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TNO report

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The impact of phasing out woody biomass for heat generation in the ADAPT and TRANSFORM scenarios

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Summary

Various environmental organisations, political parties and academia have strongly criticized the use of woody biomass for energy applications due to its environmental impact. In 2020, in response to a request of the Dutch Parliament, the Dutch Ministry of Economic Affairs and Climate Change (EZK) intends to implement a phasing out strategy for the generation of heat with solid woody biomass following the advice of the Socio Economic Council (SER). According to the SER, biobased raw materials should preferably be used for high value applications such as feedstock in industrial production processes and as fibre and building materials.

TNO has analysed the consequences of phasing out woody biomass for various heat applications within the context of the energy transition, with the precondition that the transition towards a sustainable energy system in 2050 is not endangered. For this analysis, two existing scenarios were used that describe possible developments for the transition to a sustainable energy system for the Netherlands up to 2050. The scenarios – ADAPT and TRANSFORM – achieve the objective to reduce 49% of greenhouse gas (GHG) emissions by 2030 and a 95% GHG emission reduction by 2050. ADAPT and TRANSFORM differ in the way the goals are achieved. Where in the ADAPT scenario, the Dutch economy builds on existing infrastructure and current strengths, choosing for security and preserving current lifestyle, the TRANSFORM scenario envisions a society with radical behaviour and infrastructural changes towards a sustainable economy. In both scenarios, the use of biomass makes an important contribution towards lowering GHG emissions and achieving climate goals. In the ADAPT scenario, in particular, the use of bio-energy with carbon capture and storage (or BECCS) plays an important role up to 2050.

In the present report, the phasing out of biomass for heat applications was investigated by comparing quantitative projections of two scenario variants with the ADAPT and TRANSFORM scenarios as a reference. The choice of two scenario variants and some adjustments to the reference scenarios have been discussed with the Netherlands Environmental Assessment Agency (PBL). PBL used the results of the analyses to advise the Ministry of Economic Affairs and Climate Change (EZK) on the biomass phase-out policy. The quantitative projections for the scenarios and variants have been made using a techno-economic optimization model to analyse the entire Dutch energy system as an integrated system. In the first variant, woody biomass is not used for heat applications in the built environment, including district heating. In the second variant, the use of woody biomass is additionally restricted for thermal conversion in industry and in the agriculture sector.

The two scenarios variants show that a restricted supply of woody biomass leads to shifts in the allocation of GHG emissions reductions in different sectors.

Interestingly, in the ADAPT and TRANSFORM reference scenarios, woody biomass consumption for district heating and the services sector is already phased out over the years, as biomass is more cost-effectively applied in the industry sector. Therefore, phasing out woody biomass in the built environment has a limited impact on the energy system in both scenarios.

Phasing out woody biomass in the industry and agriculture sector results initially in a decrease of total biomass supply because there seems to be no cost-effective alternative applications for the biomass elsewhere in the energy system. On the long run, there is a clear noticeable impact in the ADAPT scenario. Here, the woody biomass that becomes available is shifted to biofuel and bio-methane production. Biofuels are used in the transport sector, and bio-methane (or SNG) is blended in the natural gas grid and used in the built environment sector. In this scenario variant, carbon capture and storage (CCS) in thermal processes with biomass (BECCS) is no longer used. Other processes, such as industrial heating applications with natural gas and the production of blue hydrogen (i.e. hydrogen from natural gas in combination with CCS) use the freed space for CO_2 storage. This results in an increase in natural gas supply and more hydrogen consumption in the transport, industry and built environment sectors. Other GHG emission reduction options are required to offset negative emissions attributed to BECSS, also in other sectors.

The effects in the TRANSFORM scenario in the long run are smaller, as less biomass is available than in the ADAPT scenario and most woody biomass is used as feedstock for producing chemical products.

Both scenarios show an increase in the use of electric boilers and heat pumps in the agriculture and industry sectors to replace heat production with biomass. The extra electricity is provided by increased solar energy production.

The changes in total costs for the energy system in comparison to the reference scenarios are limited if woody biomass use is only restricted in the built environment. If woody biomass use is also restricted for thermal applications in industry and agriculture sectors, the changes in the total system costs show a noticeable increase in the ADAPT scenario. This effect is much smaller for the TRANSFORM scenario.

Contents

1 Introduction

TNO has explored a sustainable energy system in the Netherlands up to 2050 using two scenarios: ADAPT and TRANSFORM. For both scenarios, a reduction of greenhouse gas (GHG) emissions in the Netherlands is assumed to a level that is 95% lower in 2050 than in 1990 as part of the effort from the Paris Agreement on Climate Change (UNFCCC, 2015) to limit global average temperature below 1.5 degrees. The scenarios differ in the way the goal is achieved, in particular the difference in intrinsic motivation of citizens and companies. In the ADAPT scenario, the Dutch economy builds on existing infrastructure and current strengths, choosing for security and preserving current lifestyle, but with a strong limitation on CO_2 emissions. In the TRANSFORM scenario, the Dutch society plays a major role in changing behaviour and opting for a radical shift to a more sustainable economy. This makes the Netherlands less energy intensive. The two scenarios are not meant to be compared with each other, but to study the impact of certain choices in different plausible futures for the Netherlands. A detailed description of the scenarios can be found in (Scheepers, et al., 2020)

For the model analyses, the OPERA optimization model has been used, which covers the total energy system of the Netherlands, i.e. all sectors (energy production, industry, transport, built environment, agricultural sector and bunker fuels for international aviation and shipping). The OPERA model calculates the energy system and the associated emissions, given specific goals (e.g. greenhouse gas reduction target) and preconditions, at the lowest costs for society. It looks for a solution with an energy and technology mix for each sector that has the lowest possible system cost, within the given constraints. This means that technology options and energy carriers compete with each other in every sector and for every energy function and the technology-energy carrier combination is chosen with the lowest costs. This applies to both the energy demand and the energy supply, where the energy demand determines the energy carrier, and thus the type of energy supply. For the availability of energy sources, potentials are used as a boundary condition and the optimization determines how much of the potential is used in a specific scenario.

In the present study, the ADAPT and TRANSFORM scenarios are used to analyse the impact of phasing out woody biomass for heat generation in a sustainable energy system by 2050. The OPERA model is used for the analysis. The following sections describe the motivations to carry-out this analysis.

1.1 Socio-political views on woody biomass use

Various environmental organisations, political parties and academia criticize the use of biomass for energy applications because of the risks of damage to nature and biodiversity. However, the use of biomass in the energy system can make an important contribution to lowering GHG emissions and achieving climate goals. Biomass has a much shorter carbon cycle than fossil energy carriers and the CO_2 emissions from the use of biomass can be compensated by new trees and plants. PBL, the Netherlands Environmental Assessment Agency, has made an overview of these different opinions regarding availability and use of biomass (Strengers & Elzenga, 2020). In 2020, the Dutch Parliament asked the government to phase-out the use of woody biomass for heat generation (Wiebes, 2020). In response, the Minister of Economic Affairs and Climate Policy (EZK, *Ministerie van Economische Zaken en Klimaat*) sent a letter to parliament that states that there will be no new subsidy for the production of electricity with solid woody biomass, also stricter emission requirements for smaller boilers will apply, and a phasing out strategy will be developed for the generation of heat with solid woody biomass (EZK, 2020). The minister also refers to the advice of the Socio Economic Council (SER) that provides a sustainability framework for the use of biomass (SER, 2020). According to the SER advice, biobased raw materials should preferably be used for high value applications such as feedstock in industrial production processes and as fibre and building materials. The SER sees a limited role for energetic applications in the long term (in particular for electricity generation and heat production) because of the availability of alternatives. In the short-term, the SER envisages a role for woody biomass as a bridging solution in sectors that have difficulty in becoming sustainable, such as heavy road transport, aviation and shipping. In the long-term, the SER expects that for these sectors, synthetic fuels will become available as an alternative for biofuels.

1.2 Analysis of phasing out woody biomass for heat generation

The socio-political developments described above are the main reason to investigate the impact of phasing out woody biomass for heat generation on a future sustainable energy system. The question that is answered in the present study is: what are the consequences for a sustainable energy system when woody biomass is restricted in the built environment, agriculture and industry sectors?

To answer the question, the ADAPT and TRANSFORM scenarios have been updated in line with the Climate Agreement (Klimaatakkoord, 2019) using RVO prognosis[1] for biomass use (RVO, 2020). Subsequently, the phasing out of woody biomass for heat generation was analysed using the OPERA model for the new updated ADAPT and TRANSFORM scenarios in two variants. The choice of two scenario variants and some adjustment to the reference scenarios have been discussed with PBL. Also, the results of this analysis are used by PBL for an advice to the ministry of EZK on a phase out strategy for the subsidization of woody biomass for new biomass plants for heat generation. PBL's advice can be found in the report '*Advies uitfasering houtige biogrondstoffen voor warmtetoepassingen'* (Strengers & Elzenga, 2020).

In Chapter 2, the analysis approach is explained in more detail. Subsequently, in Chapter 3, the results of the analysis are presented and discussed for the physical energy system and for the total system costs. Lastly, the main conclusions are formulated in Chapter 4.

[1] A public overview of all SDE + decisions can be found at: https://www.rvo.nl/subsidie-en-financieringswijzer/stimulering-duurzame-energieproductie-en-klimaattransitie-sde/feiten-en-cijfers-sde-algemeen. Additional information has been requested for this report, which has not be disclosed publicly.

2 Approach

In the present study, the impact of phasing out woody biomass in the Dutch sustainable energy system has been investigated for the ADAPT and TRANSFORM scenarios using the optimization model OPERA. The ADAPT and TRANSFORM reference scenarios have been updated with changes in the input parameters (see section 2.2). For the analysis, we “turned the dials” of the model, changing the assumptions regarding the use of woody biomass in different end use sectors for the two scenarios.

Two variants compared to the ADAPT and TRANSORM (updated) reference scenarios have been investigated:

1. No woody biomass in the built environment, including district heating.
2. In addition to variant 1, no woody biomass in the agriculture sector and for thermal conversion in industry.

In both variants the total available amount of biomass remains the same as in the reference scenarios.

The next section describe the main differences between the two scenarios in terms of most distinctive model parameters. Then, the changes in model parameters are specified to update the ADAPT and TRANSFORM reference scenarios (section 2.2). Section 2.3 detail the assumptions undertaken for the reference and variant 1 and 2 scenarios. Lastly, the updated reference scenarios are illustrated in section 2.4

2.1 Main model parameters

To understand the results, beyond differences in biomass availability, other scenario parameters should be considered, in particular the differences between the two scenarios. Table 2-1 provides an overview of the main and distinctive parameters. See (Scheepers, et al., 2020) for more details on the input parameters.

Table 2.1 Main and distinctive parameters in the ADAPT and TRANSFORM base scenarios

	ADAPT	TRANSFORM
National GHG reduction target	2030: -49% 2050: -95%	2030: -49% 2050: -95%
GHG reduction target international aviation and shipping	2050: -50%	2050: -95%
Fossil fuel prices	Constant after 2030	Constant after 2030
Industry		
• Energy demand	↑	↓
• Production	↑	↓
Energy demand service sector	↑	↑↑
Energy demand agriculture sector	↑	↓
Mobility demand		
• Domestic	↑	↓
• International	↑	↓
Biomass availability		
• Domestic	ooo	o
• Imports	ooo	o
Carbon Capture and Storage (CCS)	Yes	No
Coal-fired power plants	No	No

↑ means growth, ↓ shrinkage and ↑↑ extra growth, ooo means ample and o limited availability

2.2 Changes in input parameters

For the ADAPT and TRANSFORM scenarios, the optimization model OPERA calculates an energy mix taking into account two objectives (minimum system costs and maximum GHG emissions) and a number of boundary conditions. Although the number of boundary conditions should be limited to allow cost optimal results and to avoid unexpected radical changes from one year to another; for the present analysis, some extra boundary conditions have been added to the reference scenarios. These conditions are added to ensure that the scenarios are more in line with the Climate Agreement for 2030 at the beginning of the considered time period (2030-2050), and also in line with the biomass use resulting from incentive policies, such as SDE (Stimuleringsregeling Duurzame Energieproductie).

The changes in parameters that have been implemented for the ADAPT and TRANSFORM reference scenarios are listed below:

- A limit of woody biomass use has been applied to the reference scenarios. This includes: (1) the use of wood for fireplaces and stoves in households kept at a constant value for all years according to (KEV, 2020) with no additional restrictions, (2) a minimum use of woody biomass in the services sector (including district heating), in agriculture and in industry according to (PBL, 2019), (3) an increase in the woody biomass potential in TRANSFORM 2030, 2035 and 2040 in order to meet the minimum uses allocated in the services, industry and agriculture sectors, and (4) a minimum use of woody biomass in TRANSFORM as raw material for feedstocks in 2035 – 2050 in line with the SER advice that biobased raw materials should be used as much as possible (SER, 2020) and is consistent with the assumption in this scenario regarding industrial transformation, i.e. implementing new sustainable production processes. In the ADAPT scenario, this boundary condition is not applied because the assumption in this scenario is that most industrial production plants will remain. In TRANSFORM in 2050, about 85% of the available woody biomass (domestic and import) is used as feedstock. The details on the specific values can be found in Table 2-4 and Table 2-5.

- Climate Agreement measures have been included for 2030 (Klimaatakkoord, 2019) such as the number of electric vehicles (EVs) and hydrogen passenger cars[2], a maximum amount of hydrogen allowed in the built environment sector[3], and a minimum use of biofuels (Table 2-4 and Table 2-5). It is also assumed that the quantity of first generation biofuels will not increase compared to the level in 2020. Moreover, it was intended to apply a cap of GHG emissions to the industry sector in 2030. However, this limit resulted in drastic and unrealistic effects. In the original scenarios (Scheepers, et al., 2020), industry already had more than 20% of GHG emissions higher in 2030 (both scenarios) than the intended cap from the Climate Agreement.

- The year 2035 has been included for the present analysis following a vintage approach to transfer the existing capacity to the following period.

- A maximum production of biogas from manure digestion limited to 1.5x the utilization[4] according to the 'doorrekening' Climate Agreement (PBL, 2019), as a 100% utilization is unrealistic in 2030.

- Combined heat and power (CHP) using woody biomass in the services sector is no longer allowed following the (KEV, 2020). In the TNO scenario study (Scheepers, et al., 2020), it played a large role, however in (KEV, 2020), CHP using woody biomass is zero (only a limited amount of boilers).

- A cap in synthetic fuels in 2030, because synthetic fuel production capacity has to be developed.

2.3 Assumptions

Table 2-2 shows the assumptions for biomass availability for the ADAPT and TRANSFORM scenarios. These assumptions remain the same in variant 1 and variant 2. The prices for biomass commodities are the same for ADAPT and TRANSFORM and are given in Table 2-3.

Table 2.4 shows the potentials for wind and solar energy used for ADAPT and TRANSFORM. Also these figures remains the same in variant 1 and 2.

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[2] About 1.5 million electric vehicles.
[3] A maximum of 0.5 PJ of hydrogen is allowed.
[4] This translates into a maximum production of 5.6 PJ of biogas from manure digestion.

Table 2.2 Assumptions on biomass availability (PJ) in ADAPT and TRANSFROM reference scenarios, variant 1 and variant 2

Biomass availability (PJ)	ADAPT scenarios				TRANSFORM scenarios			
	2030	2035	2040	2050	2030	2035	2040	2050
Total biomass domestic[5]	220	220	220	220	220	202	183.5	147
of which woody biomass	82	86	91	100	82	70	58	34
Woody biomass imports	187	269	351	515	104	110	116.4	129
Total woody biomass	269	355	442	615	186	180	174	163
Biofuels imports	10	14	18	25	10	14	18	25
BioHFO imports	1	46	91	182	1	334	66	132
Biokerosene imports	1	15	29	57	1	19	37	73

Table 2.3 Prices for biomass commodities in €$_{2015}$ per GJ for both ADAPT and TRANSFORM scenarios

Commodity	2030	2035	2040	2050
Woody biomass	8.0	8.0	8.0	8.0
Used fats and oils	16.2	16.2	16.2	16.2
Co-substrate	7.7	7.7	7.7	7.7
Oil crops	26.7	26.7	26.7	26.7
Sugar crops	20	20	20	20
Starch crops	7.5	7.5	7.5	7.5
Biofuel	23.7		46.5	69.4

Table 2.4 Wind and solar PV potentials in ADAPT and TRANSFORM scenarios

GWe	2030	2035	2040	2050
Wind onshore				
ADAPT	7.8	8.2	8.7	7.8
TRANSFORM	7.8	8.9	10.0	12.0
Wind offshore				
ADAPT	11.5	23.7	35.9	40.0
TRANSFORM	14.5	39.8	45.0	60.0
Solar PV				
ADAPT	25.5	44.4	63.2	106.7
TRANSFORM	40.5	59.3	78.2	132.1

Table 2.5 and Table 2.6 show the sector restrictions on the use of woody biomass and other biomass in the ADAPT and TRANSFORM scenarios, respectively.
In variant 1, the use of woody biomass in the services sector and for district heating has been restricted to zero for the years 2035, 2040 and 2050. In 2030, woody biomass will still be used in this sector because of the SDE++ commitments. Therefore, the RVO projection (2020) is respected with at least 9.9 PJ of woody biomass used in the services and energy sector. In variant 2, the use of woody biomass is not only restricted in the built environment sector, but also in agriculture and industry sectors. Thus, phasing out the use of woody biomass for heat generation. Because of SDE++ commitments, in 2030, at least 6.7 PJ of woody biomass is used in agriculture and 5.5 PJ in industry (RVO, 2020).

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[5] Next to domestic woody biomass, there are digestible waste streams like manure, biogenic municipal solid waste, crops for first generation biofuels, and used fats and oils.

Table 2.5 Sector restrictions on woody biomass use and other biomass (PJ) in ADAPT reference scenarios, variant 1 and variant 2[6]

	ADAPT Reference				ADAPT – variant 1				ADAPT – variant 2			
	2030	2035	2040	2050	2030	2035	2040	2050	2030	2035	2040	2050
Sector restrictions on woody biomass use (PJ)												
Households	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
Min Services and energy sector (on site and district heating)	25.7[7]	27.9			9.9[8]				9.9			
Max Services and energy sector (on site and district heating)						0	0	0		0	0	0
Min Agriculture	6.7[3]	5			6.7	5			6.7			
Max Agriculture										0	0	0
Min Combustion Industry	76.7	76.7			76.7	76.7						
Max Combustion Industry									5.5[3]	0	0	0
Min Feedstock synthesis												
Sector restrictions other biomass (PJ)												
Min total biofuels	61.7[9]				61.7				61.7			
Max first generation biofuels	6.5[10]				6.5				6.5			

6 Whenever no values appear in the table, the model has the freedom to optimize them.
7 (KEV, 2020), year 2030: Services sector 2.3; Energy sector: 23.3. Energy sector is not only district heating, since 6.4 PJ of woody biomass is used in CHP
8 (RVO, 2020)
9 Climate Agreement (Klimaatakkoord, 2019)
10 Estimated maximum for year 2020, first generation biofuel consumption cannot be larger than 2020 volume

Table 2.6 Sector restrictions on woody biomass use and other biomass (PJ) in TRANSFORM reference scenarios, variant 1 and variant 2[11]

	TRANSFORM Reference				TRANSFORM – variant 1				TRANSFORM – variant 2			
	2030	2035	2040	2050	2030	2035	2040	2050	2030	2035	2040	2050
Sector restrictions on woody biomass use (PJ)												
Households	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
Min Services and energy sector (on site and district heating)	25.7[12]	27.9			9.9[8]				9.9			
Max Services and energy sector (on site and district heating)						0	0	0		0	0	0
Min Agriculture	6.7[13]	5			6.7	5			6.7			
Max Agriculture										0	0	0
Min Combustion Industry	76.7	76.7			76.7	76.7						
Max Combustion Industry									5.5[8]	0	0	0
Min Feedstock synthesis		35	69.9	139.89[14]		35	69.9	139.89		35	69.9	139.89
Sector restrictions other biomass (PJ)												
Min total biofuels	45.6[15]				45.6[10]				61.7			
Max first generation biofuels	6.5[16]				6.5				6.5			

[11] Whenever no values appear in the table, the model has the freedom to optimize them.

[12] (KEV, 2020), year 2030: Services sector 2.3; Energy sector: 23.3. Energy sector is not only district heating, since 6.4 PJ of woody biomass is used in CHP

[13] (RVO, 2020)

[14] The 2050 value is based on a replacement of 30% of oil for feedstock, which fits with the potential assumptions. 2035 and 2040 values are based on interpolation. This also applies to variants 1 and 2.

[15] Climate Agreement (Klimaatakkoord, 2019); Note: it appeared that a minimum of 61.7 PJ of biofuel consumption was not feasible in TRANSFORM 2030-ref and 2030-v1, given the availability of biomass. Therefore, a lower minimum level is assumed.

[16] Estimated maximum for year 2020, first generation biofuel consumption cannot be larger than 2020 volume

2.4 Updated reference scenarios

Figure 2.1 depicts the ADAPT and TRANSFORM new reference scenarios. The total primary energy supply, both in ADAPT and TRANSFORM, decrease after 2030 because the energy system becomes more efficient. Electricity generation from wind and solar substitutes gas fired thermal power plants, and electric vehicles (EV's) and plug-in hybrid cars replace cars with internal combustion engines (ICE). In 2040, in the ADAPT scenario, the total primary energy supply increases because of the assumed energy demand growth in this scenario, but also because of increasing energy losses in energy conversion (e.g. hydrogen and synthetic fuel production) and energy use for CO_2 capture and storage (CCS). In 2050, the relatively high amount of oil is still used for international shipping and aviation and for feedstocks. In TRANSFORM, the energy demand is lower than in ADAPT because of scenario assumptions (e.g. behavior change of citizens resulting in less transport demand and less energy intensive industrial production). But also in this scenario, losses in the energy system increase in 2050. The use of fossil oil is declining sharply in TRANSFORM because in 2050 a 95% GHG reduction target also applies in international aviation and shipping sector – in ADAPT this is only 50% – and the use of biomass for feedstocks.

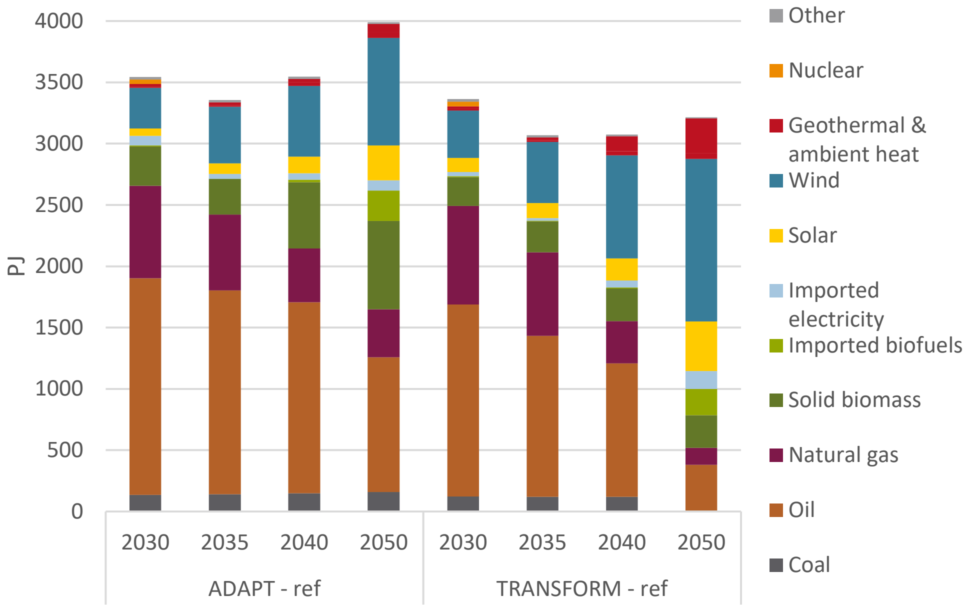

Figure 2.1 Primary energy use in ADAPT and TRANSFORM reference scenarios (including feedstock use and energy use for international aviation and shipping)[17]

The use of woody biomass is lower in TRANSFORM because there is less availability than in ADAPT. In 2050, 85% of the woody biomass potential is used for feedstocks in this scenario. This is a direct consequence of the changes in the input

[17] The final fuel consumption for international shipping and aviation is 769 PJ and 862 PJ in ADAPT 2030 and 2050, respectively; and 674 PJ and 434 PJ in TRANSFORM 2030 and 2050, respectively. Bunker fuel demand is met either with fossil fuels or with bio-based or synthetic substitutes. The non-energy use of fuel (e.g. petrochemical feedstock) is 577 PJ and 646 PJ in ADAPT 2030 and 2050, respectively; and 512 PJ and 391 PJ in TRANSFORM 2030 and 2050, respectively.

parameters (section 2.2). In comparison to the original scenarios (Scheepers, et al., 2020), the potential for woody biomass in ADAPT and TRANSFORM has only changed for TRANSFORM 2030 and 2040 (see Table 2-2). In ADAPT, it is assumed that the domestic availability increases through the years and the maximum import of woody biomass is relatively high (515 PJ in 2050). In TRANSFORM however, there is a decrease in woody biomass domestic availability and imports. For both ADAPT and TRANSFORM, the potential for other types of biomass is not fully utilized, in particular not for crop based biomass. Towards 2050 the utilization rate increases.

The next chapter discusses the results of applying variant 1 and 2 to the ADAPT and TRANSFORM scenarios.

3 Results of the scenario variants

In this chapter, the scenario results for the two variants are compared to the figures of the reference scenarios and the major changes are discussed. After presenting, the changes in primary energy supply (section 3.1) an overview is given (section 3.2) of biomass consumption in the reference, variant 1 and variant 2 scenarios to assess the changes after phasing out woody biomass in the built environment, industry and agriculture sectors. The next sections present effects in total system costs, CO_2 shadow price, changes in the specific end use sectors, energy production and carbon capture and storage.

3.1 Change in primary energy supply

The changes in primary energy supply between the two reference scenarios and variants 1 and 2 are depicted in Figure 3.1. Negative numbers indicate a reduction and positive numbers an increase of a primary energy source. In variant 1, for both scenarios, there is a small impact on primary energy supply. Effects are primarily results of shifts between applications and sectors. In variant 2 however, there is an increase in natural gas use in both scenarios and in almost all years, allocated primarily to the industry sector in the initial years.

In ADAPT variant 2, in 2030, the decrease in woody biomass supply is caused by lower demand from industrial boilers and CHP, which is not taken up for biofuel production given that there is not enough demand for biofuels in the transport sector due to high electrification of vehicles. This is different in 2040 and 2050 where woody biomass supply is shifted from industry boilers and CHP to biofuel production because of growing demand from international aviation and shipping (so called bunker fuels), thus showing a decline in oil consumption in 2040 and 2050. Also, bio-methane is produced in 2040 and 2050 which is blended with natural gas in the gas grid. Since industry cannot apply bio-energy with carbon capture and storage (BECCS), other sectors need more GHG reductions. In 2040 and 2050, an increase in ambient heat (heat used by heat pumps) and solar energy is not only compensating for the loss of biomass-based heat from industry, but also compensates for less GHG reductions in the industry sector. The significant increase in primary energy supply in ADAPT variant 2 in 2050 is mainly due to natural gas with CCS to produce hydrogen.

TRANSFORM variant 2 in 2030 and 2035 shows a decrease in woody biomass supply for the same reasons as in ADAPT variant 2. In TRANSFORM variant 2, in 2040, the woody biomass from industry is shifted to biofuels production, therefore there is no difference in its net supply. Since most of the biomass is used as feedstock, a small amount (6.5 PJ) is used in variant 2 in 2050 for production of biofuels. Also, other changes in the energy mix occur, such as a decline in ambient heat (heat pumps) in 2050, mainly in the built environment, as cost-effective emissions reduction opportunities elsewhere in the energy system exist.

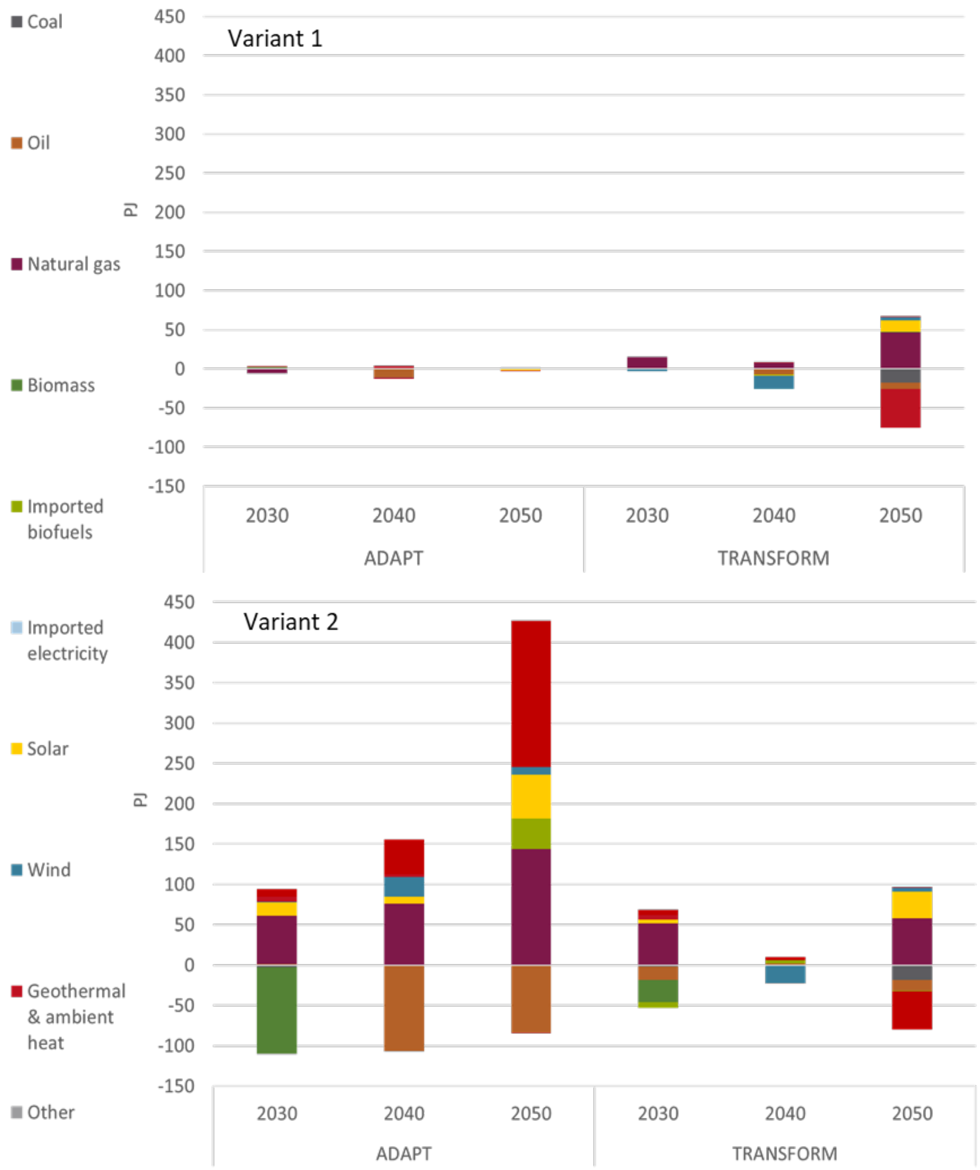

Figure 3.1 Change in primary energy supply in ADAPT and TRANSFORM variant 1 (top) and variant 2 scenarios (bottom) relative to ADAPT and TRANSFORM reference scenarios

3.2 Biomass consumption

Reference scenarios

As seen in Figure 3.2, in the reference scenarios, woody biomass consumption for district heating and the services sector (orange line) is already phased out over the years, as woody biomass is applied more cost-effectively in other sectors. In both reference scenarios and variants, the use of woody biomass in the household sector (for fireplaces and stoves) is fixed at 15.3 PJ (dark blue line).The up and down pattern for biofuels consumption (light blue line) is attributed to the minimum value set for biofuels in 2030 from the Climate Agreement (see section 2.2), followed by the growth of electric vehicles in 2035 resulting in a decrease of biofuels consumption; and after 2035, there is more biofuel needed for international aviation and shipping (bunkers fuels), causing the increase in 2040. In 2050, synthetic fuels become competitive resulting in a decline of biofuels use. In ADAPT, the use of woody biomass in industry for heat applications increases (yellow line) after 2035. In TRANSFORM, it is assumed that an increasing portion of woody biomass is used as feedstock in new industrial processes (green line). This results in a decrease of woody biomass use in boilers and combined heat and power (CHP) plants. In the reference scenario, woody biomass is not used for central electricity generation and production of synthetic natural gas (SNG).

Scenario variants ADAPT
In ADAPT reference and variant 1 scenarios, after 2035, BECCS in industry becomes an increasingly important cost-effective option leading to negative emissions. However in ADAPT variant 2, the phase out of woody biomass for heating applications in industry results in a shift of biomass use to the production of biofuels and bio-methane[18]. BECCS is no longer applied. In variant 2, woody biomass used for heating applications in industry is substituted by natural gas with CCS, heat pumps, mechanical vapor recompression (MVR) and electric boilers.

Scenario variants TRANSFORM
In TRANSFORM in 2050, 85% of the total available woody biomass (domestic and imports) is used as feedstock. In the reference scenario, the remainder is used in households and boilers in industry. In TRANSFORM variant 1, woody biomass used for district heating and in the service sector shifts to biofuels production as this is more cost-effective than heat applications in industry given that no CCS is allowed in TRANSFORM. Also in TRANSFORM variant 2, woody biomass consumption for industrial heating applications shifts to biofuels production.

[18] Bio-methane is assumed to be produced in a biorefinery process that also produces biofuels and bio-feedstock. Bio-methane or synthetic natural gas (SNG) is blended with natural gas.

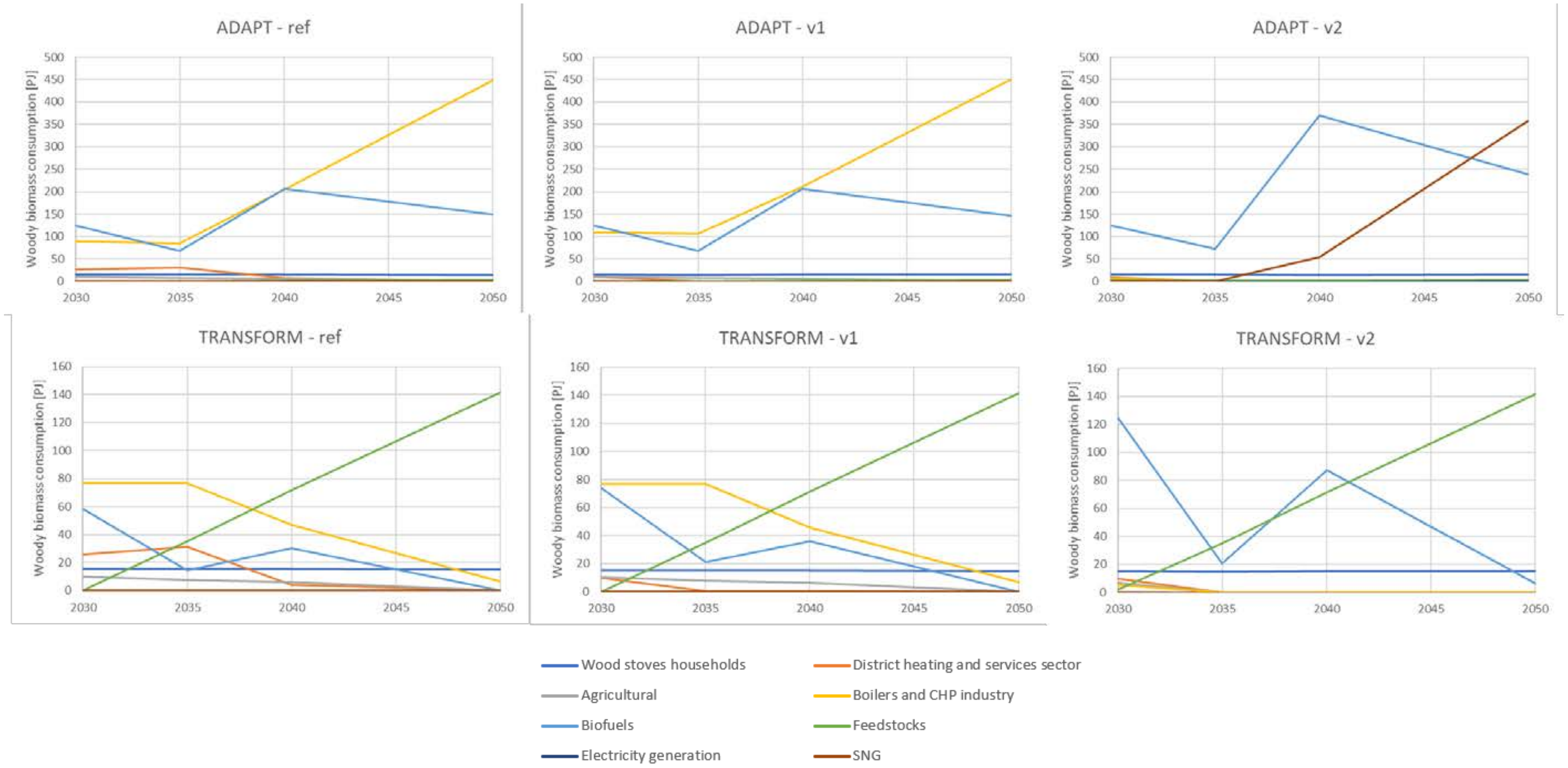

Figure 3.2 Biomass consumption in ADAPT and TRANSFORM reference, variant 1 and variant 2 scenario

Biofuels consumption
There are not many changes in biofuels consumption in variant 1 in comparison with both reference scenarios. In ADAPT variant 2 however (Figure 3.3), domestic freight transport (mainly biodiesel) becomes more attractive in 2040, but in 2050 almost all biofuels consumption is directed to international shipping and aviation (bunker fuels). In 2035 (both scenarios, both variants), the high electrification of domestic transport results in less demand for biofuels.

Figure 3.3 Biofuels consumption in ADAPT (top) and TRANSFORM (bottom) for reference, variant 1 and variant 2 scenarios

3.3 Change in total energy system costs

The OPERA model calculates the total system costs of the Dutch energy system by adding up all annual costs of energy production and usage options, along with infrastructure usage costs, costs for energy and CO_2 storage, and purchasing costs for imported minus sales revenues of exported energy. In the TRANSFORM reference scenario, the boundary condition of a minimum use of woody biomass allocated in the services sector (including district heating), agriculture and industry in 2030 and 2035 (see Table 2-5) has an increasing effect on total system costs. When this boundary condition is released in variant 1 and variant 2 the woody biomass is allocated more cost-effectively in other sectors, such as in industry or for biofuels and bio-methane production, resulting in lower total system costs in TRANSFORM variant 1 and variant 2 in 2030 and 2035 in comparison with the TRANSFORM reference scenario (Figure 3.4). Moreover, in TRANSFORM 2030 and 2035, the demand for woody biomass for biofuels production is still modest due to increasing electrification in transport. In the TRANSFORM reference scenario in 2040, there are still boilers available, which are built before 2040. Since the woody biomass can be more cost effectively used in industry, their utilization is low leading to additional costs. In variant 1 and 2, these stranded assets do not exist, therefore the total system cost of variant 1 and 2 are lower in 2040 than in the TRANSFORM reference scenario. In 2050 the restrictions on woody biomass use in the two variants lead to higher total system costs because other, more expensive technologies are needed to reduce GHG emissions.

The difference in total system costs for ADAPT variant 1 and 2 in 2030 and 2035 is almost zero in comparison to the reference scenario. The effects on total system costs in ADAPT variant 2 in 2040 and 2050 are greater because CCS is no longer used in combination with biomass (BECCS), hence more emissions have to be reduced to compensate for the negative emissions. Also, the production of biofuels and bio-methane is a more expensive route to reduce CO_2 emissions than the direct combustion of woody biomass in industry.

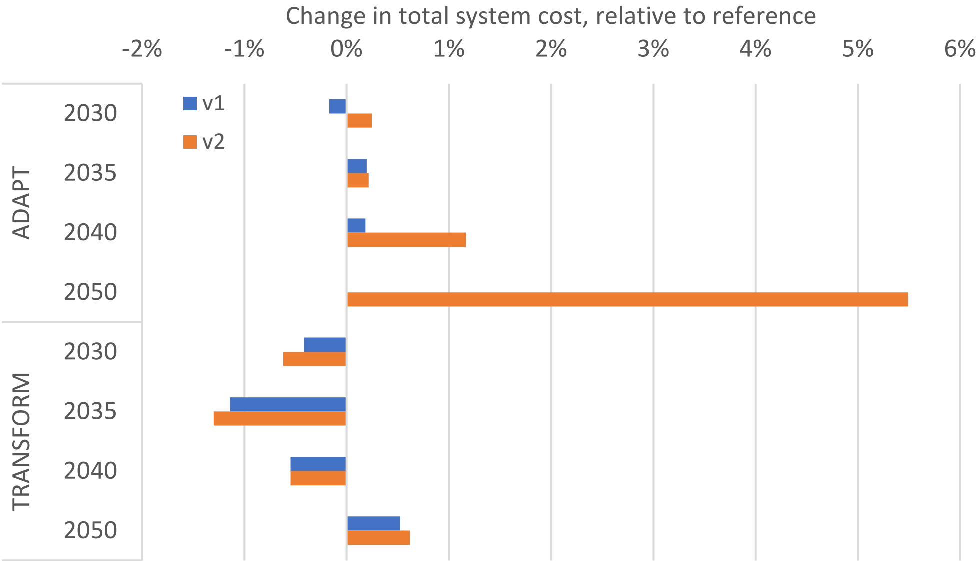

Figure 3.4 Change in total energy system costs in variant 1 and variant 2 of ADAPT and TRANSFORM relative to reference scenarios

3.4 CO_2 shadow price

The CO_2 shadow price is calculated by dividing the annual costs of the most expensive option that realizes the last kilogram of GHG reduction in the system by the GHG emission that this option reduces. The CO_2 shadow price shows the extent to which costly reduction options must be used to achieve the GHG reduction target. The CO_2 shadow price can be higher in the variants than in the reference, while the total system costs are lower. This is because some technology options can have different number of operating hours in the variants compared to the reference. Therefore, the contribution to the GHG reduction varies, while the (fixed) costs remain the same. This is the case for TRANSFORM in 2030. Overall there is an increase in the CO_2 shadow price (Figure 3.5), in particular in variant 2. In later years, the CO_2 shadow price in TRANSFORM is higher than in ADAPT because no CCS (with relative lower costs) is applied in TRANSFORM. The higher CO_2 shadow price in ADAPT variant 2 can be explained because biomass is no longer used in combination with CCS, which must be compensated by other, more expensive emission reduction options. In TRANSFORM 2050 variant 2, the CO_2 shadow price is higher than in the reference, this is attributed, amongst others, to the switch of steel production based on coal to molten oxide electrolysis (ULCOLYSIS), ammonia production from electrolysis, Power-to-Liquids (P2L) with DAC, N_2O emissions reductions and SOEC/alkaline electrolysis.

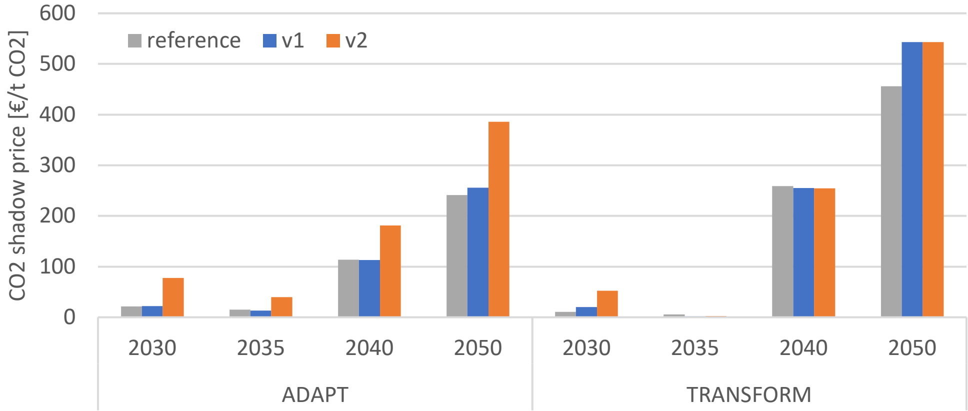

Figure 3.5 CO_2 shadow price in ADAPT and TRANSFORM reference scenarios and variant 1 and variant 2

3.5 Change in energy consumption per sector

Transport sector
Figure 3.6 depicts the changes in net energy use in the transport sector for variant 2. In variant 1, the changes in the transport sector are minor. In variant 2, the changes are more substantial, in particular from 2040 onwards. In 2035, in both variants, there are less changes in comparison to the reference scenarios as the electricity consumption in transport remains high (due to more electric vehicles) and there is less demand for biofuels. In both scenarios, there is an overall increase in biofuels use in the transport sector in 2040 and 2050 mainly for international shipping and aviation, replacing oil in ADAPT and a mix of fuels in TRANSFORM. Biofuels are either produced domestically or imported. Moreover, in variant 2, hydrogen consumption for freight transport increases in ADAPT, but decreases in TRANSFORM in 2040 due to the higher availability of woody biomass for biofuels. In this scenario, however, use of woody biomass as feedstock will increase in 2050, so that no woody biomass remains available for the production of biofuels.

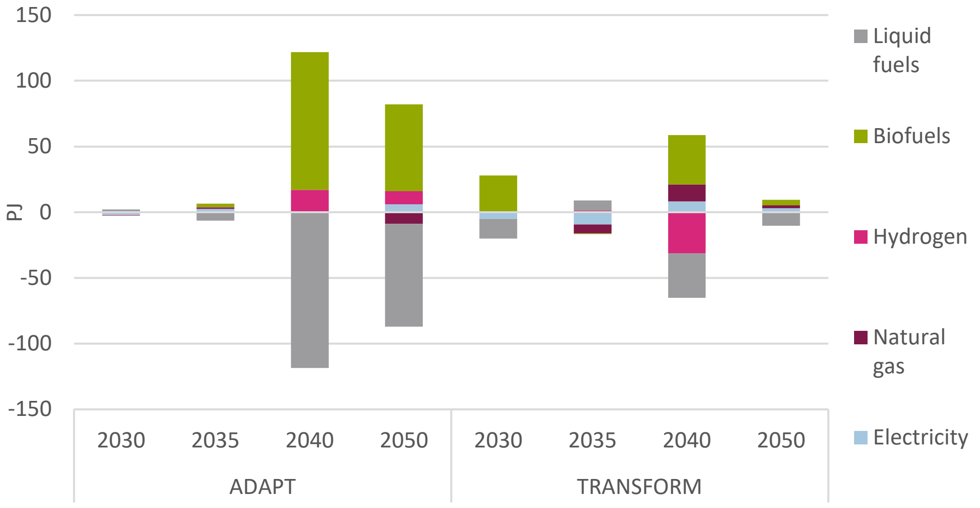

Figure 3.6 Change in net energy use in the transport sector in variant 2 for ADAPT and TRANSFORM relative to reference scenarios[19] [20]

Built environment sector
In variant 1, in both scenarios, the only woody biomass in the built environment is wood stoves in households, which is held constant throughout all years. In TRANSFORM variant 1, less emissions reductions are allocated to the built environment, as the model chooses additional reductions in industry and transport sectors instead. As a consequence, in variant 1 in 2050, the built environment uses more natural gas and less heat pumps (using ambient heat and electricity) compared to the reference scenario, similar to what is shown below for variant 2.

Figure 3.7 depicts the changes in net energy use in built environment sector for variant 2. In variant 2 in 2030, heat pumps replace electric boilers in both scenarios. In 2035 in both scenarios (and also in variant 1), biomass and oil boilers in the service sector are phased out. Here, there is a small shift to heat pumps from electric boilers, leading to higher ambient heat consumption and lower electricity consumption. Increased decentralized solar photovoltaic (PV) production also reduces the net electricity consumption from the grid. The shift to heat pumps and solar PV production can already be seen in 2030 variant 2. In 2050, electricity production from distributed solar PV increases in both scenarios.

In variant 2 in ADAPT in 2040 and 2050 bio-methane is mixed with natural gas. However, this does not lead to a visible change in gas consumption. In TRANSFORM in 2050, the growth in heat pump use in the built environment is smaller in favour of more natural gas use as a result of the cost-optimal reallocation of the permitted remaining GHG emissions across the sectors.

[19] Liquid fuels refers to oil products and their substitutes of bio and synthetic origin (i.e. diesel, biodiesel, and synthetic diesel). These are used interchangeably by the model in final energy consumption. This applies to all subsequent figures in the report.

[20] Negative changes in “liquid fuels” represent increased production of liquid fuels from biofuels (for example, biodiesel to diesel).

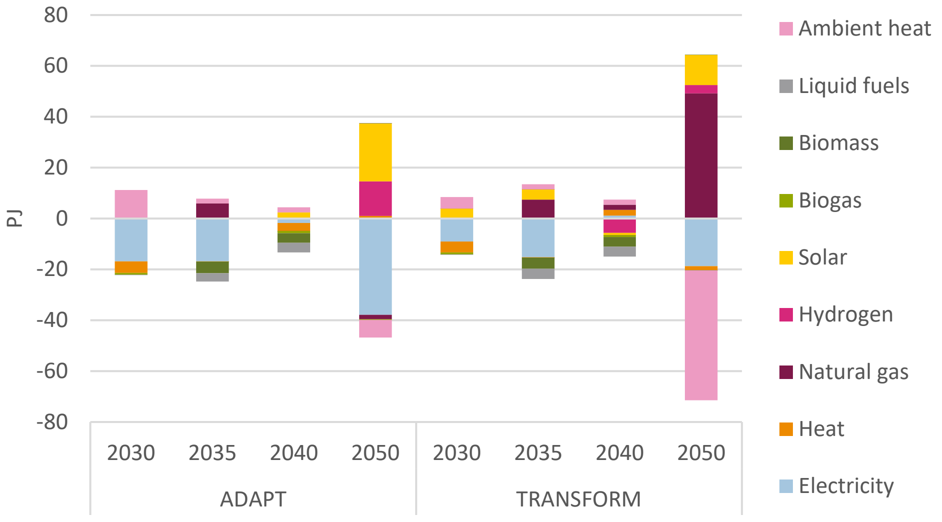

Figure 3.7 Change in net energy use in the built environment sector in variant 2 for ADAPT and TRANSFORM relative to reference scenarios

Agriculture sector
Figure 3.8 depicts the changes in net energy use in agriculture sector for variant 2. In variant 1, initially there are no major changes as the woody biomass use remains relatively the same as the reference.

In variant 2, woody biomass is phased out in the agriculture sector. In 2035, both in ADAPT and TRANSFORM scenarios, the heat from biomass boilers is replaced by natural gas boilers. In ADAPT variant 2, and also in 2050 TRANSFORM variant 2, there is more solar PV production, because of increasing electricity demand in the total energy system. The agriculture sector produces more electricity with decentralized solar PV given the limitations of using woody biomass for CHP. Note that the greater demand for electricity results on an increase in electricity prices, thus creating an incentive for investments in solar PV in end-use sectors. The sector also uses more heat pumps but less residual heat from industry.

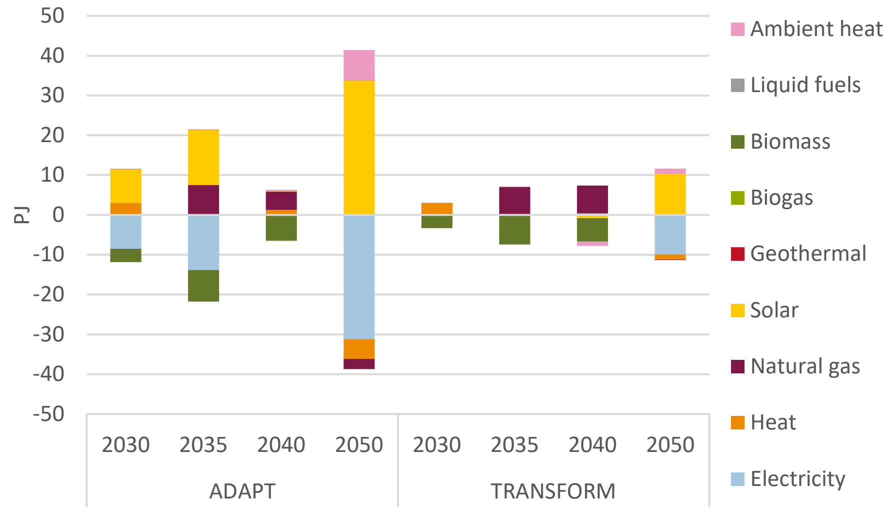

Figure 3.8 Change in net energy use (PJ) in the agriculture sector in ADAPT and TRANSFORM variant 2 scenarios relative to ADAPT and TRANSFORM reference scenarios

Industry sector
Figure 3.9 depicts the heat generation in industry for variant 2 for both scenarios, . Compared to the reference, in ADAPT and TRANFORM variant 1, there is hardly any change in the energy mix to generate heat in industry. In ADAPT variant 2, woody biomass for heat generation in industry is initially substituted by natural gas (with CCS), and in 2040 and 2050, also electrified via heat pumps, MVR, and electric boilers. Although the use of biomass for heat generation is lower in the TRANSFORM scenario, the shifts in variant 2 are similar with the ADAPT scenario. In TRANSFORM 2040 however, there is additional hydrogen, but it is replaced with electricity in 2050.

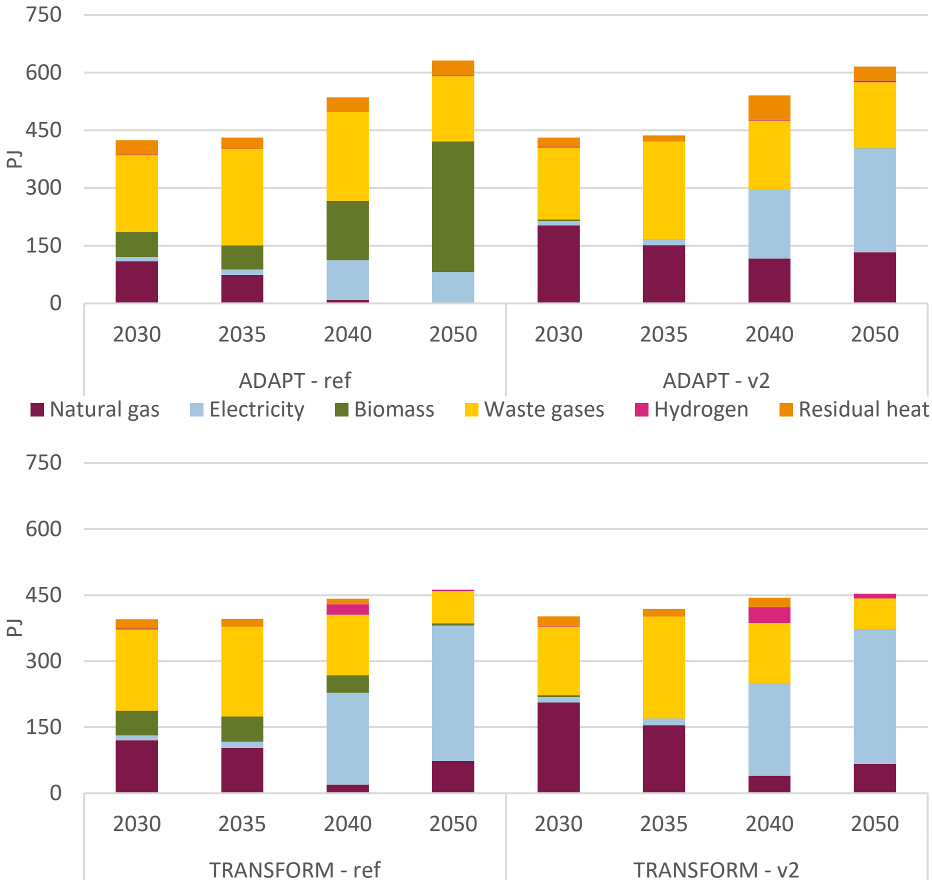

Figure 3.9 Heat generation in the industry sector in ADAPT and TRANSFORM reference scenarios and variant 2

3.6 Energy production

Heat supply
Figure 3.10 shows total heat generation including centralized heat production, built environment, agriculture sector and industry for variant 2 for both scenarios. There are no major changes in variant 1 in ADAPT and TRANSFORM in comparison to the reference scenarios. In variant 2 for both scenarios, there is an increase of heat supply from natural gas in the initial years, and in ADAPT variant 2 in 2040 and 2050, more heat is supplied with heat pumps and with natural gas (blended with SNG). In both scenarios, there are also small increases in hydrogen and geothermal heat in later years.

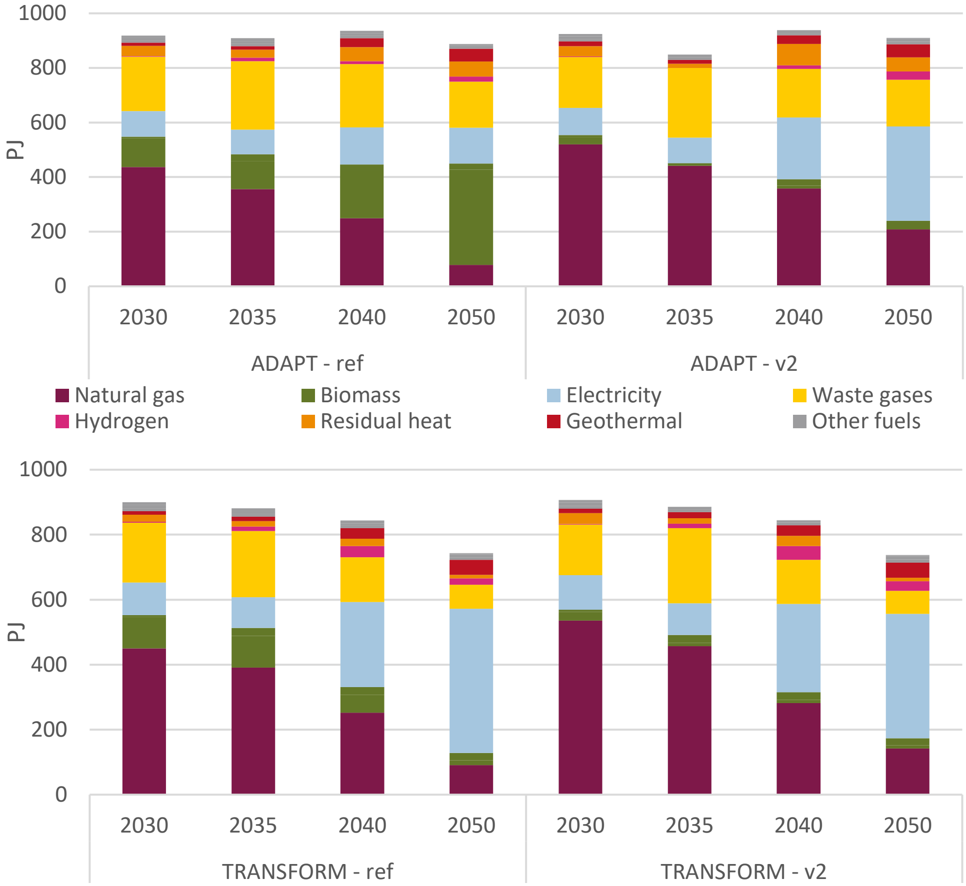

Figure 3.10 Heat supply (PJ) in ADAPT and TRANSFORM reference scenarios and variant 2

Electricity generation

Solar PV capacity mainly increases in variant 2 as can been seen in Figure 3.11. Only in ADAPT 2050 variant 2, the full potential of solar PV is utilized. The electricity generation with solar PV is partially used within the agriculture and built environment sector. Wind energy and solar PV potentials allocated in the two scenarios are found in Table 2.4.

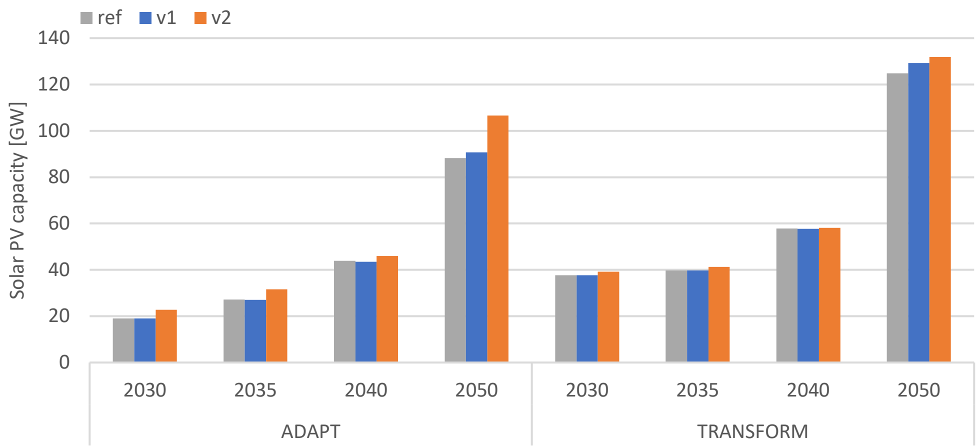

Figure 3.11 Solar PV capacity (GW) in in ADAPT and TRANSFORM reference scenarios and variant 1 and variant 2

Wind capacity reaches its full potential in 2030 and in 2050 in both scenarios, see Figure 3.12. Since the wind energy potentials are not changed in the variants, the wind energy capacity is the same in these years. For 2035 and 2040, the potentials are not fully used in both scenarios. In both variants, the wind energy capacity do hardly change in these years compared to the reference.

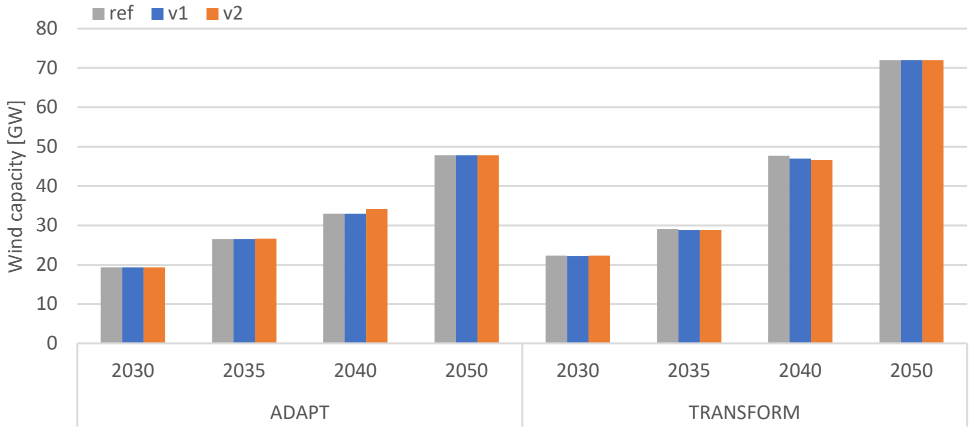

Figure 3.12 Total wind capacity (GW) in ADAPT and TRANSFORM reference scenarios and variant 1 and variant 2

3.6.1 Fuel supply

In 2035 (both variants), biofuels supply is lower than in 2030. In 2030, a minimum consumption of biofuels is assumed in line with the Climate Agreement. This condition does not exist in 2035 and due to the low demand for biofuels, the supply decreases. The biofuels supply increases in 2040 and 2050 mainly to meet the targets for international shipping and aviation (i.e. HFO/kerosene). In ADAPT 2050 variant 2, there is an overall increase on biofuels production to supply the transport sector. In ADAPT 2040 (both variants) and TRANSFORM 2040 variant 2, the Dimethyl ether (DME) technology is more attractive for generating biofuels. In ADAPT 2050, variant 2, biofuel production from other biorefinery routes is increased.

Figure 3.13 shows that in variant 2 in 2050 biofuels imports represent more than half of biofuels supply in ADAPT and almost all the supply in TRANSFORM. Imported biomass also plays an important role in both scenarios.

Figure 3.13 Biofuels supply by resource (PJ) in ADAPT and TRANSFORM reference scenarios and variant 2

Figure 3.14 shows that the synthetic fuels production increases in 2050 in variant 1 and variant 2, relatively similar as in the ADAPT and TRANSFORM reference scenarios.

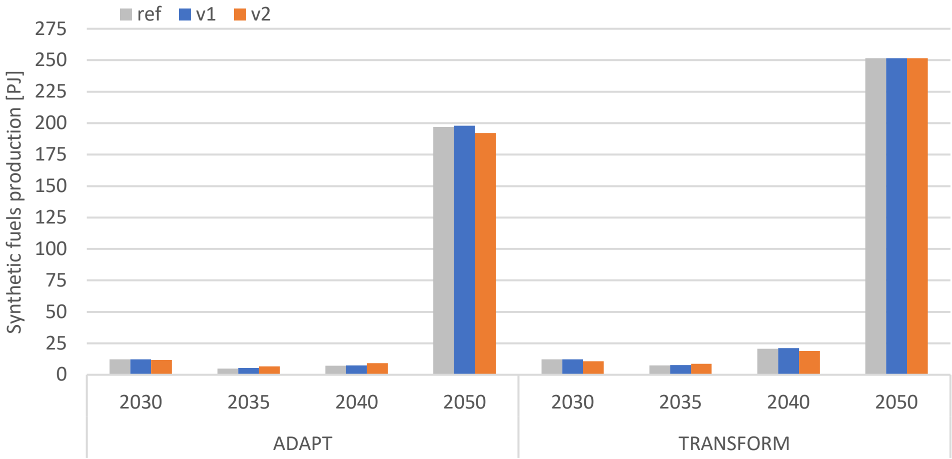

Figure 3.14 Synthetic fuels production (PJ) in ADAPT and TRANSFORM reference scenarios and variant 1 and variant 2

3.6.2 Hydrogen production

Hydrogen production mainly increases significantly in ADAPT 2050 variant 2, see Figure 3.15. This increase is related to a shift to ammonia synthesis with external hydrogen supply (90 PJ), hydrogen supply to gas networks (130 PJ), and an increase in hydrogen as fuel for heavy duty freight transport. The additional hydrogen is mainly produced via steam methane reforming (SMR) with CCS, and uses the free storage space that arise from the disappearance of the BECCS option to reduce CO_2 emissions.

When compared to the TRANSFORM reference scenarios, there is a reduction in hydrogen production in TRANSFORM in 2040 for both variants. This is due the increased volume of biofuels in the transport sector, as woody biomass is shifted from heat supply to biofuel production, thus reducing its demand for hydrogen. This effect disappears in 2050.

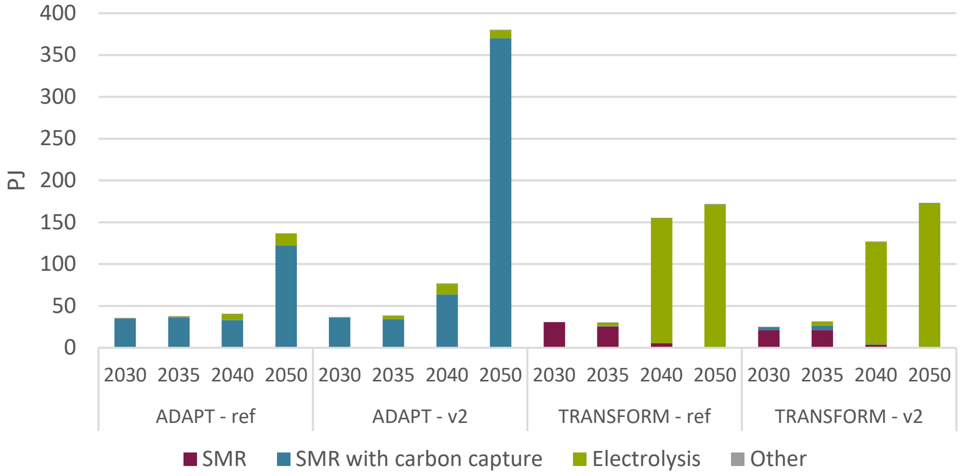

Figure 3.15 Hydrogen production (PJ) in ADAPT and TRANSFORM reference scenarios and variant 2

3.7 Carbon capture and storage (CCS)

Figure 3.16 depicts CCS and CCU in the ADAPT reference scenarios, variant 1 and variant 2. CCS is not allowed in the TRANSFORM scenarios. The ADAPT scenario depends largely on the use of BECCS, therefore there are no changes in variant 1 where woody biomass is still used in the industry sector in combination with CCS. In variant 2 however, CCS is mostly combined with SMR for hydrogen production and natural gas fired boilers and CHPs.

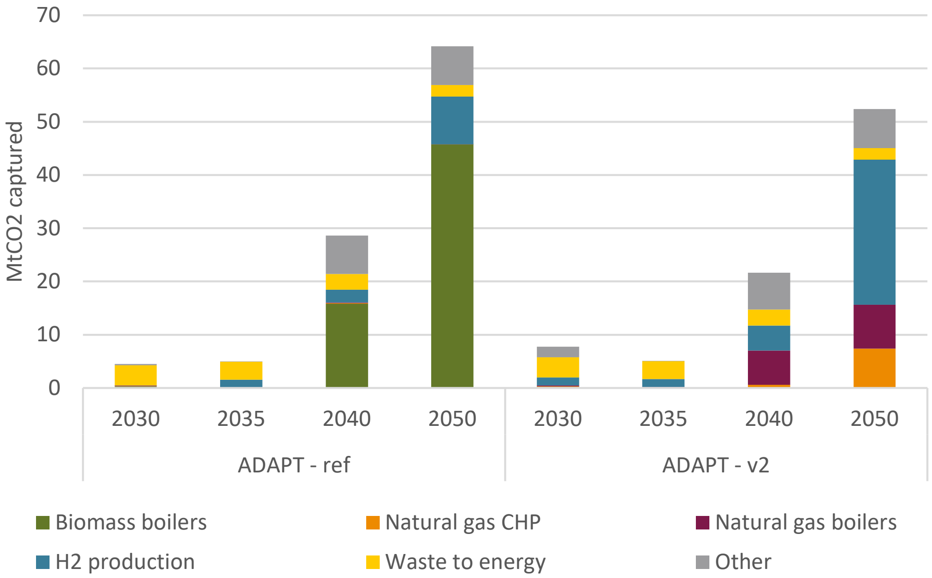

Figure 3.16 CO_2 capture (PJ) per application in ADAPT reference scenarios and variant 1 and 2[21]

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[21] CO_2 storage in 2050 is limited to 50 $MtCO_2$; the remainder of the captured CO_2 is utilized (i.e. as feedstock for synthetic fuels).

4 Discussion of the analysis

Limiting the use of woody biomass for heat applications in the built environment, agricultural and industry sectors has been investigated with an optimization model that calculates a cost-optimal energy system for the Netherlands in subsequent years with an increasing GHG reduction. The limitation of the use of biomass in two variants has been compared with two reference scenarios (ADAPT and TRANSFORM), in which this limitation does not apply. In both variants, the total amount of biomass that is available remained the same, but differs per scenario. The results of this comparison are shown in the previous chapter.

What is immediately noticeable in the comparison is that limiting the use of woody biomass in one sector has consequences for the energy mix in other sectors. The pursuit of a cost-optimal energy system not only means that the best next alternative is sought for the biomass that is no longer available for that specific sector and application, but also how the biomass that becomes available can be best allocated elsewhere in the system. Subsequently, this leads to shifts in the allocation of other energy sources and energy carriers that are again optimized over the total energy system. Many of these shifts are limited, but others are more significant. These are briefly discussed below.

4.1 Variant 1

In this variant woody biomass is phased out in the built environment and district heating.

Impact on the energy mix
Overall, in both scenarios, the impact on primary energy supply is small, meaning that the total amount of biomass used remains the same, but it shifts between applications and sectors. In the reference scenario, the use of woody biomass in the services sector and in district heating already decreases over the years, as woody biomass is applied more cost-effectively in other sectors. Therefore, the phase out has only a small impact on the built environment. The direct effect is an increased use of heat pumps. The extra electricity is mainly supplied from additional solar energy production in the agriculture sector.

In ADAPT, the woody biomass not used by services and district heating biomass is mainly used in biomass boilers and CHP in industry. This biomass use is combined with CCS (i.e. BECSS) resulting into negative emissions, which makes it a cost-effective option to reduce GHG emissions. In the TRANSFORM scenario, were CCS cannot be used, the woody biomass that becomes available is used for biofuels production, as this is a more cost-effective option than the thermal conversion of biomass.

Impact on the system costs
The difference in total system costs for ADAPT in 2030 and 2035 is relatively small in comparison to the reference scenario. For TRANSFORM, the difference in total system costs is larger. For 2030 and 2035, extra boundary conditions were used to ensure that the scenarios are in line with the Climate Agreement for 2030, and also in line with the biomass use resulting from incentive policies, such as SDE. When

the minimum use requirements for woody biomass in the services sector and district heating in 2030 and 2035 are released, this biomass is allocated more cost-effectively in other sectors, such as in industry or for biofuels production, resulting in lower total system costs in TRANSFORM. Also in 2040, in TRANSFORM, the total system costs are lower for variant 1 than in the reference. In 2040, in the reference scenario, the utilization of biomass boilers built before 2040 in services sector and district heating is low, because biomass is more cost-effectively applied in the industry sector. This low initialization leads to additional costs. In variant 1, these boilers disappear resulting in lower total system costs.

4.2 Variant 2

In this variant biomass is phased out in the built environment, district heating, agriculture sector and for thermal conversion in industry.

Impact on the energy mix
A reduction in woody biomass demand from the agriculture sector and for thermal conversion in industry leads to a lower biomass supply in 2030 and 2035 for both scenarios. A shift to biofuel production is not taking place because in these years the demand for biofuels is still too low. In 2040 (both scenarios) and 2050 (only in ADAPT), all the woody biomass that becomes available is shifted to biofuel and bio-methane production. Biofuels are used in the transport sector and bio-methane (or SNG) is blended in the natural gas grid and used in the built environment sector. In the TRANSFORM scenario, this shift is smaller because most of the available biomass – which is less than in ADAPT – is used in 2050 as feedstock.

In the ADAPT reference scenario, BECCS is applied in industry, particularly in combination with thermal conversion of biomass. Because it is not possible to use biomass for thermal conversion in variant 2, the possibility of BECCS with these options is eliminated. With no BECCS, there is room to store more CO_2 from other industrial processes, such as natural gas used for industrial heating applications and the production of blue hydrogen (i.e. hydrogen from natural gas in combination with CCS). In the cost-optimization, these options are apparently more attractive than applying CCS in a biorefinery process where bio-fuels, biomethane and bio-feedstock are produced. In the reference scenario, BECCS results in so called ‘negative emissions’. In variant 2, this extra emission reduction has to be compensated in other sectors. Natural gas consumption is increasing, because of the increased blue hydrogen production and natural gas use in boilers with CCS. The extra hydrogen that is produced is used in the transport, built environment and industry sectors. Heating applications in industry are also electrified with heat pumps, mechanical vapor recompression and electric boilers.

In TRANSFORM, in 2050, some other changes occur, e.g. a shift in the built environment from the use of heat pumps to natural gas boilers, as more GHG emissions are reduced in the industry sector, such as the increased use of direct air capture (DAC) for synthetic fuel production. The cost-optimization model reallocates the remaining GHG emissions (with the 95% reduction target in 2050, there is still 5% GHG emissions) between the sectors.

In both scenarios, heat production in the agriculture sector with woody biomass is substituted by heat pumps. Additional electricity demand for industry and agriculture (in 2050) is provided in both scenarios by increased solar energy production, since the solar energy potential is not yet fully utilized in the reference scenario; while for (onshore and offshore) wind energy the latter is the case.

Impact on the system costs
Some of the impacts on the total system costs are similar to variant 1, i.e. small impacts in 2030 and 2035 for ADAPT, and lower costs in 2030, 2035 and 2040 for TRANSFORM (see explanation above). In ADAPT, in 2040 and 2050, the impact is larger because BECCS is no longer used. More GHG emissions reductions elsewhere in the system lead to higher system costs. Furthermore, the production of more biofuels results in higher total system costs.

5 Conclusions

For two scenarios, ADAPT and TRANFORM, a cost-optimal energy system for the Netherlands has been calculated for subsequent years with increasing GHG reductions. This results in an energy supply mix, an energy mix for various end-use sectors and total system costs. Subsequently, the phasing out of biomass was investigated by first limiting the use of woody biomass in the built environment and district heating, and then also limiting the use of woody biomass in the agricultural sector and for thermal conversion in industry.

In both cases, the limited supply of woody biomass leads to shifts in the sectoral allocation of CO_2 emissions reductions within the maximum GHG emission cap.

If only the use of woody biomass is limited in the built environment, the impact on the energy system is limited in both scenarios, because in the reference scenarios the use of woody biomass is already more cost-effectively allocated in other sectors than in the built environment.

If the use of woody biomass is also limited in the agricultural sector and for thermal conversion in industry, the total biomass supply will initially decrease because there are no cost-effective alternative applications for this biomass elsewhere in the energy system. On the longer term, there is a clear visible impact for the ADAPT scenario, because biomass is no longer used in combination with CCS (i.e. BECCS). Other GHG emission reduction options are required to offset negative emissions attributed to BECSS, also in other sectors. In the TRANSFORM scenario, the impact in the long run is smaller because the use of woody biomass for thermal conversion in industry is less, since most of the biomass is used as feedstock.

The phasing out of woody biomass for heat application initially shows lower system costs. However, this is mainly due to the fact that a number of adjustments have been made to the reference scenarios to align with the Climate Agreement and to take into account biomass projects that were started before 2030. This leads to higher total system costs in the reference scenarios, and lower total system costs in the variants when the boundary conditions are released. In the long term, the phasing out of woody biomass for heat applications will lead to higher system costs, especially in the ADAPT scenario, due to the loss of the BECCS option for biomass heat applications in the industry sector.

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