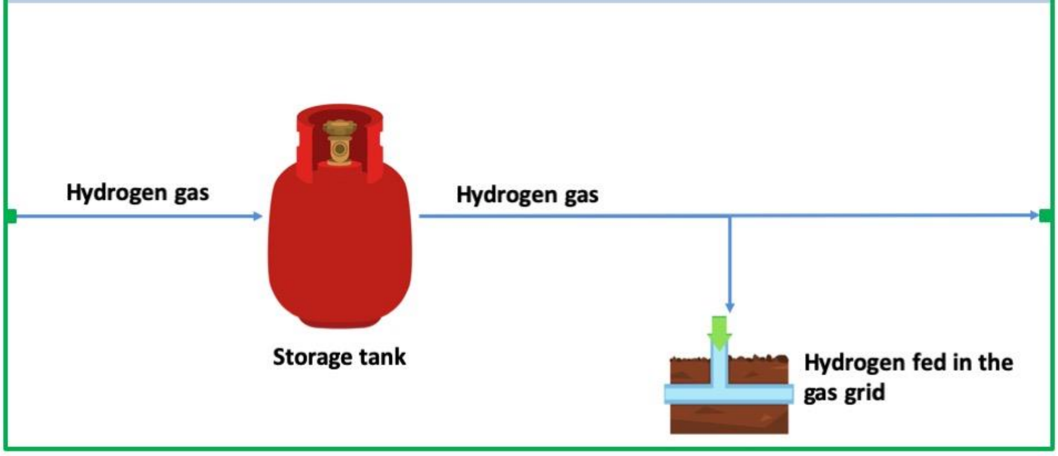
HYDROGEN

Local sources like PV pannels and windturbines can generate excess power at times when local demand is lower than production. The excess power can be converted into hydrogen. Hydrogen can be used in many different processes.



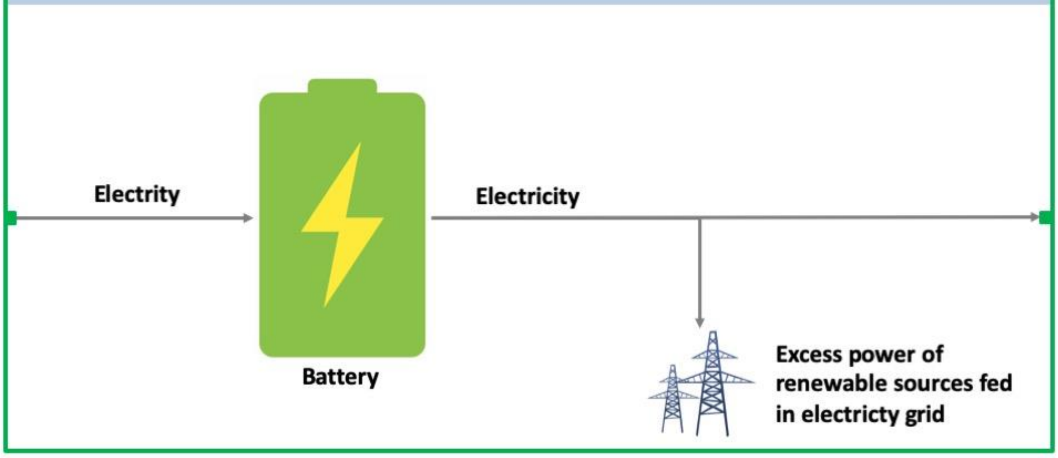
HYDROGEN

Hydrogen (gas) can be stored in storage tanks for later use in the biogas process or as fuel. In future, hydrogen can be injected in the gas grid.



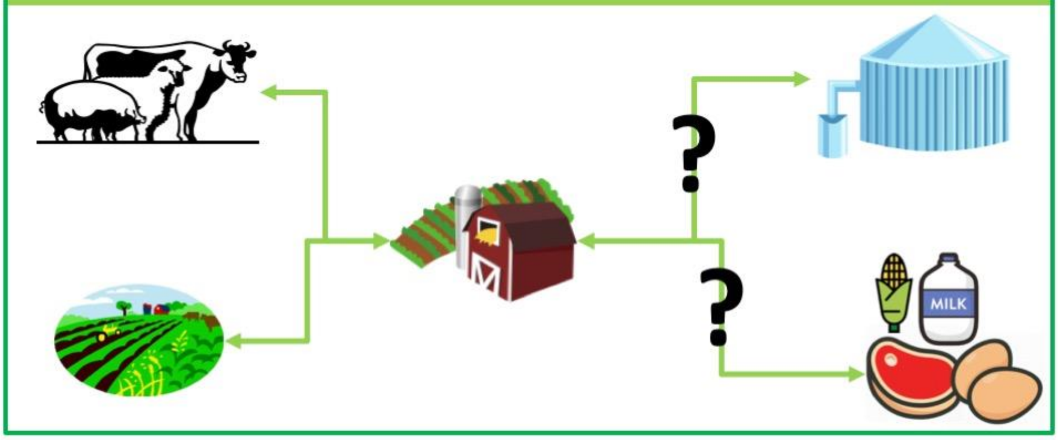
BATTERIES

Electricity can be stored in batteries for later use in the biogas process.



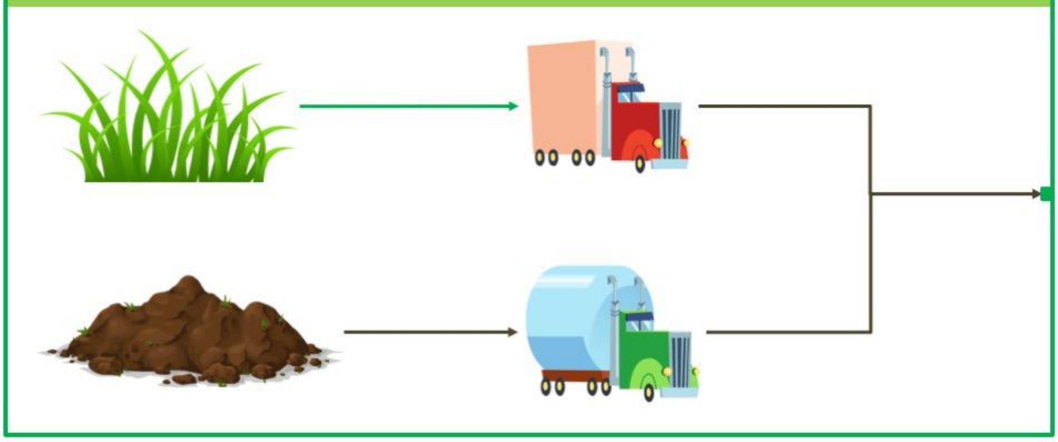
OPTIMAL FARMING

The operation of farms and systems at farms change continuously, often instigated by changing regulation or environmental requirements. What are the effects on the business operation and on total biomass chains?



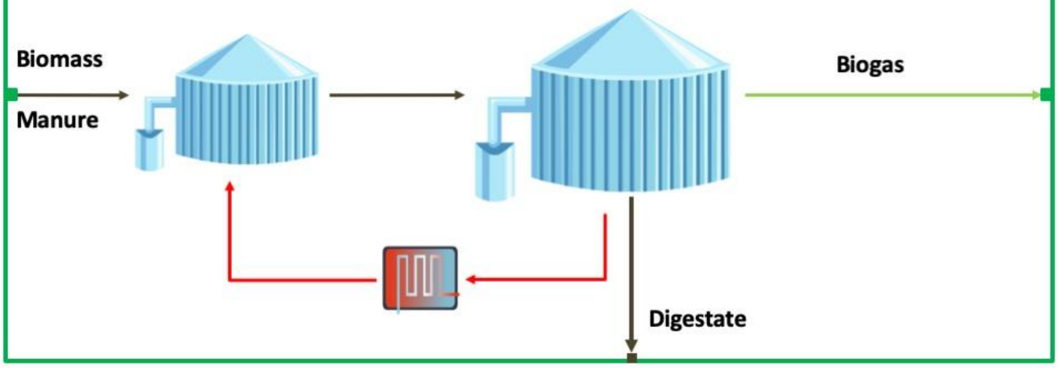
BIOMASS FOR DIGESTING

The cooperative uses *local* biomass residues like road side grass, beet root tops and manure to minimise transport of biomasss.



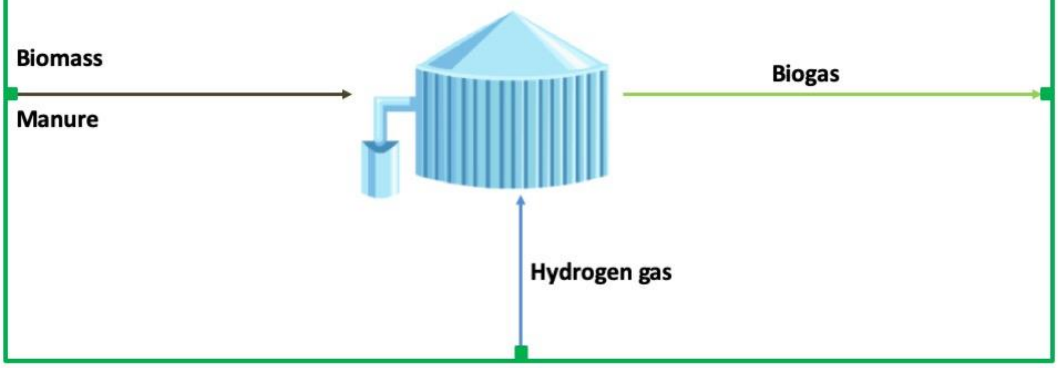
THE COOPERATIVE DIGESTER

In the bio-digester and the 2nd digester, biogas can be produced in the most optimal way by using (local) residual waste or residual heat.



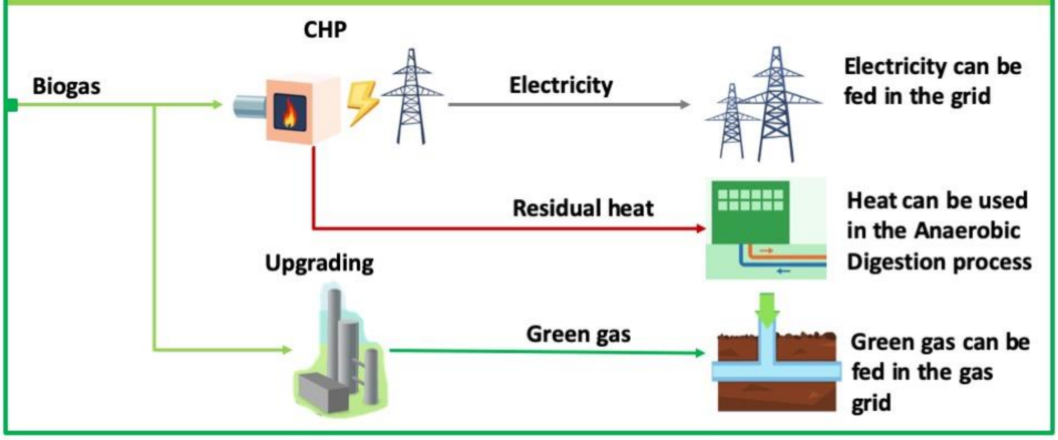
BIO-POWER TO GREEN GAS

Hydrogen can be injected in a bio-digester to enhance biogas production by additional conversion of carbondioxide into methane and water. The methane content of the biogas increases, and so does the energy production of the digester.



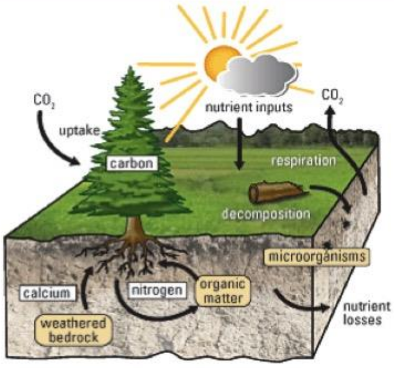
UPGRADING AND CONVERSION OF ENERGY

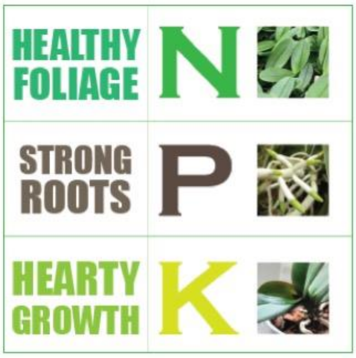
Biogas can be upgraded to green gas and converted to electricity or heat for local energy use. Excess green gas or electricity can be fed in the grid.



NUTRIENT CYCLES

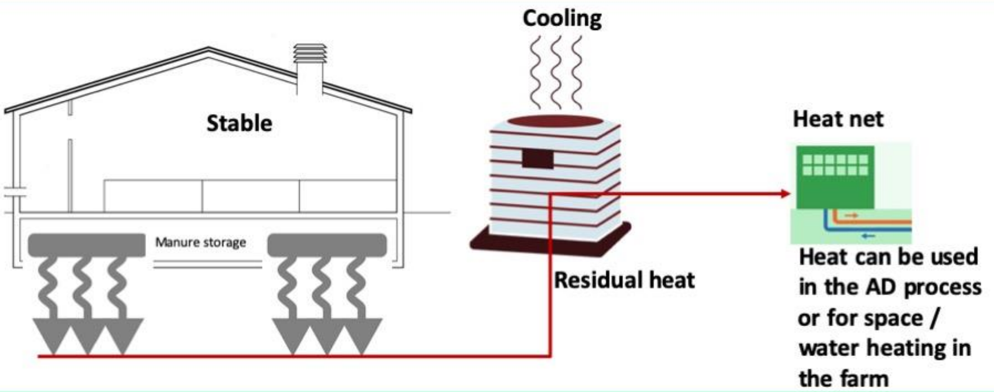
What is the flow of nutrients within a farm or cooperative? What part of the cycle can be within the system boundaries, what is import or export. Digestion can be used to produce several substitutes for manure. The research question is which substitute fits best, considering the closing of nutrient cycles.





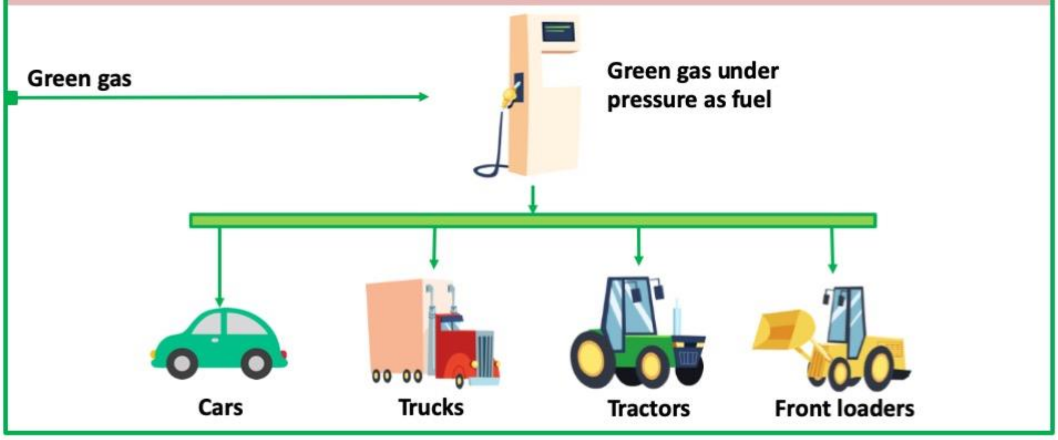
MANURE COOLING

Unprocessed manure is a source of GHG emissions. By cooling the stored manure below 4 degrees, the decomposition of manure can be prevented, resulting in decreased emissions and increased organic material for the digestion process.



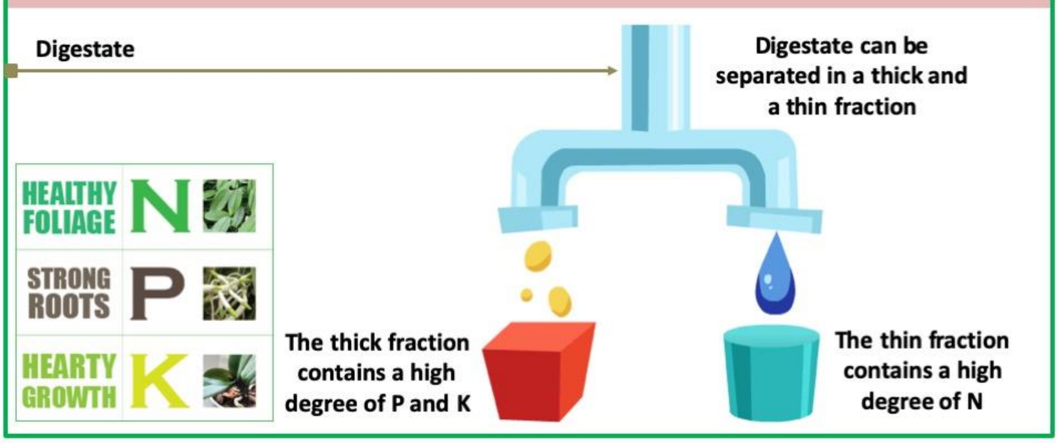
GREEN FUELS

Green gas can be converted in green fuels (or compressed green gas) for heavy-duty farm vehicles.



GREEN FERTILIZER

Digestate can be upgraded to green fertilizer. After separating the thick fraction from the thin (liquid) fraction, the liquid fraction is upgraded.



E. Publications & presentations

Scientific contributions

Fokkema, J. E., Land, M. J., Coelho, L. C., Wortmann, H., & Huitema, G. B. (2020). A continuous-time supply-driven inventory-constrained routing problem. *Omega, 92, 102151.*

Fokkema, J.E., Combining biogas, wind and solar energy to match local demand: The production-storage trade-off",
Presentation at POMS (Production and Operations Management Society) conference in May 2019

Dute, E.F., Fokkema, JE., Land, M.J., Wortmann, J.C., Douwes, M. The role of hydrogen storage for large offshore wind parks: the North Sea Wind Power Hub case
Submitted to Renewable & *Sustainable Energy Reviews August, 2019*

Fokkema, JE., Uit het Broek, M.A.J, Schrotenboer, A.H., Land, M.J., Foreest, N.D.
Solving grid congestion problems with storage for decentralized solar parks
Submitted to OMEGA June, 2020

Fokkema, JE., Land, M.J., Wortmann, M.J., Huitema, G.B., Storage flexibility for electricity grid congestion management: The distribution - storage capacity trade-off
Submitted to Applied Energy July, 2020

Fokkema, JE., Land, M.J., Wortmann, M.J., Huitema, G.B. Combining biogas, wind and solar energy to match local demand: The production--storage trade-off
Submitted to Applied Energy June, 2020

Hoang DL, Davis C, Moll HC, Nonhebel S. Impacts of biogas production on nitrogen flows on Dutch dairy system: Multiple level assessment of nitrogen indicators within the biogas production chain. *J Ind Ecol*. 2019;1–16. https://doi.org/10.1111/jiec.12956

Hoang, D. L., Moll, H., Davis, C., & Nonhebel, S. (2019). Towards a circular bio-economy: Evaluating ideals versus constraints for biogas feedstock availability in the Netherlands. Abstract from 2019 Conference ISIE, Beijing, China.

Hoang, D.L.; Davis, C.; Moll, H.C.; Nonhebel, S. Can Multiple Uses of Biomass Limit the Feedstock Availability for Future Biogas Production? An Overview of Biogas Feedstocks and Their Alternative Uses. *Energies 2020, 13, 2747*. https://doi.org/10.3390/en13112747

Hoang DL, Davis C, Moll HC, Nonhebel S. Impacts of biogas production on nitrogen flows on Dutch dairy system: Multiple level assessment of nitrogen indicators within the biogas production chain. *J Ind Ecol*. 2019;1–16. https://doi.org/10.1111/jiec.12956

F. Pierie, C.E.J. van Someren, S.N.M. Kruse, G.A.H. Laugs, R.M.J. Benders, H.C Moll. Local versus central balancing of the electricity grid: Focused on analyzing the effectiveness and costs of local balancing within a case of an average village in the Netherlands.
Submitted to Sustainable Energy, Grids and Networks 2020-06-11

Hoang, D.L.; Moll, H.C.; Nonhebel, S. Impact of biogas production on carbon influxes to soil of a Dutch dairy farm. *Expected submission date: 31/07/2020*

Hoang, D.L.; Moll, H.C.; Nonhebel, S. Multi-criteria assessment on biomass for biogas production on Dutch dairy farms. *Expected submission date: 15/11/2020*

Non-scientific publications and activities

- Poster A4 transfuture festival June 12th, 2019 at EnTranCe
  https://www.dinalog.nl/wp-content/uploads/2019/07/POSTER-Juni-2019-Adapner-1.pdf
- Serious game : BioGas Game: T*he full explanation, the map and the cards can be downloaded here: www.wegosustainable.nl/adapner-game*
- Podcast-soundcloud: November 2019
  https://soundcloud.com/studium-generale-2/ask-a-scientist-te-veel-stikstof-wat-nu

Colophon

Adaptive Logistics in Circular Economy

End report of the ADAPNER project (NWO 438-15-519).

https://www.dinalog.nl/project/adapner/

https://www.rug.nl/cope/projecten/adaptive-logistics-in-circular-economy-_adapner_

Date: June 2020

Authors: Project team ADAPNER

Editor: Tineke van der Meij

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