

<u>Output T2.2</u> **Pre-feasibility Study Austria**

WP T2: Project main output

December, 2022

Project co-funded by the European Union funds (ERDF, IPA) www.interreg-danube.eu/danup-2-gas



PROJECT WEBSITES - USBIT - AND L



DOCUMENT CONTROL SHEET

Project reference	
Full title of the project	Innovative model to drive energy security and diversity in the Danube Region via combination of bioenergy with surplus renewable energy
Acronym	DanuP-2-Gas
Programme priority	Priority 3
Programme priority specific objective	SO 3.2 Improve energy security and energy efficiency
Duration	01.07.2020 - 31.12.2022
Project website	www.interreg-danube.eu/danup-2-gas
Project coordinator	TZE

Short Description

The document contains the prefeasibility study for Power2Gas (P2G) hubs for Austria, in three basic configuration options: collocated with renewable energy or industrial plants or as a greenfield investment. Optimization tool V2.0 is used for obtaining all the results in this pre-feasibility study.

Document Details	
Title of document	Pre-feasibility Report Austria
Action	WP T2 Transnational Infrastructure and Biomass assessment & Pre- feasibility Studies
Deliverable	Output T2.2
Delivery date	December 2022

Version			ersion Date Author		Organization	Description	
V1	12.12.2022	Darja Markova	EI-JKU	1 st version			



IMPRINT

This document is issued by the consortium formed for the implementation of the DanuP-2-Gas project by the following partners:

- LP Technology Centre Energy University of Applied Sciences Landshut (DE)
- ERDF PP1 Energy AGency of Savinjska, Koroška and Šaleška Region (SI)
- ERDF PP2 Tolna County Development Agency Nonprofit Public Ltd.(HU)
- ERDF PP3 Energy Institute at the Johannes Kepler University Linz (AT)
- ERDF PP4 Black Sea Energy Research Centre (BG)
- ERDF PP5 URBASOFIA SRL (RO)
- ERDF PP6 Deggendorf Institute of Technology (DE)
- ERDF PP7 National Recycling Agency of Slovakia (SK)
- ERDF PP8 Institute of Technology and Business in České Budějovice (CZ)
- ERDF PP9 MAHART-Freeport Co. Ltd (HU)
- ERDF PP10 International Centre for Sustainable Development of Energy, Water and Environment Systems (HR)
- ERDF PP11 Energy Institute Hrvoje Požar (HR)
- ERDF PP12 University of Zagreb Faculty of Electrical Engineering and Computing (HR)
- IPA PP1 Regional Agency for Socio Economic Development Banat Ltd (RS)

Responsible Partner for the compilation of this document

ERDF PP3 Energy Institute at the Johannes Kepler University Linz (AT)



PROJECT WEBSITES - USED - PACINE



CONTENT

1. METHODOLOGY	7
2. Case Studies	7
3. Results	7
3.1 Summary	7
3.1 RESULTS WITH CURRENT GAS PRICES WITHOUT SUBSIDIES	8
3.2 RESULTS WITH CURRENT GAS PRICES WITH SUBSIDIES	11
3.3 RESULTS WITH INCREASED GAS PRICES WITHOUT SUBSIDIES	14
3.4 RESULTS WITH INCREASED GAS PRICES WITH SUBSIDIES	17
4. Conclusions	19



1. METHODOLOGY

Infrastructure and Biomass databases for Austria given within the Atlas are prerequisite for any use of Optimization tool (OT). After the selection or manual entry of sources, connection points, etc. is done, optimization of P2G hub sizing and operation with the OT can be started.

2. CASE STUDIES

Three locations for potential P2G investment are considered¹. The first one is industrial plant near Vienna (noted as IP), the second one is a wind park in Styria (noted as REP). The third one is a greenfield location (noted as GF) in south-eastern part of Austria.

3. RESULTS

3.1SUMMARY

For each one of case studies (IP, REP and GF), variations of natural gas prices and subsidies are considered. In Table 1, the overview about the calculated business cases are given:

		e natural gas / atural gas« pric		Higher natural gas / »renewable natural gas« prices				
	No increase	No increase	No increase	10x increase	10x increase			
	IP	REP	GF	IP	REP	GF		
No subsidy	Hydrogen	Hydrogen	Hydrogen	Renewable	Renewable	Renewable		
	production	production	production	gas and	gas and	gas and		
	Fig. 1	Fig. 2	Fig. 3	biochar	biochar	biochar		
				production,	production,	production,		
				Fig. 7	Fig. 8	Fig. 9		
Subsidy of	Hydrogen	Hydrogen	Hydrogen	Renewable	Renewable	Renewable		
50%	production	production	production	gas and	gas and	gas and		
	Fig. 3	Fig. 5	Fig. 6	biochar	biochar	biochar		
				production,	production,	production,		
				Fig. 10	Fig. 11	Fig. 12		

Table 1. Simulation cases

Every solution from Table 1 is obtained using the simulation period of one year. Increases of natural gas / »renewable natural gas« prices noted as "10x increase" refer to the increases in the "Gas price without grid/operator fees, including taxes" which is an attribute in the Gas prices section of the Excel interface of the OT. Its conservative value ("1x") is set to 0,0468 \in /kWh for both winter and summer period. Grid fees and taxes of gas price are not affected with this increase. Hydrogen selling price is set to 10 \in /kg. All set inputs for the case studies may be checked in the annexed OT Excel interface documents for all the

¹ In case publicly available data wasn't available, estimations have been used instead.



considered 12 scenarios. They are given in a zip file with Excel names clearly indicating each of the 12 case studies. Detailed results of simulations are given in the following sections.

3.1 RESULTS WITH CURRENT GAS PRICES WITHOUT SUBSIDIES

Figures 1 to 6 shows results for cases without additional subsidies and current / conservative natural gas / »renewable natural gas prices. Best investment option is to produce hydrogen via electrolysis and sell the by-product oxygen, as well as to produce »renewable natural gas« in the IP case. The production of biochar, for example, wouldn't be economically feasible for all three cases as shown in Figures 1 to 3.

nves	tment specifications				
	Element	Cost		Size	
	Dry anaerobic digestor	0,00	I	0,000000	kgals
	Wet anaerobic digestor	0,00	I I	0,000000	k g/s
	Dry biomass to biochar plant	0,00	I	0,000000	kgals
	Wet biomass to biochar plant	0,00	I I	0,000000	k g/s
	Combined heat and power (CHP)	0,00	I	0,00	kWe
8	Carbon capture plant	0,00	I I	0,000000	molfs
^o rocesses	Gasification + water gas shift plant	0,00	I	0,000000	kgals
2	Methanation reactor	0,00	I	0,000000	molfs
۵.	Electrolyser	5 373 677,25	I I	2 149,47	k₩
	Demineralizer	535,97	1	5,359654	
	Precipitation collector	2 000,00	1	1 000,00	
	Heat exchanger	18 518,52	I I	185,19	kW –
	Gas compressor station	0,00	I I	0,0000	kWe
	Total for processes	5 394 731,73	1		
	Dry biomass storage	0,00	I I	0,00	kg
	Wet biomass storage	0,00	I I	0,00	kg
	Biochar storage	0,00	1	0,00	kg
	Biogas storage	0,00	I I	0,00	kg
96	Hydrogen storage tank	0,00		0,00	kg
Storages	Oxygen storage tank	0,00		0,00	
t5	Methane storage tank	0,00	1	0,00	kg
	Syngas storage tank	0,00	1	0,00	kg
	Carbon dioxide storage tank	0,00	1	0,00	kg
	Water storage tank	0,00	1	0,00	m³
	Total for storages	0,00	I		
ent	Electrical connection	0,00	1		MW
actic Je m	Gas connection	0,00	1	0,00	MW
Connections enlargement	Water connection	0,00	1	0,35	m³h
ŏ ē	Total for connections	0,00			
	Total investment	5 394 731,73	1		
	Payoff period	11,94	years		

		Cost		Amount	
	Produced by REP	0,00	I.		MWh
≥	Consumed by IP	41 920 000,00		320 000.00	MWh
Electrical energy	Net consumption without investment	41 920 000,00	i.	320 000,00	MWh
<u></u>	Mean peak power without investment	2 191 780,82	i.	36,53	МW
ti ti	Consumed by P2G	2 504 073,66	i.	19 115,07	MWh
<u>e</u>	Net consumption with investment	44 424 073,66	Ì	339 115,07	M₩h
	Mean peak power with investment	2 322 708,16	I.	38,71	м₩
	Produced by REP	0,00	I.	0,00	MWh
	Produced IP	0,00	L	0,00	MWh
Heat	Net production without investment	0,00	L	0,00	MWh
	Consumed by P2G	0,00	L	-1622,22	MWh
	Net production with investment	0,00	I.	1 622,22	M₩h
6 g	Produced by REP	0,00	L	0,00	MWh
E B	Consumed by IP	878 902,36	L	11 630,00	MWh
Gas (methane) to/from the grid	Net consumption without investment	878 902,36	L	11 630,00	MWh
	Produced by P2G	0,00	L	0,00	MWh
õ õ	Net consumption with investment	878 902,36	L	11 630,00	M₩h
) (stor	Water from the grid consumed by P2G	4 209,00	L	2 475,88	m³
Water	Collected precipitation consumed by P2G	nła	I I	819,00	m³
10	Dry biomass bought	0,00	Ι	0,00	t
병훈	Wet biomass bought	0,00	L I	0,00	t
Input materials	Biochar bought	0,00	L I	0,00	t
	Total cost of input materials	0,00	1		
	Hydrogen sold (in bottles)	3 650 000,00	1	365,00	t
<u>a</u>	Oxygen sold (in bottles)	36 500,00	I.	365,00	t
Additional sales	Methane sold (in bottles)	0,00	L I	0,00	t
° ∛q	Biochar sold	0,00	L	0,00	t
·	Total revenue from additional sales	3 686 500,00	I.		
	Residue from dry anaerobic digester	0,00	L	0,00	t
S	Residue from wet anaerobic digester	0,00	I.	0,00	t
Residues	Tar from gasification + water gas shift plan	0,00	L	0,00	t
Ř	CO2 emitted	0,00	L	0,00	t
	Total cost of residues	0,00	L		
	Total operational cost without invest	44 990 683,18	I.		
	Total operational cost with investme	43 943 393,19	L		
	Savings with introduction of P2G	1 047 290,00			

Fig. 1 Results for optimal P2G hub next to IP with conservative prices of natural gas / »renewable natural gas« and no subsidy.

This business case shows optimal scenario for current prices of natural gas / »renewable natural gas« and Industrial Plant (IP) nearby (see Fig. 1). It is recommended to produce hydrogen (it reaches also the maximum in this case). As no biochar is produced means that its production is not recommended, because it wouldn't be economically feasible. For implementation of such a business case investments at around 5 Mio. Euros are needed. The calculated payoff period would be around 12 years.



DanuP-2-Gas

nves	tment specifications				
	Element	Cost		Size	
	Dry anaerobic digestor	0,00	1	0,000000	kg/s
	Wet anaerobic digestor	0,00	1	0,000000	kg/s
	Dry biomass to biochar plant	0,00	1	0,000000	kgals
	Wet biomass to biochar plant	0,00	1	0,000000	kgals
	Combined heat and power (CHP)	0,00		0,00	kWe
5	Carbon capture plant	0,00	1	0,000000	mol/s
Processes	Gasification + water gas shift plant	0,00	1	0,000000	kg/s
ě	Methanation reactor	0,00	1	0,000000	mol/s
۵.	Electrolyser	5 373 677,25	1	2 149,47	k₩
	Demineralizer	5 000,00		50,000000	mol/s
	Precipitation collector	2 000,00		1 000,00	m²
	Heat exchanger	18 518,52		185,19	k₩
	Gas compressor station	0,00	1	0,0000	kWe
	Total for processes	5 399 195,77			
	Dry biomass storage	0,00	1	0,00	kg
	Wet biomass storage	0,00	1	0,00	kg
	Biochar storage	0,00	1	0,00	kg
	Biogas storage	0,00	1	0,00	kg
68	Hydrogen storage tank	0,00	1	0,00	kg
Storages	Oxygen storage tank	0,00	1	0,00	kg
ţ,	Methane storage tank	0,00	1	0,00	kg
	Syngas storage tank	0,00	1	0,00	kg
	Carbon dioxide storage tank	0,00		0,00	kg
	Water storage tank	3 903,54		177,43	m³
	Total for storages	3 903,54			
a t	Electrical connection	0,00		0,00	MW
Connections enlargement	Gas connection	0,00		0,00	MW
Connections enlargement	Water connection	0,00		3,25	m∛h
8 E	Total for connections	0,00			
	Total investment	5 403 099,31			
	Payoff period	9,94	years		

		Cost	Amount	
	Produced by REP	580 750.00	6 900.00	h dù t (b
Electrical energy	Consumed by IP	0.00		MWh
	Net consumption without investment	-580 750,00	-6 900,00	
6	Mean peak power without investment	0.00		MW
2	Consumed by P2G	2 504 073.66	19 115.07	
ect	Net consumption with investment	1 609 551.23	12 215,07	
Ξ	Mean peak power with investment	128 968.25		M₩
	Produced by REP	0.00		MWh
	Produced IP	0,00		MWh
Heat	Net production without investment	0.00		MWh
	Consumed by P2G	0,00	-1622,22	
	Net production with investment	0.00	1 622,22	
о п	Produced by REP	0,00		MWh
aria	Consumed by IP	0.00		MWh
Gas (meth: offrom the	Net consumption without investment	0,00		MWh
	Produced by P2G	0.00		MWh
	Net consumption with investment	0.00		MWh
	Water from the grid consumed by P2G	4 209.00	2 475,88	
Water	Collected precipitation consumed by P2G	n/a I	819,00	
	Dry biomass bought	0.00	0,00	
백	Wet biomass bought	0.00	0.00	
af a	Biochar bought	0.00	0.00	t
Additional Input & Gas (methane) sales materials a to/from the grid	Total cost of input materials	0.00		
	Hydrogen sold (in bottles)	3 650 000.00 1	365.00	t
	Oxygen sold (in bottles)	36 500.00	365.00	t
ales I	Methane sold (in bottles)	0,00	0,00	t
N R	Biochar sold	0.00	0.00	t
-	Total revenue from additional sales	3 686 500,00		
	Residue from dry anaerobic digester	0.00	0,00	t
s	Residue from wet anaerobic digester	0,00	0,00	t
ign	Tar from gasification + water gas shift plant	0,00	0,00	t
Residues	CO2 emitted	0,00	0,00	t
_	Total cost of residues	0,00		
	Total operational cost without investm	-580 750,00		
	Total operational cost with investmen			
	Savings with introduction of P2G	1 363 021.51	_	

Fig. 2 Results for optimal P2G hub next to REP with conservative prices of natural gas / »renewable natural gas« and no subsidy.

For this scenario with current prices of gas and without subsidies, P2G hub next to renewable energy plant shows similar results as the previous scenario (see Fig. 2). Using renewable electricity to produce hydrogen and also oxygen as by-products and selling it would be highly profitable and the limit is reached in the maximum allowed amount of daily hydrogen and oxygen sales. Payoff for this business case would be around 10 years. Biochar production is not recommended.



Inve	tment specifications			
	Element	Cost	Size	
	Dry anaerobic digestor	0,00	0,000000	k g/s
	Wet anaerobic digestor	0,00	0,000000	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kg/s
	Wet biomass to biochar plant	0,00	0,000000	k g/s
	Combined heat and power (CHP)	0,00	0,00	kWe
ø	Carbon capture plant	0,00	0,000000	mol/s
889	Gasification + water gas shift plant	0,00	0,000000	k g/s
Processes	Methanation reactor	0,00	0,000000	mol/s
a.	Electrolyser	5 373 677,25	2 149,47	kW
	Demineralizer	514,60	5,145962	mol/s
	Precipitation collector	2 000,00	1 000,00	m²
	Heat exchanger	18 518,52	185,19	k₩
	Gas compressor station	0,00	0,0000	kWe
	Total for processes	5 394 710,36		
	Dry biomass storage	0,00	0,00	kg
	Wet biomass storage	0,00	0,00	ka
	Biochar storage	0,00	0,00	kg
	Biogas storage	0,00	0,00	kg
68	Hydrogen storage tank	0,00	0,00	kg
Storages	Oxygen storage tank	0,00	0,00	ka
5	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	227,33	10,33	m³
	Total for storages	227,33		
enlargement	Electrical connection	577 046,68	2,19	MW
Ē	Gas connection	0,00	0,00	MW
Brg	Water connection	0,00	0,33	m³h
5 5	Total for connections	577 046,68 I		
	Total investment	5 971 984,38	1	
	Payoff period	12,68 year	s	

Fig. 3 Results for optimal P2G hub as GF with conservative prices of natural gas / »renewable natural gas« and no subsidy.

Building P2G hub as GF investment shows again that producing and selling biochar is not profitable with current prices used in the OT. The production of renewable hydrogen and selling it beside the selling of by-products would be economically feasible option (see Fig. 3). The limit of daily hydrogen production / selling (1 ton) is reached. Payoff period is around 13 years.



3.2RESULTS WITH CURRENT GAS PRICES WITH SUBSIDIES

For development of energy system related business cases additional subsidies may be needed. Following figures show results for scenarios where subsidies are included. Although the OT can use different subsidies for each part of P2G hub, Figures 4 to 6 show results for scenarios with current natural gas / »renewable natural gas« prices and 50% of subsidies on entire investments needed.

IVCS	stment specifications	Cost		Size	
	Dry anaerobic digestor	0.00		0,000000	kala
	Wet anaerobic digestor	0,00	-	0,000000	
		0,00		0,000000	
	Dry biomass to biochar plant				-
	Wet biomass to biochar plant	0,00	-	0,000000	
	Combined heat and power (CHP)	0,00	-		kWe
88	Carbon capture plant	0,00		0,000000	
Processes	Gasification + water gas shift plant	0,00	-	0,000000	
ē.	Methanation reactor	0,00		0,000000	
_	Electrolyser	2 686 838,62		2 149,47	
	Demineralizer	267,98	-	5,359654	
	Precipitation collector	1 000,00		1 000,00	
	Heat exchanger	9 259,26	-	185,19	
	Gas compressor station	0,00	-	0,0000	kWe
	Total for processes	2 697 365,87	1		
	Dry biomass storage	0,00	1	0,00	kg
	Wet biomass storage	0,00	I I	0,00	kg
	Biochar storage	0,00	L	0,00	kg
	Biogas storage	0,00	L	0,00	kg
89	Hydrogen storage tank	0,00	L	0,00	kg
Storages	Oxygen storage tank	0,00	L	0,00	kg
đ	Methane storage tank	0,00	L	0,00	kg
	Syngas storage tank	0,00	I I	0,00	kg
	Carbon dioxide storage tank	0,00	I	0,00	kg
	Water storage tank	0,00	L	0,00	m³
	Total for storages	0,00	L		
a t	Electrical connection	0,00	I I	0,00	MW
Connections enlargement	Gas connection	0,00	I I	0,00	МW
e é	Water connection	0,00	1	0,35	m³h
35	Total for connections	0,00	1		
	Total investment	2 697 365,87	-		
	Payoff period		years		

operau	onal costs for selected period				
		Cost		Amount	
	Produced by REP	0,00	1	0,00	MWh
Â6	Consumed by IP	41 920 000,00	L	320 000,00	MWh
Electrical energy	Net consumption without investment	41 920 000,00	1	320 000,00	MWh
a	Mean peak power without investment	2 191 780,82	I	36,53	MW
ji	Consumed by P2G	2 504 073,66	I I	19 115,07	MWh
- Hereita - Here	Net consumption with investment	44 424 073,66	I.	339 115,07	M₩h
-	Mean peak power with investment	2 322 708,16	1	38,71	мw
	Produced by REP	0,00	I I	0,00	MWh
	Produced IP	0,00	I I	0,00	MWh
Heat	Net production without investment	0,00	I	0,00	MWh
	Consumed by P2G	0,00	I	-1622,22	MWh
	Net production with investment	0,00	1	1 622,22	M₩h
ି ଅ	Produced by REP	0,00			MWh
E E	Consumed by IP	878 902,36	I	11 630,00	MWh
Gas (methane) to/from the grid	Net consumption without investment	878 902,36	I I	11 630,00	MWh
s E	Produced by P2G	0,00	I	0,00	MWh
₫ Ö	Net consumption with investment	878 902,36	1	11 630,00	MWh
Sec. 1	Water from the grid consumed by P2G	4 209,00	I	2 475,88	m³
Water	Collected precipitation consumed by P2G	nła	I	819,00	m ³
	Dry biomass bought	0,00	I	0,00	t
Water materials	Wet biomass bought	0,00	I I	0,00	t
	Biochar bought	0,00	I I	0,00	t
E	Total cost of input materials	0,00	I I		
	Hydrogen sold (in bottles)	3 650 000,00	I I	365,00	t
0	Oxygen sold (in bottles)	36 500,00	I	365,00	t
Additional sales	Methane sold (in bottles)	0,00	I	0,00	t
° §9	Biochar sold	0,00	I I	0,00	t
-	Total revenue from additional sales	3 686 500,00	I		
	Residue from dry anaerobic digester	0,00	L	0,00	t
8	Residue from wet anaerobic digester	0,00	I I	0,00	t
Residues	Tar from gasification + water gas shift plar	0,00	I	0,00	t
Ř	CD2 emitted	0,00	L	0,00	t
_	Total cost of residues	0,00	1		
	Total operational cost without invest	44 990 683,18	I	1	
	Total operational cost with investme	43 943 393,19	I	1	

Fig. 4 Results for optimal P2G hub next to IP with conservative prices of natural gas / »renewable natural gas« and subsidy of 50%.

Adding subsidy in all calculated cases do not change any plant sizes or production and consumption profiles, but only has an impact on payoff period duration, which would shorten from 12 years (see Fig. 1) to around 9 years (see Fig. 4).



D	а	n	u	Ρ	-	2	-	G	а	S	

	Element	Cost		Size	
	Dry anaerobic digestor	0,00	I I	0,000000	k g/s
	Wet anaerobic digestor	0,00	I	0,000000	k g/s
	Dry biomass to biochar plant	0,00	I	0,000000	k g/s
Processes	Wet biomass to biochar plant	0,00	I	0,000000	k g/s
	Combined heat and power (CHP)	0,00	I I	0,00	kWe
	Carbon capture plant	0,00	I	0,000000	mol/s
	Gasification + water gas shift plant	0,00	I	0,000000	k g/s
	Methanation reactor	0,00	I	0,000000	mol/s
n .	Electrolyser	2 686 838,62	I	2 149,47	k₩
	Demineralizer	2 500,00	I	50,000000	mol/s
	Precipitation collector	1 000,00	I	1 000,00	rn²
	Heat exchanger	9 259,26	I	185,19	k₩
	Gas compressor station	0,00	I	0,0000	kWe
	Total for processes	2 699 597,88	I I		
	Dry biomass storage	0,00	I I	0,00	kg
	Wet biomass storage	0,00	I	0,00	kg
	Biochar storage	0,00	I	0,00	kg
	Biogas storage	0,00	I	0,00	kg
8	Hydrogen storage tank	0,00	I	0,00	kg
Storages	Oxygen storage tank	0,00	I I	0,00	kg
ž	Methane storage tank	0,00	I I	0,00	kg
	Syngas storage tank	0,00	I	0,00	kg
	Carbon dioxide storage tank	0,00	I	0,00	kg
	Water storage tank	1 951,77	I	177,43	rn³
	Total for storages	1 951,77	I .		
t	Electrical connection	0,00	I I	0,00	MW
enlargement	Gas connection	0,00	I	0,00	MW
arg	Water connection	0,00	I	3,25	m³h
6	Total for connections	0,00	I I		
	Total investment	2 701 549,65	I I		
	Payoff period	7 47	years		

		Cost	Amount	
			Amount	
	Produced by REP	580 750,00	6 900,00	
è	Consumed by IP	0,00		MWh
ane	Net consumption without investment	-580 750,00	-6 900,00	
8	Mean peak power without investment	0,00		MW
Ē	Consumed by P2G	2 504 073,66	19 115,07	
Ē	Net consumption with investment	1 609 551,23 🛛	12 215,07	M₩h
	Mean peak power with investment	128 968,25	2,15	мw
	Produced by REP	0,00	0,00	MWh
÷	Produced IP	0,00	0,00	MWh
-Fea	Net production without investment	0,00	0,00	MWh
Residues Additional sales Input materials C as (methane) in to from the grid Electrical energy (□ -1 : 20 : 21 -1 : 02 : 10 : 21 -1 : 02 : 10 : 10 : 22 -1 : 02 : 10 : 10 : 10 : 22 -1 : 10 : 10 : 10 : 10 : 10 : 10 : 10 :	Consumed by P2G	0,00	-1622,22	MWh
	Net production with investment	0,00	1 622,22	M₩h
Gas (methane) to/from the grid	Produced by REP	0,00	0,00	MWh
	Consumed by IP	0,00	0,00	MWh
	Net consumption without investment	0,00	0,00	MWh
	Produced by P2G	0,00	0,00	MWh
õğ	Net consumption with investment	0,00	0,00	M₩h
	Water from the grid consumed by P2G	4 209,00	2 475,88	rn³
Water	Collected precipitation consumed by P2G	n/a j	819,00	rn³
	Dry biomass bought	0,00	0,00	t
ts [∦] ĕ	Wet biomass bought	0,00	0,00	t
Water	Biochar bought	0,00	0,00	t
	Total cost of input materials	0,00		
	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
<u>.</u>	Oxygen sold (in bottles)	36 500,00	365,00	t
ales I	Methane sold (in bottles)	0,00	0,00	t
δų μ	Biochar sold	0,00	0.00	t
	Total revenue from additional sales	3 686 500,00		
	Residue from dry anaerobic digester	0,00	0,00	t
8	Residue from wet anaerobic digester	0.00	0.00	
ğ	Tar from gasification + water gas shift plan	0,00	0,00	
Sec	CO2 emitted	0,00	0,00	
-	Total cost of residues	0,00	0,00	1.
	Total operational cost without invest			
	Total operational cost with investme			
	Savings with introduction of P2G	1 363 021,51		

Fig. 5 Results for optimal P2G hub next to REP with conservative prices of natural gas / »renewable natural gas« and subsidy of 50%.

When needed investment costs are subsidised by a half, the payoff period reduces accordingly by around 2 years to 7,5 years (see Fig. 5). The biochar production is still not profitable in this case.



DanuP-2-Gas

	Element	Cost	Size		ional costs for selected period	Cost
	Dry anaerobic digestor	0,00	0,000000 ka/s		Produced by REP	0,0
	Wet anaerobic digestor	0.00	0,000000 ka/s	2	Consumed by IP	0.0
	Dry biomass to biochar plant	0,00	0,000000 ka/s	L L	Net consumption without investment	0,0
	Wet biomass to biochar plant	0.00	0.000000 ka/s	<u> </u>	Mean peak power without investment	0.0
	Combined heat and power (CHP)	0,00	0.00 kWe	Ë	Consumed by P2G	2 504 073,66
	Carbon capture plant	0.00	0.000000 mol/s	Electrical energy	Net consumption with investment	2 504 073,66
	Gasification + water gas shift plant	0,00	0,000000 ka/s	ш	Mean peak power with investment	130 926,54
	Methanation reactor	0.00	0.000000 mol/s		Produced by REP	0.00
	Electrolyser	2 686 838,62	2 149,47 kW		Produced IP	0,00
	Demineralizer	257.30	5.145962 mol/s	Teat	Net production without investment	0.00
	Precipitation collector	1000,00	1000,00 m ²	I	Consumed by P2G	0,00
	Heat exchanger	9 259,26	185,19 kW		Net production with investment	0,00
	Gas compressor station	0.00	0.0000 kWe	2.7	Produced by REP	0.00
	Total for processes	2 697 355,18	0,0000 1.110	e is	Consumed by IP	0,00
	Dry biomass storage	0.00	0,00 kg	the et-	Net consumption without investment	0,00
	Wet biomass storage	0.00	0.00 kg	5.5	Produced by P2G	0,00
	Biochar storage	0.00	0,00 kg	Gas (methane) to/from the grid	Net consumption with investment	0,00
	Biogas storage	0,00	0.00 kg		Water from the grid consumed by P2G	4 209,00
	Hydrogen storage tank	0.00	0,00 kg	Water	Collected precipitation consumed by P2G	
	Oxygen storage tank	0,00	0,00 kg		Dry biomass bought	0,00
	Methane storage tank	0.00	0.00 kg	ti se	Wet biomass bought	0.00
	Svngas storage tank	0,00	0,00 kg	Input materials	Biochar bought	0,00
	Carbon dioxide storage tank	0.00	0.00 kg	Ë	Total cost of input materials	0.00
	Water storage tank	113,67	10.33 m ³		Hydrogen sold (in bottles)	3 650 000.00
	Total for storages	113,67			Oxygen sold (in bottles)	36 500,00
Ĕ		577 046,68	2,19 MW	Additional sales	Methane sold (in bottles)	0,00
Ē	Gas connection	0,00	0,00 MW	s dd	Biochar sold	0,00
enlargement	Water connection	0,00	0,33 m³h		Total revenue from additional sales	3 686 500,00
ŝ	Total for connections	577 046,68			Residue from dry anaerobic digester	0,00
	Total investment	3 274 515,53	1	8	Residue from wet anaerobic digester	0,00
	Payoff period	9,21 year	S	Residues	Tar from gasification + water gas shift pla	0,00
	· · ·		-	Res	CO2 emitted	0,00
				_	Total cost of residues	0,00
					Total operational cost without inves	0,00
					Total operational cost with investme	-1 047 290,80
					Savings with introduction of P2G	1 047 290.80

Fig. 6 Results for optimal P2G hub as GF with conservative prices of natural gas / »renewable natural gas« and subsidy of 50%.

Like in the previous cases with REP and IP, adding subsidies did not change any plant sizes or production and consumption profiles and amounts. The payoff period shortens by 3 years and the operation would be profitable after around 9 years (see Fig. 6).



3.3RESULTS WITH INCREASED GAS PRICES WITHOUT SUBSIDIES

As natural gas price is increasing constantly during the last year, scenarios with higher natural gas prices are included in the analysis. For the next six scenarios (Figures 7 to 12), 10x increase in natural gas / »renewable natural gas« prices is used in the OT. Such sensitivity calculations are made to explore optimal business cases and whether other possible plants and production pathways may became economically feasible. Figures 7 to 9 show scenarios for IP, REP and GF without investment and Figures 10 to 12 show scenarios with 50% subsidy on the investment cost. Results show that after this significant price increase, »renewable natural gas« production and biochar production becomes economically profitable. As well as the capacity of the electrolyser increased.

nves	tment specifications		_		
	Element	Cost		Size	
	Dry anaerobic digestor	2 430 555,56		0,115741	kg/s
	Wet anaerobic digestor	2 430 555,56		0,115741	k g/s
	Dry biomass to biochar plant	0,00		0,000000	kg/s
Processes	Wet biomass to biochar plant	0,00		0,000000	kg/s
	Combined heat and power (CHP)	0,00		0,00	kWe
	Carbon capture plant	0,00		0,000000	molfs
9886	Gasification + water gas shift plant	2 314,81		0,002315	k g/s
Process	Methanation reactor	3 093 202,08		7,278123	molfs
	Electrolyser	16 223 931,95		6 489,57	k₩
	Demineralizer	1 711,25		17,112460	mol/s
	Precipitation collector	2 000,00		1 000,00	m²
	Heat exchanger	237 863,23		2 378,63	k₩
5	Gas compressor station	46 821,48		58,5269	kWe
	Total for processes	24 468 955,91			
	Dry biomass storage	100 000,00		10 000,00	kg
	Wet biomass storage	50 000,00		10 000,00	kg
	Biochar storage	15 000,00		1 000,00	kg
	Biogas storage	0,00		0,00	kg
68	Hydrogen storage tank	0,00		0,00	kg
Storages	Oxygen storage tank	0,00		0,00	kg
ŝ	Methane storage tank	0,00		0,00	kg
	Syngas storage tank	0,00		0,00	kg
	Carbon dioxide storage tank	0,00		0,00	kg
	Water storage tank	0,00		0,00	m³
	Total for storages	165 000,00			
i ti	Electrical connection	0,00		0,00	MW
1	Gas connection	79 689,46		0,53	MW
enlargement	Water connection	0,00		1,11	m³h
3 5	Total for connections	79 689,46			
	Total investment	24 713 645,37			
	Payoff period	8,20	ears		

Operati	onal costs for selected period		
		Cost	Amount
	Produced by REP	0,00	0,00 MWh
8	Consumed by IP	41 920 000,00	320 000,00 MWh
Le L	Net consumption without investment	41 920 000,00	320 000,00 MWh
a	Mean peak power without investment	2 191 780,82	36,53 MW
÷Ę.	Consumed by P2G	14 377 350,63	109 750,77 MWh
Electrical energy	Net consumption with investment	56 297 350,63	429 750,77 MWh
_	Mean peak power with investment	2 943 500,64	49,06 MW
	Produced by REP	0,00	0,00 MWh
+	Produced IP	0,00	0,00 MWh
Heat	Net production without investment	0,00	0,00 MWh
-	Consumed by P2G	0,00	-20 307,57 MWh
	Net production with investment	0,00	20 307,57 MWh
€₽	Produced by REP	0,00	0,00 MWh
Gas (methane) to/from the grid	Consumed by IP	5 777 458,36	11 630,00 MWh
	Net consumption without investment	5 777 458,36	11 630,00 MWh
	Produced by P2G	20 016 307,16	51 323,86 MWh
	Net consumption with investment	-15 480 607,16	-39 693,86 MWh
Water	Water from the grid consumed by P2G	15 584,61	9 167,42 m ³
vv atei	Collected precipitation consumed by P2G	n/a j	819,00 m ³
(0	Dry biomass bought	881 131,57	3 650,00 t
Input naterials	Wet biomass bought	200 955,12	3 650,00 t
트	Biochar bought	0,00	0,00 t
E	Total cost of input materials	1 082 086,68	
	Hydrogen sold (in bottles)	3 650 000,00	365,00 t
	Oxygen sold (in bottles)	36 500,00	365,00 t
Additional sales	Methane sold (in bottles)	0,00	0,00 t
₽°	Biochar sold	222 650,00	365,00 t
· ·	Total revenue from additional sales	3 909 150,00	
	Residue from dry anaerobic digester	0,00	109,50 t
S	Residue from wet anaerobic digester	0,00	547,50 t
Residues	Tar from gasification + water gas shift plan	0,00	7,30 t
ě	CO2 emitted	0,00	0,00 t
	Total cost of residues	0,00	
	Total operational cost without invest	49 889 239,18	
	Total operational cost with investme	40 948 765,41	
	Savings with introduction of P2G	8 940 473,78	

Fig. 7 Results for optimal P2G hub next to IP with higher prices of natural gas / »renewable natural gas« (x10) and no subsidy.

P2G hub next to IP with large biochar production and »renewable natural gas« production is an economically optimal solution for this input parameters and, beside the production of hydrogen, also the selling of oxygen is part of this particular business case (see Fig. 7). As well as electrolyser capacity increased significantly. Hydrogen and biochar (restricted by biomass input limits) production reaches their daily production limits. The payoff period is shorter, when the natural gas / »renewable natural gas« prices are higher (compared to business case displayed in Fig. 1) and is around 8 years for this business case.

Optimal business case for REP shows similar results, where the production of biochar and »natural renewable gas« would became feasible (see Fig. 8).



DanuP-2-Gas

	Element	Cost	Size			Cost	Amount
	Dry anaerobic digestor	2 430 555.56	0,115741 ka/s		Produced by REP	580 750.00 1	6 900.00 MW
	Wet anaerobic digestor	2 430 555,56	0,115741 ko/s	>	Consumed by IP	0.00	0.00 MW
	Dry biomass to biochar plant	0.00	0,000000 ko/s	E E	Net consumption without investment	-580 750.00	-6 900.00 MW
	Wet biomass to biochar plant	0.00	0,000000 kg/s	-	Mean peak power without investment	0.00	0,00 MW
	Combined heat and power (CHP)	0.00	0.00 kWe	Electrical energy	Consumed by P2G	14 589 958,16	111 373,73 MW
_	Carbon capture plant	0.00	0.000000 mol/s	et	Net consumption with investment	13 686 058.16	104 473.73 MW
89868	Gasification + water gas shift plant	2 314,81	0,002315 kon/s		Mean peak power with investment	762 059,49	12,70 MW
Process	Methanation reactor	3 093 202.08	7.278123 mol/s		Produced by REP	0.00	0.00 MW
ĩ	Electrolyser	16 223 931,95	6 489,57 kW		Produced IP	0.00	0,00 MW
	Demineralizer	1981.66	19,816603 mol/s	Heat	Net production without investment	0.00	0.00 MW
	Precipitation collector	2 000.00	1000.00 m ²	I	Consumed by P2G	0.00	-20 307.57 MW
	Heat exchanger	237 863,23	2 378,63 kW		Net production with investment	0,00	20 307,57 MW
	Gas compressor station	195 036.85	243,7961 kWe	÷ 7	Produced by REP	0.00	0.00 MW
	Total for processes	24 617 441,69	210,1001 1110	Gas (methane) to/from the grid	Consumed by IP	0.00	0.00 MW
	Dry biomass storage	100 000.00	10 000,00 kg	the fat	Net consumption without investment	0.00	0.00 MW
	Wet biomass storage	50 000.00	10 000.00 kg	5.5	Produced by P2G	20 008 824.14	51 323.86 MW
	Biochar storage	15 000.00	1000,00 kg	j 8	Net consumption with investment	-20 008 824,14	-51 323,86 MW
	Biogas storage	0.00	0.00 kg		Water from the grid consumed by P2G	15 584.61	9 167,42 m ³
8	Hydrogen storage tank	0.00	0,00 kg	Water	Collected precipitation consumed by P2G	n/a I	819.00 m ³
ororadas	Oxugen storage tank	0.00	0,00 kg		Dry biomass bought	394 260,86	3 650.00 t
8	Methane storage tank	0.00	0.00 kg	Input materials	Wet biomass bought	207 574.03	3 650.00 t
	Syngas storage tank	0.00	0,00 kg	ater D	Biochar bought	0.00	0.00 t
	Carbon dioxide storage tank	0.00	0.00 kg	Ë	Total cost of input materials	601 834.90	-,, -
	Water storage tank	625.14	28.42 m ³		Hydrogen sold (in bottles)	3 650 000.00	365.00 t
	Total for storages	165 625,14		5	Oxygen sold (in bottles)	36 500,00	365.00 t
Ħ	Electrical connection	1 331 923,86	8,88 MW	Additional sales	Methane sold (in bottles)	0.00	0.00 t
enlargement	Gas connection	16 756 531,34	5.86 MW	lip s	Biochar sold	222 650,00	365.00 t
arge	Water connection	0.00	1,29 m³h		Total revenue from additional sales	3 909 150,00	
E.	Total for connections	18 088 455,20 1			Residue from drv anaerobic digester	0.00	109.50 t
	Total investment	42 871 522,03		2	Residue from wet anaerobic digester	0,00	547,50 t
	Pavoff period	11.09 years		Zesidues	Tar from gasification + water gas shift plant	0.00	7.30 t
	· ·			Sec. 1	CD2 emitted	0,00	0,00 t
				1	Total cost of residues	0,00	
					Total operational cost without investm		_
					Total operational cost with investmen		
					Savings with introduction of P2G	8 271 686,99	

Fig. 8 Results for optimal P2G hub next to REP with higher prices of natural gas / »renewable natural gas« (x10) and no subsidy.

Due to increased natural gas (renewable natural gas) prices by 10, production of biochar is getting economically feasible and thus become part of this business case. The capacity of the electrolyser increased by three times comparing to the business case with actual gas prices and without additional subsidies. Additionally, also selling of biochar is, beside the selling of hydrogen, oxygen and »renewable natural gas« becomes economically feasible. However, the payoff period of this business case is around 11 years, which is the longest time period between all calculated REP cases.



	Element	Cost	Size	
	Dry anaerobic digestor	2 430 555,56	0,115741	kg/s
	Wet anaerobic digestor	2 430 555,56	0,115741	kg/s
	Dry biomass to biochar plant	0,00	0,000000	kgn/s
	Wet biomass to biochar plant	0,00	0,000000	kgals
Storages	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	molfs
	Gasification + water gas shift plant	2 314,81	0,002315	k g/s
	Methanation reactor	3 093 202,08	7,278123	moli/s
	Electrolyser	16 223 931,95	6 489,57	k₩
	Demineralizer	1689,88	16,898768	moli/s
	Precipitation collector	2 000,00	1 000,00	m²
	Heat exchanger	237 863,23	2 378,63	k₩
orages	Gas compressor station	46 821,48	58,5269	kWe
	Total for processes	24 468 934,54		
	Dry biomass storage	100 000,00	10 000,00	kg
	Wet biomass storage	50 000,00	10 000,00	kg
	Biochar storage	15 000,00	1 000,00	kg
	Biogas storage	0,00	0,00	kg
88	Hydrogen storage tank	0,00	0,00	kg
01ag	Oxygen storage tank	0,00	0,00	kg
ŝ	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	227,33	10,33	m³
	Total for storages	165 227,33		
ent	Electrical connection	3 305 683,95	12,53	MW
	Gas connection	33 461 174,83	5,86	MW
a g	Water connection	0,00	1,10	m³h
Connections enlargement Storages	Total for connections	36 766 858,78		
	Total investment	61 401 020,65		
	Payoff period	13,83 ye	ears	

		Cost		Amount	
	Produced by REP	0.00	1		MWh
≥	Consumed by IP	0,00			MWh
Diel.	Net consumption without investment	0.00		0.00	MWh
e	Mean peak power without investment	0.00		0.00	MW
Ĕ	Consumed by P2G	14 377 350,63	I	109 750,77	MWh
<u>e</u>	Net consumption with investment	14 377 350,63		109 750,77	
ш	Mean peak power with investment	751 719,02	-	12,53	
	Produced by REP	0.00	-		MWh
	Produced IP	0,00		0.00	MWh
leat	Net production without investment	0.00			MWh
Additional Input Cas (methane) Residues Additional Input Cas (methane) Residues sales materials to/from the grid	Consumed by P2G	0,00	1	-20 307,57	MWh
	Net production with investment	0,00	1	20 307,57	MWh
<u>و</u>	Produced by REP	0,00	1	0,00	MWh
Gas (methane to/from the grid	Consumed by IP	0,00	1	0,00	MWh
	Net consumption without investment	0,00	1	0,00	MWh
n an	Produced by P2G	20 016 307,16	1	51 323,86	MWh
§ §	Net consumption with investment	-20 016 307,16	1	-51 323,86	MWh
) (abar	Water from the grid consumed by P2G	15 584,61	1	9 167,42	m³
water	Collected precipitation consumed by P2G	n/a	1	819,00	m³
	Dry biomass bought	389 114,63	1	3 650,00	t
ti iž	Wet biomass bought	208 880,44	I	3 650,00	t
트월	Biochar bought	0,00	I	0,00	t
	Total cost of input materials	597 995,06			
	Hydrogen sold (in bottles)	3 650 000,00	I	365,00	t
	Oxygen sold (in bottles)	36 500,00	1	365,00	t
ale:	Methane sold (in bottles)	0,00	I	0,00	t
-	Biochar sold	222 650,00	I	365,00	t
· ·	Total revenue from additional sales	3 909 150,00	1		
	Residue from dry anaerobic digester	0,00	I	109,50	t
es	Residue from wet anaerobic digester	0,00	1	547,50	t
sidu	Tar from gasification + water gas shift plan	0,00		7,30	t
Ř	CO2 emitted	0,00		0,00	t
	Total cost of residues	0,00			
	Total operational cost without invest	0,00	1		
	Total operational cost with investme	-8 182 807,84			
	Savings with introduction of P2G	8 182 807,84			

Fig. 9 Results for optimal P2G hub as GF with higher prices of natural gas / »renewable natural gas« (x10) and no subsidy.

Similar results are obtained with natural gas / »renewable natural gas« price increase on scenario with GF investment as with REP and IP scenarios (see Fig. 9). Very long payoff period should be noticed here.



3.4 RESULTS WITH INCREASED GAS PRICES WITH SUBSIDIES

	Element	Cost	Size	
	Dry anaerobic digestor	1 215 277,78	0,115741	k g/s
	Wet anaerobic digestor	1 215 277,78	0,115741	kg/s
	Dry biomass to biochar plant	0,00	0,000000	k g/s
Processes	Wet biomass to biochar plant	0,00	0,000000	kg/s
	Combined heat and power (CHP)	0,00	0,00	kWe
	Carbon capture plant	0,00	0,000000	mol/s
	Gasification + water gas shift plant	1 157,41	0,002315	k g/s
	Methanation reactor	1 546 601,04	7,278123	mol/s
	Electrolyser	8 111 965,97	6 489,57	k₩
	Demineralizer	855,62	17,112460	mol/s
	Precipitation collector	1000,00	1 000,00	m²
	Heat exchanger	118 931,61	2 378,63	k₩
	Gas compressor station	23 410,74	58,5269	kWe
	Total for processes	12 234 477,96		
	Dry biomass storage	50 000,00	10 000,00	kg
	Wet biomass storage	25 000,00	10 000,00	kg
	Biochar storage	7 500,00	1 000,00	kg
	Biogas storage	0,00	0,00	kg
8	Hydrogen storage tank	0,00	0,00	kg
safipinio	Oxygen storage tank	0,00	0,00	kg
8	Methane storage tank	0,00	0,00	kg
	Syngas storage tank	0,00	0,00	kg
	Carbon dioxide storage tank	0,00	0,00	kg
	Water storage tank	0,00	0,00	m,
	Total for storages	82 500,00 I		
ent	Electrical connection	0,00	0,00	MW
8	Gas connection	79 689,46	0,53	MW
enlargement	Water connection	0,00	1,11	m³h
5	Total for connections	79 689,46		
	Total investment	12 396 667,42		
	Payoff period	6,61 yea	ars	

Operati	onal costs for selected period			
		Cost	Amount	
	Produced by REP	0,00	0,00	MWh
6	Consumed by IP	41 920 000,00	320 000,00	MWh
Le	Net consumption without investment	41 920 000,00	320 000,00	MWh
<u></u>	Mean peak power without investment	2 191 780,82	36,53	MW
ji ji	Consumed by P2G	14 377 350,63	109 750,77	MWh
Electrical energy	Net consumption with investment	56 297 350,63	429 750,77	M₩h
_	Mean peak power with investment	2 943 500,64	49,06	мw
	Produced by REP	0,00	0,00	MWh
	Produced IP	0,00	0,00	MWh
Heat	Net production without investment	0,00	0,00	MWh
-	Consumed by P2G	0,00	-20 307,57	MWh
	Net production with investment	0,00	20 307,57	MWh
<u>e</u> e	Produced by REP	0,00	0,00	MWh
E B	Consumed by IP	5 777 458,36	11 630,00	MWh
t g	Net consumption without investment	5 777 458,36	11 630,00	MWh
L) SI L	Produced by P2G	20 016 307,16	51 323,86	MWh
Gas (methane) to/from the grid	Net consumption with investment	-15 480 607,16	-39 693,86	M₩h
Water	Water from the grid consumed by P2G	15 584,61	9 167,42	m³
water	Collected precipitation consumed by P2G	nta I	819,00	m³
	Dry biomass bought	881 131,57	3 650,00	t
병훈	Wet biomass bought	200 955,12	3 650,00	t
Input materials	Biochar bought	0,00	0,00	t
E	Total cost of input materials	1 082 086,68		
	Hydrogen sold (in bottles)	3 650 000,00	365,00	t
	Oxygen sold (in bottles)	36 500,00	365,00	t
Additional sales	Methane sold (in bottles)	0,00	0,00	t
PP ∞	Biochar sold	222 650,00	365,00	t
	Total revenue from additional sales	3 909 150,00		
	Residue from dry anaerobic digester	0,00	109,50	t
8	Residue from wet anaerobic digester	0,00	547,50	t
Residues	Tar from gasification + water gas shift plant	0,00	7,30	t
Ř	CO2 emitted	0,00	0,00	t
	Total cost of residues	0,00		
	Total operational cost without investm	49 889 239,18		
	Total operational cost with investmen	40 948 765,41		
	Savings with introduction of P2G	8 940 473,78		

Fig. 10 Results for optimal P2G hub next to IP with higher prices of natural gas / »renewable natural gas« (x10) and subsidy of 50%.

Subsidy only affects the payoff period, which is shorter than in the case without subsidies (see Fig. 7) and is around 6,5 years (Fig. 10).

	Element	Cost		Size	
ø	Dry anaerobic digestor	1 215 277,78	I I	0,115741	kogks
	Wet anaerobic digestor	1 215 277,78	I I	0,115741	kop/s
	Dry biomass to biochar plant	0,00	I	0,000000	k g/s
	Wet biomass to biochar plant	0,00	I I	0,000000	kop/s
	Combined heat and power (CHP)	0,00	I I	0,00	kWe
	Carbon capture plant	0,00	L	0,000000	molifs
Processes	Gasification + water gas shift plant	1 157,41	1	0,002315	k g/s
ĕ	Methanation reactor	1 546 601,04	I I	7,278123	molifs
<u>n</u> .	Electrolyser	8 111 965,97	1	6 489,57	k₩
	Demineralizer	1 0 33,86	I I	20,677210	molifs
	Precipitation collector	1 000,00	I I	1 000,00	m²
	Heat exchanger	118 931,61	1	2 378,63	k₩
	Gas compressor station	97 518,43	I I	243,7961	kWe
	Total for processes	12 308 763,88	I I		
	Dry biomass storage	50 000,00	L	10 000,00	kg
	Wet biomass storage	25 000,00	I	10 000,00	kg
	Biochar storage	7 500,00	I I	1 000,00	kg
	Biogas storage	0,00	L	0,00	kg
8	Hydrogen storage tank	0,00	I	0,00	kg
storages	Oxygen storage tank	0,00	I I	0,00	kg
5	Methane storage tank	0,00	L	0,00	kg
	Syngas storage tank	0,00	I	0,00	kg
	Carbon dioxide storage tank	0,00	I I	0,00	kg
	Water storage tank	495,06	L	45,01	m³
	Total for storages	82 995,06	I		
enlargement	Electrical connection	1 332 892,04	1	8,89	MW
enlargement	Gas connection	16 756 531,34	I I	5,86	MW
larg	Water connection	0,00	1	1,34	۳³h
5	Total for connections	18 089 423,38	I		
	Total investment	30 481 182,32	I		
	Payoff period	9,33	years		

perae	onal costs for selected period	Cont	Amount	
		Cost	Amount	
Electrical energy	Produced by REP	580 750,00	6 900,00 M	
	Consumed by IP	0,00	0,00 M	
	Net consumption without investment	-580 750,00	-6 900,00 M	
	Mean peak power without investment	0,00	0,00 M	
	Consumed by P2G	14 589 958,16	111 373,73 M	
	Net consumption with investment	13 686 058,16	104 473,73 M	
	Mean peak power with investment	761 949,63	12,70 M	
Heat	Produced by REP	0,00	0,00 M	
	Produced IP	0,00	0,00 M	
	Net production without investment	0,00	0,00 M	
	Consumed by P2G	0,00	-20 307,57 M	
	Net production with investment	0,00	20 307,57 M	
Gas (methane) to/from the grid	Produced by REP	0,00	0,00 M	
	Consumed by IP	0,00	0,00 M	
	Net consumption without investment	0,00	0,00 M	fWh
s j	Produced by P2G	20 008 824,14	51 323,86 M	fWh
ΰġ	Net consumption with investment	-20 008 824,14	-51 323,86 M	1Wh
Water	Water from the grid consumed by P2G	15 584,61	9 167,42 m	1 ³
mator	Collected precipitation consumed by P2G	n/a I	819,00 m	1 ³
\$	Dry biomass bought	394 260,86	3 650,00 t	
Input aterial	Wet biomass bought	207 574,03	3 650,00 t	
Input materials	Biochar bought	0,00	0,00 t	
	Total cost of input materials	601 834,90		
	Hydrogen sold (in bottles)	3 650 000,00	365,00 t	
<u> </u>	Oxygen sold (in bottles)	36 500,00	365,00 t	
Additional sales	Methane sold (in bottles)	0,00	0,00 t	
₽₽ ₽₽	Biochar sold	222 650,00	365,00 t	
-	Total revenue from additional sales	3 909 150,00		
	Residue from dry anaerobic digester	0,00	109,50 t	
8	Residue from wet anaerobic digester	0,00	547,50 t	
Residues	Tar from gasification + water gas shift plant	0,00	7,30 t	
Res	CO2 emitted	0,00	0,00 t	
	Total cost of residues	0,00		
	Total operational cost without investm	-580 750,00		
	Total operational cost with investmen	-8 852 546,84		
	Savings with introduction of P2G	8 271 796,84		

Fig. 11 Results for optimal P2G hub next to REP with higher prices of natural gas / »renewable natural gas« (x10) and subsidy of 50%.



Additional subsidies reduced the payoff period in comparison with the results with no subsidies (Fig. 8).

	Element	Cost		Size	
Processes	Dry anaerobic digestor	1 215 277,78	L	0,115741	kg/s
	Wet anaerobic digestor	1 215 277,78	I I	0,115741	kg/s
	Dry biomass to biochar plant	0,00	I I	0,000000	kg/s
	Wet biomass to biochar plant	0,00	1	0,000000	kg/s
	Combined heat and power (CHP)	0,00	1	0,00	kWe
	Carbon capture plant	0,00	I .	0,000000	moli/s
	Gasification + water gas shift plant	1 157,41	I .	0,002315	kg/s
	Methanation reactor	1 546 601,04	1	7,278123	moli/s
	Electrolyser	8 111 965,97	1	6 489,57	k₩
	Demineralizer	844,94	I .	16,898768	moli/s
	Precipitation collector	1 000,00	I .	1 000,00	m²
	Heat exchanger	118 931,61	I	2 378,63	k₩
	Gas compressor station	23 410,74	I	58,5269	kWe
	Total for processes	12 234 467,27	1		
	Dry biomass storage	50 000,00	I .	10 000,00	kg
	Wet biomass storage	25 000,00	I	10 000,00	kg
	Biochar storage	7 500,00	I	1 000,00	kg
	Biogas storage	0,00	I	0,00	kg
Storages	Hydrogen storage tank	0,00	I .	0,00	kg
	Oxygen storage tank	0,00	1	0,00	kg
	Methane storage tank	0,00	I	0,00	kg
	Syngas storage tank	0,00	I	0,00	kg
	Carbon dioxide storage tank	0,00	1	0,00	kg
	Water storage tank	113,67	I	10,33	m³
	Total for storages	82 613,67	1		
ent.	Electrical connection	3 305 683,95	I	12,53	MW
connections enlargement	Gas connection	33 461 174,83	1	5,86	MW
	Water connection	0,00	L	1,10	m³h
5	Total for connections	36 766 858,78			
	Total investment	49 083 939,71	1		
	Payoff period	12.06	vears		

Cost Amount Produced by PEP 0.00 0.00 M Mean peak power without investment 14 377 350.63 109 750.77 M Mean peak power with investment 751 719.02 12,53 M Produced by PEP 0.00 0.00 M Produced by PEP 0.00 0.00 M Consumed by P2G 0.00 0.00 M Net production without investment 0.00 0.00 M Consumed by P2G 0.00 0.00 M Verduced by PEP 0.00 0.00 M Consumed by P2G 0.00 0.00 M Verduced by PEP 0.00 0.00 M Consumed by P2G 0.00 0.00 M Verduced by PEP 0.00 0.00 M Met production without investment 0.00 0.00 M	/h /h /h /h /h /h /h /h
Ensumed by IP 0.00 0.00 Monos Net consumption without investment 0.00 0.00 Monos Mean peak power without investment 0.00 109 750.77 M Mean peak power with investment 14 377 350.63 109 750.77 M Net consumed by P2G 14 377 350.63 109 750.77 M Mean peak power with investment 751 719.02 12,53 M Produced by REP 0.00 0.00 Monos Net production without investment 0.00 0.00 Monos Net production with investment 0.00 0.00 Monos Produced IP 0.00 0.00 Monos Monos Net production with investment 0.00 0.00 Monos Monos Produced by PEG 0.00 0.00 Monos Monos Monos State 0.00 0.00 Monos Monos Monos Monos Value for the grid consumed by PEG 0.00 0.00 Monos Monos Monos Monos	/h /h /h /h /h /h /h /h
Met consumption without investment 0.00 0.00 Mmodel Mean peak power without investment 0.00 0.00 Mmodel 0.00 Mmodel Mean peak power without investment 14 377 350.63 109 750.77 Mmodel Mmodel 109 750.77 Mmodel Mean peak power with investment 14 377 350.63 109 750.77 Mmodel 109 750.77 Mmodel Mmodel Mmodel Mmodel 100 750.77 Mmodel	/h /h vh /h /h /h /h
Mean peak power with investment 751 719.02 12,53 M1 Produced by PEP 0.00 0.00 M Produced Dy PEP 0.00 0.00 M Net production without investment 0.00 0.00 M Consumed by P2G 0.00 0.00 M Very production without investment 0.00 0.00 M Consumed by P2G 0.00 0.00 M Consumed by P2FP 0.00 0.00 M Consumed by IP 0.00 0.00 M Produced by PEP 0.00 0.00 M Net consumption without investment 0.00 0.00 M Produced by P2G 20 016 307.16 51 323.86 M Water Water from the grid consumed by P2G 15 584.61 9 167.42 m² Collected precipitation consumed by P2G n4 8130.00 m² 38 114 63 3850.00 m²	/ /h /h /h /h /h /h
Mean peak power with investment 751 719.02 12,53 M1 Produced by PEP 0.00 0.00 M Produced Dy PEP 0.00 0.00 M Net production without investment 0.00 0.00 M Consumed by P2G 0.00 0.00 M Very production without investment 0.00 0.00 M Consumed by P2G 0.00 0.00 M Consumed by P2FP 0.00 0.00 M Consumed by IP 0.00 0.00 M Produced by PEP 0.00 0.00 M Net consumption without investment 0.00 0.00 M Produced by P2G 20 016 307.16 51 323.86 M Water Water from the grid consumed by P2G 15 584.61 9 167.42 m² Collected precipitation consumed by P2G n4 8130.00 m² 38 114 63 3850.00 m²	/h √h /h /h /h
Mean peak power with investment 751 719.02 12,53 M1 Produced by PEP 0.00 0.00 M Produced Dy PEP 0.00 0.00 M Net production without investment 0.00 0.00 M Consumed by P2G 0.00 0.00 M Very production without investment 0.00 0.00 M Consumed by P2G 0.00 0.00 M Consumed by P2FP 0.00 0.00 M Consumed by IP 0.00 0.00 M Produced by PEP 0.00 0.00 M Net consumption without investment 0.00 0.00 M Produced by P2G 20 016 307.16 51 323.86 M Water Water from the grid consumed by P2G 15 584.61 9 167.42 m² Collected precipitation consumed by P2G n4 8130.00 m² 38 114 63 3850.00 m²	√h /h /h /h /h
Mean peak power with investment 751 719.02 12,53 M1 Produced by PEP 0.00 0.00 M Produced Dy PEP 0.00 0.00 M Net production without investment 0.00 0.00 M Consumed by P2G 0.00 0.00 M Net production with investment 0.00 0.00 M Consumed by P2G 0.00 0.00 M Valued by PEP 0.00 0.00 M Consumed by PEP 0.00 0.00 M Valued by PEP 0.00 0.00 M Net consumption without investment 0.00 0.00 M Valued by P2G 20 016 307.16 51 323.86 M Water Valer from the grid consumed by P2G 15 584.61 9 167.42 m² Collected precipitation consumed by P2G n4 8130.00 m² 38 114 63 38 500.01 m²	√ /h /h /h /h
Produced by PEP 0.00 0.00 M Produced IP 0.00 0.00 M Net production without investment 0.00 0.00 M Net production with investment 0.00 0.00 M Net production with investment 0.00 -20 307,57 M Net production with investment 0.00 20 307,57 M Vectorsumed by PEP 0.00 0.00 M Consumed by IP 0.00 0.00 M Net consumption without investment 0.00 0.00 M Produced by PES 20 016 307,16 51323,86 M Water Vater from the grid consumed by P2G 15 584,61 9 167,42 m² Collected precipitation consumed by P2G n4 8130,00 m² 3610 m²	/h /h /h /h
Produced IP 0.00 0.00 Mode Net production without investment 0.00 0.00 Mode 0.00 Mode 0.00 Mode Mode 0.00 Mode Mode 0.00 Mode Mode 0.00 Mode	/h /h /h √h
Image: Net production without investment 0.00 I 0.00 Met production without investment 0.00 I 0.00 Met production with investment 0.00 I 0.00 Met production with investment 0.00 I 0.00 I 0.00 Met production with investment 0.00 I 0.00 Met produced by PEP	/h /h √h
Consumed by P2G 0,00 -20 307,57 M Net production with investment 0,00 20 307,57 M Perform of the production with investment 0,00 0,00 Consumed by IP 0,00 0,00 Consumed by IP 0,00 0,00 Net consumption without investment 0,00 0,00 Net consumption with investment -20 016 307,16 51 323,86 Water Water from the grid consumed by P2G 15 584,61 9 167,42 m² Callected precipitation consumed by P2G na 8130,00 m² 38114 316 314 31 3165000	/h √h
Consumed by P2G 0,00 -20 307,57 M Net production with investment 0,00 20 307,57 M Perform of the production with investment 0,00 0,00 Consumed by IP 0,00 0,00 Consumed by IP 0,00 0,00 Net consumption without investment 0,00 0,00 Net consumption with investment -20 016 307,16 51 323,86 Water Water from the grid consumed by P2G 15 584,61 9 167,42 m² Callected precipitation consumed by P2G na 8130,00 m² 38114 316 314 31 3165000	√h
Produced by PEP 0.00 0.00 MM Consumed by IP 0.00 0.00 MM Consumed by IP 0.00 0.00 MM Net consumption without investment 0.00 0.00 MM Water Met consumption with investment -20016 307.16 -51 323.86 MM Water Collected precipitation consumed by P2G 15 584.61 9 167.42 m² During the precipitation consumed by P2G na 81 14 63 385000 m²	
Image: Second strength Consumed by IP 0.00 0.00 MM Net consumption without investment 0.00 0.00 MM Produced by P2G 20 016 307.16 51 323.86 MM O Net consumption with investment -20 016 307.16 51 323.86 MM Water Water from the grid consumed by P2G 15 584.61 9 167.42 m ² Drubingers burght -20 016 307.16 -51 323.86 MM 36 114 31 323.86	/h
Water Water from the grid consumed by P2G 15 584,61 9 167,42 m ³ Collected precipitation consumed by P2G r/a 1 813,00 m ³ Drucking Drucking 39 114,631 356,000 m ³ 156,000 m ³	
Water Water from the grid consumed by P2G 15 584,61 9 167,42 m ³ Collected precipitation consumed by P2G r/a 1 813,00 m ³ Drucking Drucking 39 114,631 356,000 m ³ 156,000 m ³	/h
Water Water from the grid consumed by P2G 15 584,61 9 167,42 m ³ Collected precipitation consumed by P2G r/a 1 813,00 m ³ Drucking Drucking 39 114,631 356,000 m ³ 156,000 m ³	/h
Water Water from the grid consumed by P2G 15 584,61 9 167,42 m ³ Collected precipitation consumed by P2G r/a 1 813,00 m ³ Drucking Drucking 39 114,631 356,000 m ³ 156,000 m ³	/h
Water Collected precipitation consumed by P2G r/a 819,00 m ² Dru biomass boundst 389,114,63 I 3,650,00 I	∜h
Collected precipitation consumed by P2G n/a 819,00 m ³	
Dry biomass bought 389 114,63 1 3 650,00 t	
물 뿐 Wet biomass bought 208 880,44 1 3 650,00 t	
Biochar bought 208 880,44 3 650,00 t Biochar bought 0,00 0,00 t	
Total cost of input materials 597 995,06 I	
Hydrogen sold (in bottles) 3 650 000,00 365,00 t	
Te a Dxygen sold (in bottles) 36 500,00 I 365,00 t	
B Cxygen sold (in bottles) 36 500,00 365,000 t B Methane sold (in bottles) 0,00 t 0,00 t B Biochar sold 222 650,00 365,00 t	
Biochar sold 222 650,00 I 365,00 t	
Total revenue from additional sales 3 909 150,00 I	
Residue from dry anaerobic digester 0,00 109,50 t	
8 Residue from wet anaerobic digester 0,00 I 547,50 t	
generative Residue from wet anaerobic digester 0,00 547,50 Tar from gasification + water gas shift plan 0,00 7,30 7,30 CC2 emitted 0,00 0,00 0,00 0,00	
🖉 CO2 emitted 0,00 I 0,00 t	
Total cost of residues 0,00 I	
Total operational cost without invest 0,00	
Total operational cost with investmer -8 182 807,84	
Savings with introduction of P2G 8 182 807,84	

Fig. 12 Results for optimal P2G hub as GF with higher prices of natural gas / »renewable natural gas« (x10) and subsidy of 50%.

Additional subsidies did not change any plant sizes and production volumes, but had an impact only on the shorter payoff period, which is still quite long in comparison with all other business cases calculated (see Fig. 12).



4. CONCLUSIONS

Pre-feasibility studies for three typical location cases for a P2G hub investment in Austria have been conducted with the Optimization Tool developed during the project. Maximum allowed return on investment period of 20 years was set for all business cases, however often the optimum economical setup of the investment yields in much shorter return on investment periods. In general, production of renewable hydrogen takes place in all the cases in Austria, however the production of renewable natural gas gets feasible only when the price for selling and injecton is higher as natural gas prices in the baseline scenario. Also, similar tendencies are observed also for biochar production.