



University of Groningen

Biomass or batteries

Miedema, Jan Hessels

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version

Publisher's PDF, also known as Version of record

Publication date:

2019

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Miedema, J. H. (2019). Biomass or batteries: The role of three technological innovations in the energy transition. Groningen: University of Groningen.

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Biomass or batteries

The role of three technological innovations in the energy transition

Jan Hessels Miedema

Colophon

This research has been financed by a grant of the Energy Delta Gas Research (EDGaR) program and the University of Groningen. EDGaR is co-financed by the Northern Netherlands Provinces, the European Fund for Regional Development, the Ministry of Economic Affairs and the Province of Groningen.

PhD thesis: Jan Hessels Miedema
Date: 14 January 2019

Biomass or batteries: the role of three technological innovations in the energy transition

Cover: Danny Boonstra | July Interactive

Publisher: University of Groningen, Groningen, the Netherlands

Printed by: Ipskamp Printing

Layout: Jan Hessels Miedema and Marjet Miedema

ISBN: 978-94-034-1292-4

ISBN: 978-94-034-1291-7

© 2019 by Jan Hessels Miedema

All rights reserved. No part of the material protected by this copyright notice may be reproduced or utilised in any form by any means, electronically or mechanically, including photocopying, recording, or by any information storage and retrieval system, without the prior permission of the author.



university of
 groningen

Biomass or batteries

The role of three technological innovations in the energy transition

PhD thesis

To obtain the degree of PhD at the
 University of Groningen
 on the authority of the
 Rector Magnificus Prof. E. Sterken
 and in accordance with
 the decision by the College of Deans.

This thesis will be defended in public on

Monday 14 January 2019 at 16.15 hours

by

Jan Hessels Miedema

Born on 12 September 1985
 in Leeuwarden

Supervisor

Prof. H.C. Moll

Co-supervisor

Dr. H.J. van der Windt

Assessment Committee

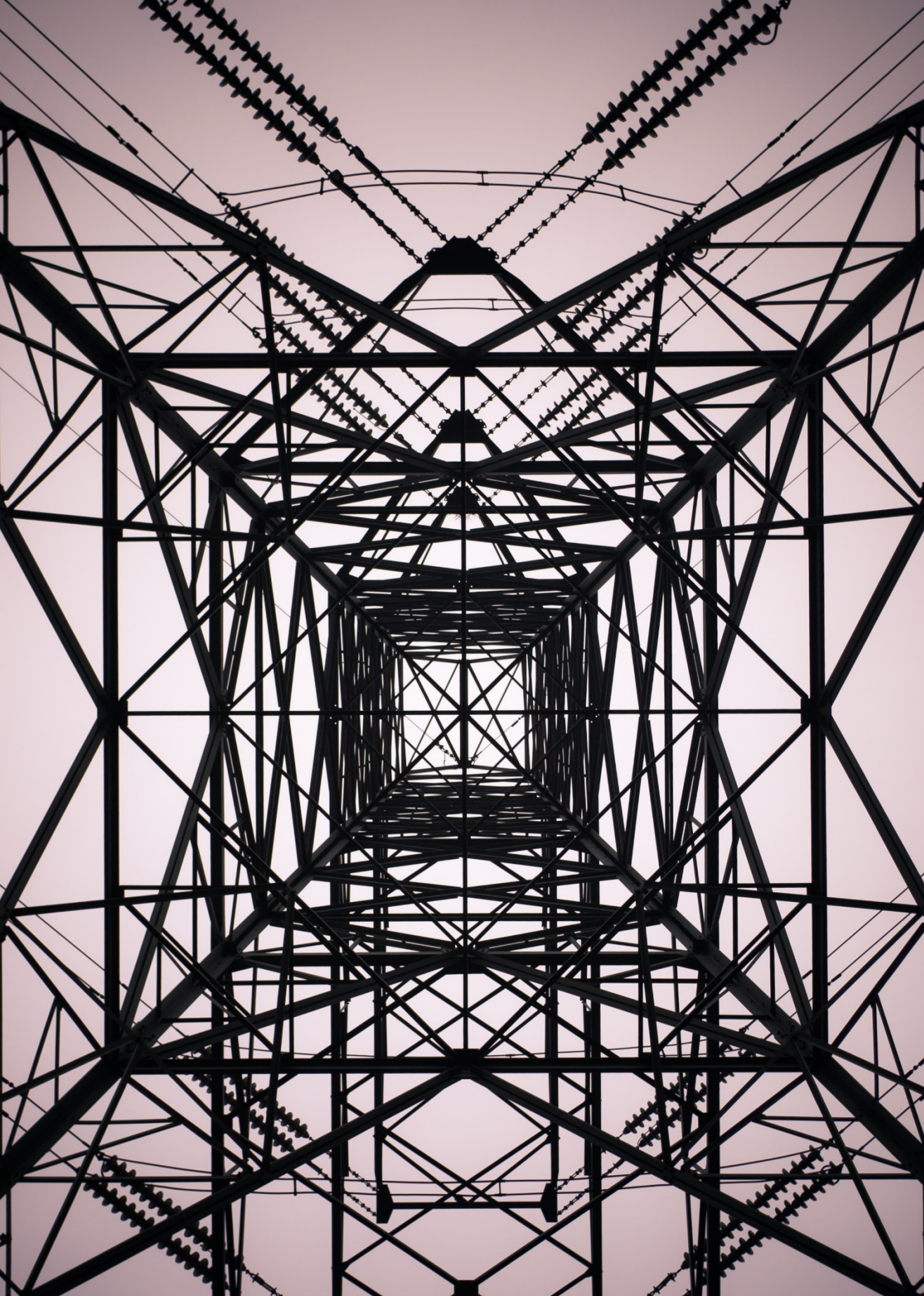
Prof. M.A. Herber

Prof. F.M.D. Vanclay

Prof. E. Worrell

This research was conducted under the auspices of the Graduate School for Socio-Economic and Natural Sciences of the Environment (SENSE).

Preface



When I aimed to finish my master degree in Energy and Environmental Sciences at the University of Groningen at the end of 2011, I ended up having the same discussion with my wife as roughly two and a half years before, when I finished my bachelor degree in Environmental Science at the Van Hall Larenstein. “What are you gonna do with your life?”. Whilst I studied systems and scenarios, I found out that in life only one scenario can be lived; thus, at a certain point one has to choose a direction. After the “unilateral” agreement, with my wife, that I wasn’t welcome home if I didn’t make sure that, Henk Moll, my supervisor during my master thesis, knew I wanted a PhD position, I made sure he did. Sadly, the few positions available were already given out. However, about two months later a position became available and, partially due to the interest I had shown before, I ended up as a PhD student in April 2012.

Almost seven years later my thesis lies before you. It was a bumpy road, with ecstatic highs and incredible lows, challenging my intellectual abilities and mental perseverance. I owe a number of people my gratitude for their support during those seven years; there is, however, not enough space in this preface to name all the people who helped me, in every way possible. Still, there are a few people that I specifically want to thank. First of all, my promotor Henk Moll, for being bold enough to give me this position, whilst knowing that I had gone and was still going through the most challenging years of my life together with my wife, who was, at that time, recently diagnosed with a diffuse astrocytoma. Thank you for giving me the space I needed, and for having confidence in me bringing this journey to a successful end. Aside from this, I’m grateful that you continuously challenged my intellectual abilities and gave me the opportunity to further develop myself. Second, my co-promotor Henny van der Windt, who showed vast quantities of patience, over the years, in widening my technical perspectives towards a more general understanding of the importance of, among other factors, our society when thinking about system change. Third, René Benders, for developing similar models as I did in order to confirm my results, especially in the first years of my PhD trajectory. Your critical notions related to my results and subsequent interpretation have substantially contributed to this thesis.

In addition, to my supervisors there are a few others that I want to mention. Once in a while, during my PhD trajectory, I tended to joke about my “traditional” marriage, since my wife always makes me the best sandwiches one can imagine for lunch. Sanderine Nonhebel was the only one connecting the dots when she asked me if everything was all right, at the moment she noticed me buying lunch in the canteen, instead of bringing my own. In addition, thank you Sanderine, for always taking the time to have some coffee and provide me with motivating words in my times of need and pointing out the opportunity to participate in the best international conference ever. Against my expectations, I made two friends for life at this conference, David Alejandro Zambrana Vasquez and René Buffat. Anyone who sends me roughly two kilograms of Swiss chocolate (where weight and shipping cost are optimised) has my loyalty. Furthermore, I want to thank Ton Schoot Uiterkamp, especially during the last few years, where we shared a room in the Energy Academy Building. I’m grateful for the talks that we had about science and the future of our planet, but I am even more grateful for you sharing some of your life experience with me when this was appropriate or needed. Additionally, I would like to thank Anemiek Huizinga for helping me out with a lot of organisational questions and obviously for extending my rights as a staff member after my contract had finished. Even though some doors literally got locked for me, at least I could always get free coffee. Furthermore, I would like to thank my paranymphs, Ron de Vrieze and Gideon Laugs. Ron and I found that we had more in common than I initially thought, given our age difference and educational background. Thank you for our conversations, for me it contributed to determining what is actually important in life. Gideon, my officemate for several years. Thank you for listening to obscure music with me for about five

years in a row; what a relief that we ended up with each other! Our musical preference has often resulted in strange looks and remarks from people questioning whether we were able to work productively whilst listening to the genius of, for example, Devin Townsend. One of the highlights for me was that you were willing to “neglect” your children by picking them up late from kindergarten, since you helped me jumpstart my car (more than once), in order to get home safely. Besides that, I want to thank everyone at IVEM for always making me feel at home and giving me the opportunity and trust to start a new job as a lecturer in Environmental Physics at the Van Hall Larenstein, University of Applied Sciences in Leeuwarden before the end of my PhD. Sometimes one has to grab opportunities when they present themselves. Therefore, I also want to express my gratitude towards my colleagues in Leeuwarden for giving me the time and space to finish my PhD thesis. Thank you for letting me be a part of your team at the Environmental Science department. I’m looking forward to many more years. As well as my colleagues, I want to thank the third year students of the module “Adviesbureau voor duurzame oplossingen” in 2017-2018, for thinking with me about possible sustainable solutions for the energy transition. In addition, I want to thank Cor Herder for reading parts of this manuscript and for providing useful advice on grammar and spelling.

Finally, I owe a lot to my family. My father, for passing the same “defects” on to me, as he inherited from his father, which contributed to me becoming a lecturer. Besides that, he motivated me to work harder by arguing that he did think I would get my high school degree, but probably not in the regular time. At that time he wasn’t right, since I did graduate without delay, but these words still echoed in my mind when my discipline and perseverance were tested during this PhD journey. My mother, for knowing me without words being spoken, and for knowing me when words were being spoken on the phone, sometimes for hours during the good and the bad times of this whole experience. To my sister, who is living in Bolivia: I’m proud of what you achieved so far and I know the same holds for you, when it comes to me. “Los dos estamos tratando de contribuir a un mundo mejor a nuestra manera.” Both my parents in law, for always showing their interest in what I was doing and, for being there for me and my wife in our times of need. My father in law for providing me with the famous words “it komt dochs altyd oars dan asto tinkst”, when things didn’t go as planned. Furthermore, I want to thank my brother in law Danny Boonstra for designing the cover art for this dissertation.

Most of all I owe my wife, who I cherish and adore, a lot. In order to express this in the best way I can, I will finalise this preface in Frisian.

Ik draach dit boek op aon myn frau Marjet, myn foarbyld, om’t ik nea ien sjoen ha mei sa’n bjusterbaarliik trochsettingsfermogen. Nettsjinsteande dat hja dat sels lang net altyd sa sjocht, wit ik fêst dat ik nea safier kommen wie as sy net altyd foar my klear stie; mei ynspiraasje, in harkjend ear, wurden fan motivaasje, bôle foar wilens it skoft, of in skop foar myn bealch. Do bist myn alles.

Sincerely,

Jan Hessels Miedema

Table of contents

1	Introduction	17
1.1	General introduction	19
1.2	The Industrial Revolution	19
1.3	The need for an energy transition	20
1.4	Carbon lock-in and sustainability transitions theory	22
1.5	European energy policy	25
1.6	Aim and scope of the thesis	26
2	Lithium supply and demand dynamics	29
2.1	Introduction	31
2.2	Research context	32
2.2.1	Lithium supply curve	32
2.2.2	Vehicle development in the EU27	34
2.2.3	Lithium per battery	35
2.2.4	Recycling of Li-ion batteries	35
2.3	Model and scenarios	36
2.3.1	Model description	36
2.3.2	Scenarios	37
2.4	Results	37
2.4.1	Substitution of lithium compounds in other end-use markets and recycling	38
2.4.2	Full electric scenario	40
2.5	Discussion	41
2.5.1	Sensitivity analysis	42
2.5.2	Thought experiment	42
2.6	Conclusion	43
3	Biomass co-combustion	45
3.1	Introduction	47
3.2	Methodology and system components	48
3.2.1	Coal mining	49
3.2.2	Biomass production	49
3.2.3	Biomass and coal pretreatment	50
3.2.4	Technical possibilities for biomass co-combustion in Dutch pulverised coal power plants	52
3.2.5	Modal energy intensity of transport modes	52
3.2.6	Conversion efficiency	53
3.2.7	Net renewable power production	53
3.2.8	Supply chain scenarios	54
3.3	Results	54
3.3.1	Biomass and coal requirements	54
3.3.2	Biomass production and coal mining	55
3.3.3	Biomass and coal pretreatment	56
3.3.4	Transport performance by truck and bulk carrier	57

3.3.5	Energy consumption and emissions of the whole supply chain	58
3.3.6	Summation of results	59
3.4	Discussion	60
3.4.1	Sensitivity analysis	61
3.5	Conclusion	62
4	Synthetic Natural Gas Supply Chain Analysis	65
4.1	Introduction and background	67
4.2	Methods	68
4.2.1	Model description	68
4.2.2	Performance indicators	68
4.3	Scenarios and boundaries	69
4.3.1	Production systems	69
4.3.2	Pretreatment options	70
4.3.3	Storage and seasonality	70
4.3.4	Biomass gasification	70
4.3.5	SNG injection and distribution	71
4.3.6	Transport efficiency	71
4.3.7	System boundaries	72
4.3.8	Reference scenario	72
4.3.9	Scenario delineation	73
4.3.10	Input data	74
4.4	Results	74
4.4.1	Performance of the reference scenario	76
4.4.2	Performance of the scenarios	77
4.4.3	Sensitivity analysis	78
4.4.4	Energetic feasibility of torrefaction and pelleting	78
4.5	Discussion	80
4.6	Conclusion	81
5	Green gas in the Dutch residential sector	83
5.1	Introduction	85
5.2	Methodology and frameworks	86
5.2.1	Sustainability transition frameworks	86
5.2.2	Data collection	88
5.3	Results	89
5.3.1	Green gas production routes	89
5.3.2	TIS description of biomass gasification	90
5.3.3	Implementation in the residential sector	95
5.3.4	The natural gas regime	98
5.4	Discussion	100
5.5	Conclusion	101
6	Conclusion and discussion	103
6.1	General introduction	105
6.2	General conclusions	105
6.2.1	Lithium and battery electric vehicles	105
6.2.2	Co-combustion of biomass and coal	106
6.2.3	Biomass production for green gas supply	106
6.2.4	Green gas implementation in the Dutch residential sector	107
6.2.5	Contribution to the energy transition: biomass and batteries	108
6.3	Reflection on the results	108
6.3.1	Reflection on the results from the cases	108
6.3.2	General reflection	110
6.4	Exploration of options	112

7 References	115
Appendices	135
Appendix A Calculation of the modal energy intensity and load limitations	137
Appendix B Overview of the energy consumption and GHG emissions in the supply chain scenarios	139
Summary	141
Samenvatting	149
About the author	157
Scientific contributions	159

List of figures

Figure 1-1: Overview of economic cascading of biomass in a bioeconomy.	23
Figure 1-2: The unsolved triangle of European energy policy.	26
Figure 2-1: The relative supply forecast for Li_2CO_3 until 2050 for the BC and BAU scenario.	33
Figure 2-2: Simplified block schedule of the dynamic Stella II 3.0.7 [®] model.	36
Figure 2-3: The demand from the EU27 as a share of the global production of Li_2CO_3 .	38
Figure 2-4: The estimated supply and demand for virgin Li_2CO_3 in the EU27.	39
Figure 2-5: The contribution of recycling and substitution.	40
Figure 3-1: Coal exports from the United States to the Netherlands.	47
Figure 3-2: Overview of the system boundaries of the analysed supply system for biomass and coal.	49
Figure 3-3: Overview of the analysed supply chain scenarios.	54
Figure 3-4: The biomass and coal requirements before pretreatment.	55
Figure 3-5: Energy consumption and GHG emissions for biomass production and coal mining.	56
Figure 3-6: The energy consumption for biomass pretreatment.	56
Figure 3-7: The energy consumption and GHG emissions related to biomass and coal grinding.	57
Figure 3-8: The energy consumption and GHG emissions related to transport by truck.	58
Figure 3-9: The energy consumption and GHG emissions related to transport by Supramax.	58
Figure 3-10: The total energy consumed for 1 MJ_e output in the whole supply.	59
Figure 3-11: The relative change in GHG emissions.	60
Figure 4-1: Overview of the different process steps in the applied model.	68
Figure 4-2: Schematic overview of the MILENA gasification process.	71
Figure 4-3: Break-even transport distances for torrefaction and pelleting by truck and short sea barge.	79
Figure 5-1: Overview of the TIS functions for biomass gasification.	89
Figure 5-2: Overview of the possible green gas production routes.	90
Figure 5-3: Residential heat demand for space heating, hot water and cooking.	98
Figure A-1: Calculated modal energy intensity for truck and bulk carrier.	138
Figure B-1: Detailed overview of the supply chain energy consumption without conversion.	139
Figure B-2: Detailed overview of the supply chain GHG emissions without conversion.	139

List of tables

Table 2-1: Absolute estimated global supply data for Li_2CO_3 for both scenarios.	33
Table 2-2: Summarised input parameters for the Best case and Business as Usual scenario.	37
Table 3-1: Energy consumption and GHG emissions of coal mining and biomass production.	50
Table 3-2: The energy losses and required fossil inputs for different types of biomass pretreatment.	52
Table 3-3: Input data for coal and biomass after different types of pretreatment.	53
Table 3-4: Performance of the different scenarios per MJ of biomass.	61
Table 4-1: Upstream biomass to SNG routes.	74
Table 4-2: Input data for the simulations addressing energy consumption and GHG emissions.	75
Table 4-3: Environmental and energetic performance of the simulated scenarios.	78
Table 4-4: The environmental and energetic performance with 5% more efficient transport.	78
Table 5-1: TIS system functions and operationalised indicators applied in this research.	87
Table 5-2: Overview of the present (+) and absent (-) system functions and the systemic barriers.	93
Table 5-3: Barriers affecting change in the residential sector.	97
Table A-1: The maximum load (t) of truck and Supramax bulk carrier.	137

List of abbreviations

AD	Anaerobic digestion
BAU	Business as usual
BC	Best case
BEV	Battery electric vehicle
BFB	Bubbling fluidised bed
CHP	Combined heat and power
CO ₂ eq.	Carbon dioxide equivalent
CO ₂	Carbon dioxide
db	Dry basis
DSO	Distribution system operator
EBN	Energiebeheer Nederland
ECN	Energy research centre of the Netherlands
EE	Energy efficiency
EJ	Exajoule
EPBD	Energy performance of buildings directive
ER	Energy ratio
EU	European union
GHG	Greenhouse gas
GJ	Gigajoule
Gt	Gigaton
GTS	Gasunie transport services
GW	Gigawatt
ha	Hectare
HEV	Hybrid electric vehicle
HFO	Heavy fuel oil
ICE	Internal combustion engine
ILUC	Indirect land use change
km	Kilometre
kt	Kiloton
kWh	Kilowatt-hour
LCA	Life cycle analysis
Li ₂ CO ₃	Lithium carbonate
Li-Ion	Lithium-ion
Mha	Million hectare
MILENA	Biomass gasification technology developed by ECN optimized for SNG
MJ	Megajoule
MLP	Multi-level perspective
Mt	Megaton
Mtoe	Megaton oil equivalent
MW	Megawatt
MW _e	Megawatt electric
NAM	Nederlandse Aardolie Maatschappij
NLs	Netherlands

NO _x	Nitrogen oxides
PHEV	Plug-in hybrid electric vehicle
PJ	Petajoule
ppm	Parts per million
R&D	Research and development
RED	Renewable energy directive
SNG	Synthetic natural gas
SO _x	Sulphur oxides
t	Ton (i.e. 10 ³ kg)
TIS	Technological innovation system
tkm	Ton kilometre
TOP	Torrefaction and pelleting
TSO	Transmission system operator
US	United States
wb	Wet basis

