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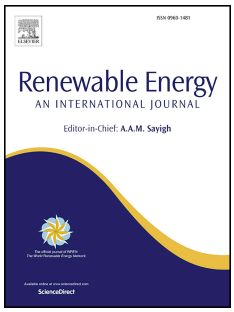

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Job creation and economic impact of renewable energy in the Netherlands

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Abstract

This study evaluates the economic impact of a shift towards renewable electricity mix in the Netherlands using the neo-Keynesian CGEM ThreeME (Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy). This scenario has been inspired by the Urgenda's report 'Energy 100% Sustainable in the Netherlands by 2030', which have been quantified using the Energy Transition Model (ETM) developed by Quintel. Using the output of the ETM regarding the change in the electricity generation shares as input in ThreeME, we derive the impact in terms of key economic variables (GDP, employment, investment, value-added, prices, trade, tax revenue, etc.). We find that transition to renewable energy may have a positive impact on the Dutch economy, creating almost 50 000 new jobs by 2030 and adding almost 1% of gross domestic product.

Keywords: Energy transition, Climate policy, Energy-economy modeling, Netherlands
JEL code: E12, E17, E27, E37, E47, D57, D58

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1 Introduction

The Paris Agreement signed in December 2015 during the COP 21 (2015 United Nations Climate Change Conference) has the ambition to limit the global temperature increase to 1.5°C compared to pre-industrial level. The Intergovernmental Panel on Climate Change (IPCC) estimated that the world has used more than 65 percent of the carbon dioxide budget allowing to stay within the 2°C limit and that to stay within this limit, global carbon neutrality should be achieved between 2055 and 2070" (UNEP, 2014 p. XV). Meeting a 1.5 °C target implies a big effort both for developing and advanced countries which have to implement a rapid and major change in the structure of their supply and demand of energy. This is likely to have an important impact on energy sectors but also on the rest of the economy.

The Paris Agreement acknowledges also the historical responsibility of advanced countries regarding the current situation, implying that they will have to support a larger share of the efforts. In particular, they are expected to demonstrate the feasibility of the energy transition to a low carbon economy. There is also more and more internal pressure to respect existing commitments. After the plaint of Urgenda and nine hundred co-plaintiffs, the District court of The Hague ordered the Dutch government to reduce its emissions by a minimum of 25% by 2020 compared to 1990 (www.urgenda.nl/en/climate-case/, 24 June 2015). The Netherlands are currently on a path towards 17% in 2020.

It is therefore useful to evaluate the feasibility of ambitious scenarios where the energy system is largely based on renewable energy. This is a difficult task involving both technical and economic issues since one expects the future energy system to provide equivalent performance as the current one while been economically affordable. This rises the following questions. Is a high penetration of renewable energy for power generation technically feasible? Does it lead to an increase in the electricity price? What is the impact on the economic activity (sectorial employment, investment, value-added, prices, trade, tax revenue, etc.)?

Energy and economic models may help answering these questions. Here we simulate the economic impact of a shift towards a renewable scenario on the Dutch economy. This scenario has been inspired by the one developed by Urgenda (www.urgenda.nl) using the open source Energy Transition Model (ETM) developed by Quintel (www.quintel.nl). This tool can be used to evaluate the technical feasibility of the scenario. The Urgenda scenario is detailed in Urgenda (2014). It aims for a large decrease of the carbon intensity of the economy by 2030. This is achieved by changes occurring both on the demand and on the supply side of the energy market. On one hand, wide adoption of more energy efficient technologies in the building and transport sector, as well as by industry, is expected to reduce the final demand for energy by half. On another hand, electricity and heat is produced only from renewable source, with the increasing role of local sources, such as rooftop PV panels and heat pumps. Biomass and green gas are used as back-up technologies for the intermittent solar and wind plants. Liquid fuels are still present in the economy, but they are 100%

from biological origin. The production of Dutch natural gas is entirely exported. In this paper, we only analyze the economic impact of the supply side part of the Urgenda scenario. Namely, we focus on the adoption of solar and wind technology for electricity generation and biomass for heat production. Demand side measures, as well as biofuels and green gas, are left outside of the analysis for the time being.

In this study, we use the neo-Keynesian CGEM (Computable General Equilibrium Model) ThreeME (Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy). Using the output of the ETM regarding the change in the energy system as input in ThreeME, we derive the impact in terms of key economic variables (GDP, employment, investment, value-added, prices, trade, tax revenue, etc.). Whereas partial equilibrium bottom-up energy models such as MARKAL (Fishbone & Abilock, 1981), LEAP (Heaps, 2008), TIMES (Loulou, Goldstein, Kanudia, Lehtila, & Remme, 2016), or PRIMES (E3MLab, 2016) generally assume that the demand for energy and the costs of the different technologies are exogenous, CGEMs take into account the interaction and feedbacks between supply and demand by modeling prices and the demand endogenously. There are mainly two types of CGEMs in the literature. Walrasian CGEMs (e.g. Shoven & Whalley, 1994) assume that the perfect flexibility of prices and quantities (production factors, consumption, etc) ensures the instantaneous equilibrium between supply and demand. The economy is described in real terms (inflation is not modeled) and there is no (involuntary) unemployment. Examples of these models include GTAP (Center for Global Trade Analysis - GTAP, 2014), GEM-E3 (Capros, Van Regemorter, Paroussos, & Karkatsoulis, 2013) or ENV-Linkages (Chateau, Dellink, & Lanzi, 2014). The assumption of perfect flexibility contrasts with the reality where the adjustments of prices and quantities are generally relatively slow. Walrasian CGEMs are therefore long term models. On the contrary, in neo-Keynesian CGEMs, prices do not clear the markets and market "imperfections" are taken into account. In coherence with empirical evidences, they assume that prices and quantities are rigid in the short run and that they adjust slowly over time toward their optimal level. In the short and medium run, there can be situations of disequilibrium between the optimal supply and the actual supply and of underutilization of the production capacity (in particular involuntary unemployment). This framework is better suited for policy purposes because it provides information regarding the transition phase of a particular policy (not only about the long term). Econometric models such as 3EME (Cambridge Econometrics, 2014), NEMESIS (Brécard, Fougeyrollas, Le Mouël, Lemiale, & Zagamé, 2006; ERASME, n.d.) or GINFORS (Lutz, Meyer, & Wolter, 2010) are examples of neo-Keynesian CGEMs. ThreeME is not an econometric model since the model's equations are not systematically estimated. However we use econometric estimation from the literature to calibrate the parameters of the model: elasticities and adjustment parameters (for more detail, see the online Supplementary material A: Main equations of ThreeME).

We find that more renewable energy in power and heat generation has the potential for creating jobs and growth for the Dutch economy. On the one hand, our modeling exercise projects that around 50 000 new full time jobs can be created by 2030 and the GDP is expected to increase by 0.85% relatively to the baseline scenario. This positive impact is explained by a relatively higher labor and capital intensity of wind and solar technologies, compared to gas and coal plants, and this

creates growth opportunities primarily for domestic, but not imported, products. On the other hand, these positive effects are accompanied by an increase in the future electricity price, mainly due to much higher capital intensity for renewable technologies. We also show that the relative increase in electricity price strongly depends on the projected costs of the technologies, giving the uncertainty range of relative price increase between 2 and 18%. And lastly, we have also demonstrated the importance of using a general equilibrium model with price effects when considering impacts on macroeconomic indicators, such as GDP and employment. We show that neglecting of the feedback effects of prices can lead to substantially overestimated impacts.

Section 2 gives a short description of the ThreeME model. Section 3 presents ThreeME for the Netherlands. Section 4 defines the scenario. Section 5 presents the simulation results and Section 6 concludes.

2 Overview of the ThreeME model

ThreeME is a country-generic and open source model developed since 2008 by the ADEME (French Environment and Energy Management Agency), the OFCE (French Economic Observatory) and TNO (Netherlands Organization for Applied Scientific Research). Initially developed to support the energy/environment/climate debate in France (G. Callonnec, Landa, Malliet, & Reynès, 2013), ThreeME is now been applied to other national contexts such as Indonesia (Reynès, Malliet, & Marizi, 2017), Mexico (Landa Rivera, Reynès, Islas Cortes, Bellocq, & Grazi, 2016) and the Netherlands. This section provides a short non-technical description of ThreeME. A more technical presentation is given in the online Supplementary material A: Main equations of ThreeME [1].

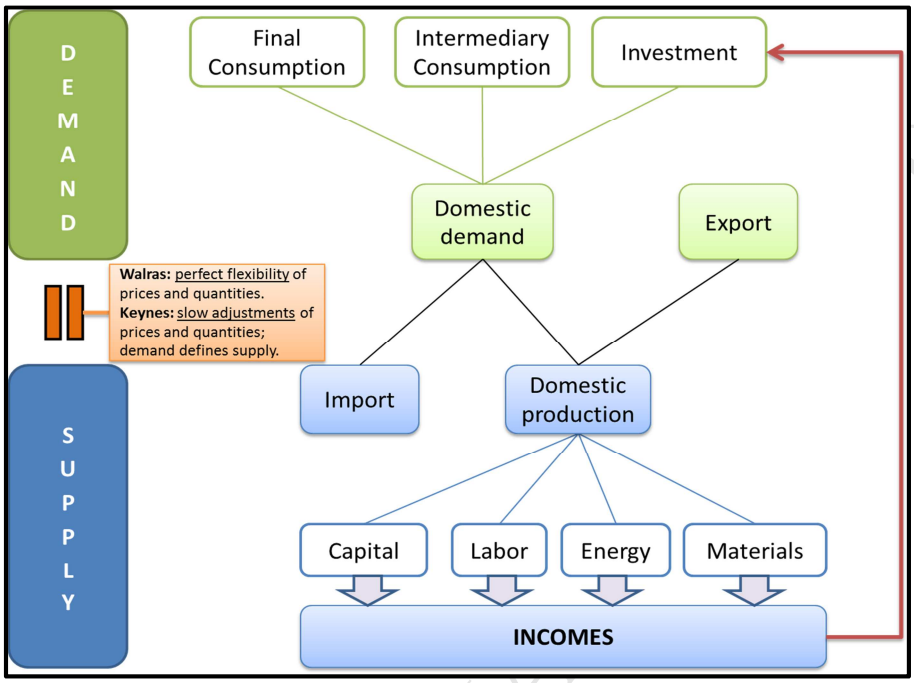
The model is specially designed to evaluate the medium and long term impact of environmental and energy policies at the macroeconomic and sector levels. For this, ThreeME combines several important features:

- Its sectorial disaggregation allows analysis of the effect of transfer of activities from one sector to another in particular in terms of employment, investment, energy consumption or trade balance.
- The energy disaggregation allows analysis of the energy behavior of economic agents. Sectors can arbitrate between different energy investments: substitution between capital and energy when the relative energy price increases; substitution between energy sources

[1] For full description of ThreeME see Callonnec et al. (2013).

when their relative prices change. Consumers can substitute between energy sources, between transport choices or between goods and services.

Figure 1. Architecture of a CGEM



- ThreeME is a CGEM (Computable General Equilibrium Model). It therefore takes into account the interaction and feedbacks between supply and demand (see Figure 1). The demand (consumption, investment) defines the supply (production). The supply defines in return the demand through the incomes generated by the production factors (labor, capital, etc.). Compared to bottom-up energy models such as MARKAL (Fishbone & Abilock, 1981) or LEAP (Heaps, 2008), ThreeME goes beyond the mere description of the sectoral/technological dimension by linking those with the global economic system.
- ThreeME is a neo-Keynesian model. Compared to standard Walrasian-type CGEMs, the capital stock is endogenous. Investment depends not only on interest rates but also on anticipated demand, prices do not clear instantaneously supply and demand. Instead the model is dynamic and prices and quantities adjust slowly[2]. This has the advantage to allow for situations of disequilibrium between supply and demand (in particular the presence of involuntary unemployment). This framework is better suited for policy purposes because it

[2] Econometric models such as 3EME (Cambridge Econometrics, 2014), NEMESIS (Brécard et al., 2006; ERASME, n.d.) and MESANGE (Klein & Simon, 2010) use a similar framework. Whereas their adjustment dynamic is (for most equations) estimated econometrically, it is imposed in our model. The value of parameters defining the speed of adjustment regarding prices, labor, capital, consumption, etc. is defined in accordance with econometric studies made at the macroeconomic level. Our approach is less costly in terms of data while delivering similar dynamic properties compared to econometric models. See Callonnec et al. (2016) for a comparison of ThreeME with MESANGE for France.

provides information regarding the transition phase of a particular policy (not only about the long term).

3 ThreeME for the Netherlands

The version of ThreeME model for the Netherlands is constructed by filling in the generic architecture of the model, as shown in Figure 1, with the Dutch statistical data. As for any CGEM, it requires the following data inputs: (1) supply and use tables, where production structure, final consumption and intermediate consumption of commodities are recorded; (2) capital stocks and investment matrix, where consumption of commodities as capital goods is given; (3) demographic and labor market data such as population, employment and unemployment statistics; (4) the data on taxes, savings, government and international transfers. Due to the focus of ThreeME on energy transition issues, we have also added data on carbon dioxide emissions as an environmental extension. Most of the data that went into the calibration of the model for the Netherlands came from official statistical sources, such as Eurostat (ec.europa.eu/eurostat) and the Dutch Statistical Office (CBS, *Centraal Bureau voor de Statistiek* in Dutch, www.cbs.nl). More details on the sources used is given in the online Supplementary material B: Detail on the scenario calibration calculation.

As explained before, one of the key features of ThreeME is the sectoral (energy) detail. The Dutch version of the model distinguishes between 23 economic activities, or sectors, and 15 types of commodities (see Table 1). The level of disaggregation has been chosen is such a way that, on the one hand, the behavior of the main energy producers and energy consumers can be modelled in detail and, on the other hand, the total number of sectors is limited in order to avoid computation issues and to facilitate the analysis of the results. The list of sectors includes 8 types of electricity generation technologies (among which nuclear, fuel, gas, coal, wind, solar and hydraulic plants), 4 types of transport modes and industrial sectors are split into energy intensive and non-energy intensive industries. The number of commodities is lower than the number of sectors because electricity is treated as one commodity, independently from the generation technology. Indeed, the final consumer cannot choose the type of electricity she buys[3].

[3] Although at the moment energy companies offer more specific contracts to consumers, such as Dutch Wind or Eco, the choice of the consumers does not change the electricity mix on the macro scale.

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Table 1. Sectorial disaggregation of ThreeME for the Netherlands

Index	Sectors/Activities	Commodities
1	Agriculture, forestry and fishing	Idem
2	Energy intensive industries	Idem
3	Non-energy intensive industries	Idem
4	Construction of buildings and Civil engineering	Idem
5	Rail transport (Passenger and Freight)	Idem
6	Transport by road (Passenger and Freight)	Idem
7	Air transport	Idem
8	Water transport	Idem
9	Services	Idem
10	Coal and non-energy mining	Idem
11	Crude oil mining	Idem
12	Refinery petroleum products (oil and biofuel)	Idem
13	Gas - Transmission and distribution	Gas
14	Natural and manufactured gas	
15	Electricity - Transmission and distribution	Electricity Heat
16	Nuclear plant	
17	Fuel plant	
18	Gas plant	
19	Coal plant	
20	Wind turbine	
21	Solar panel and thermal	
22	Hydraulic plant	
23	Other: Wood, Biomass, Waste incineration, Geothermal	

Supply and use tables from official statistical sources do not provide as much detail on energy commodities and sectors as required by ThreeME. They therefore need to be disaggregated. The main issue in this process is the lack of consistent monetary data. Using physical data from energy balances to disaggregate monetary data is an option, but it requires to make assumptions about the prices of different energy sources. In this case we have assumed that the price per TJ for different energy source is similar. Another issue is that electricity and gas companies are represented as a single sector in the official statistics. To make a meaningful assessment of energy transition scenarios we need, firstly, to separate electricity and gas markets and, secondly, to split electricity between the commodity part and the part related to distribution and other related services. But the statistics on the turnover of companies involved into network management and transmission and distribution is often hidden in order to protect commercial interests of these companies. We have assumed that on average transmission and distribution costs amount for around 60% of the price of electricity and gas. Using this ratio we are able to reproduce the structure of household expenses quite precisely: 36% is spent on electricity, 4% on heat and 60% on gas[4].

[4] This structure is compared to the data of *Rijksdienst voor Ondernemend Nederland*: http://rvo.databank.nl/jive/

Figure 2 below presents a condensed version of the Dutch supply and use tables used for the base year calibration. This table gives the equilibrium between supply and demand per commodities, the structure of the economic activities (capital, labor intensity per sectors), the interactions between the sectors (through intermediate consumptions) and the composition of GDP.

Figure 2. Equilibrium between supply and demand in 2010 (in billion euros)

		SUPPLY															DEMAND													
		Agriculture	Industry	Services	Electricity - Transmission and distribution	Nuclear plant	Fuel plant	Gas plant	Coal plant	Wind turbine	Solar panel and thermal	Hydraulic plant	Other: Wood, Biomass, Waste incineration,	Energy other	Taxes	Margins	TOTAL SUPPLY = TOTAL DEMAND	Agriculture	Industry	Services	Electricity - Transmission and distribution	Nuclear plant	Fuel plant	Gas plant	Coal plant	Wind turbine	Solar panel and thermal	Hydraulic plant	Other: Wood, Biomass, Waste incineration,	Energy other	CONSUMPTION (Household + Government)	INVESTMENT	EXPORTS - IMPORTS
COMMODITIES	Agriculture	24.7	0.2	0.0											0.5	9.4	34.8	4.9	15.9	1.3									0.1	0.0	6.1	0.4	6.1
	Industry	0.3	200.0	8.8		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	21.9	92.4	324.7	5.0	96.1	57.3	0.4	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0	1.8	99.4	33.0	31.3
	Services	1.3	24.5	775.6		0.0	0.2	2.1	0.1	0.0	0.0	0.0	0.2	1.3	23.5	-106.0	722.8	4.5	37.5	279.1	1.4	0.0	0.1	1.1	0.2	0.0	0.0	0.0	0.1	3.9	305.6	71.0	18.2
	Electricity	0.1	0.1	0.1	12.3	0.3	0.3	5.2	1.6	0.3	0.0	0.0	0.7	0.0	4.1		25.1	0.3	4.0	5.4	3.1	0.1	0.2	2.5	0.4	0.1	0.0	0.0	0.3	4.4	3.9		0.6
	Energy other	0.2	3.6	2.7			0.2	2.4	0.0				0.2	66.3	12.7	4.2	92.5	2.6	15.7	19.2	0.4	0.2	0.2	4.1	0.7	0.0	0.0	0.0	0.0	38.2	20.8	0.0	-9.5
	TOTAL	26.6	228.3	787.3	12.3	0.3	0.7	9.8	1.7	0.3	0.0	0.0	1.0	68.8	62.7	0.0	1199.9	17.3	169.1	362.3	5.3	0.3	0.5	8.0	1.4	0.1	0.0	0.0	0.6	48.4	435.7	104.3	46.7
PRODUCTION	Intermediary consumption	17.3	169.1	362.3	5.3	0.3	0.5	8.0	1.4	0.1	0.0	0.0	0.6	48.4																			
	Value-Added	9.4	59.2	425.0	7.0	0.0	0.2	1.8	0.4	0.2	0.0	0.0	0.5	20.4			524.1	GDP = VA + TAX = C + I + EXP - IMP												586.8			
	Labour (1000 FTE)	259	746	6074	8	0.2	0.4	6	1.1	0.3	0.0	0.0	1.1	21			7116.8																
	Capital stock	47	146	1721	12	0.9	0.9	5	2.3	1.1	0.1	0.0	3.1	52			1991.6																
	CO2 emissions (million tonne)	7.2	37.0	66.0		0.3	3.2	14.5	18.3				2.0	13.6			218.6														56.5		

Source: Authors' calculations.

4 Scenarios

4.1 The baseline scenario

The baseline (reference or business-as-usual) scenario is the path the model predicts when all exogenous variables follow their "business-as-usual" trend. The baseline scenario is meant to be a realistic vision of a possible future rather than a real forecast. It is the virtual scenario predicted by the model for a given trajectory of the exogenous variables. Although it excludes cyclical fluctuations, the idea is to reflect as much as possible the expected changes regarding key exogenous variables such as population, productivity gains, tax rates, elasticities, external demand, etc. By definition, the baseline scenario always excludes the impact of any policy being studied since this can be seen as a shock compared to the reference scenario and is simulated as an alternative scenario (see Section 4.2). The main hypothesis relative to the baseline are as follows:

- Population increases from 16.575 to 17.204 million people between 2010 and 2030 as assumed in the Urgenda scenario.
- Labor productivity grows with the annual rate of 1.7%, which together with the population growth gives 2% annual growth of the real economy.
- The inflation target is assumed to be 2% per year.
- Electricity and heat production technology mix is stable between 2010 and 2030.

- Investment costs of generation technologies (in terms of euro/kWh), or capital intensity, are decreasing for renewables, e.g. -1.8% annually for wind and -3.1% annually for solar, and increasing for non-renewables, .e.g. +0.15% annually for gas and +0.4% annually for nuclear[5].
- ThreeME assumes a three-level production structure (see Figure 3). The first level assumes a technology with four production factors (capital, labor, energy and material), using a Variable Output Elasticities Cobb-Douglas function (Reynès, 2011). This flexible function allows for a different level of substitution between each input pair. However, in this study we have constrained the level of elasticities such as it replicates a nested Constant Elasticity of Substitution (CES) function. As reported in Table 2, conservative elasticities of substitution have been used in these simulation.

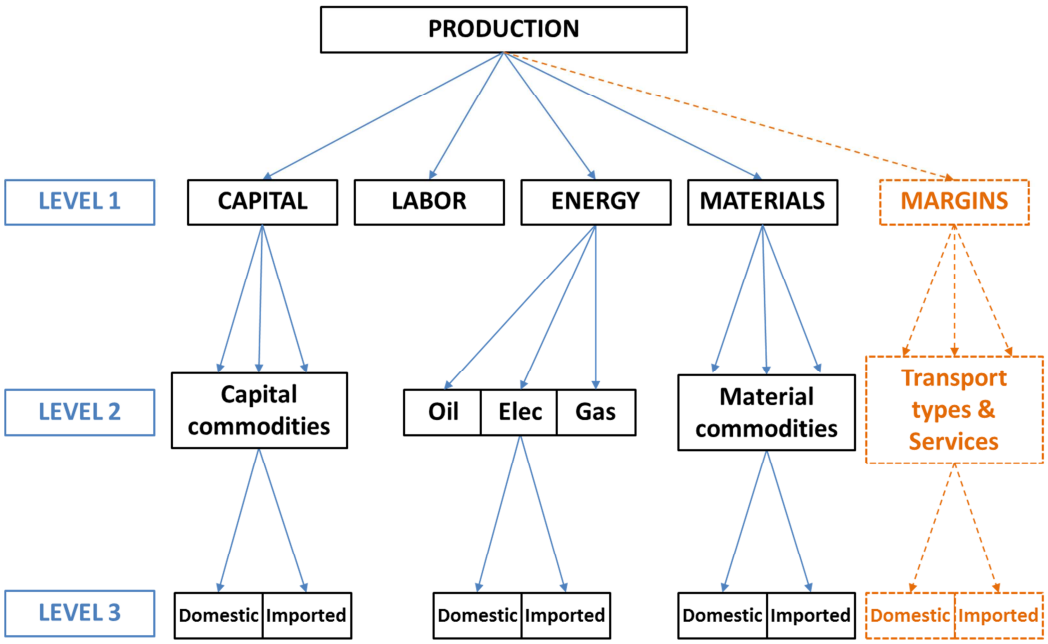
Table 2. Value of Elasticity of Substitution

Description	Value
Level 1: KLEM Elasticity	
Between Material and the nest Capital/Labor/Energy in all sectors	0
Between Labor and the nest Capital/Energy in non-energy sectors	0.5
Between Labor and the nest Capital/Energy in energy sectors	0
Between Capital and Energy in non-energy sectors	0.5
Between Capital and Energy in energy sectors	0
Level 2	
Between energy intermediate input in all sectors	0.8
Between transport margins	0.8
Between investment goods and between material goods	0
Level 3	
Armington elasticity of substitution between domestic and foreign goods	0.8
Between final consumption godos	0.5
Elasticity of exports	0.8

Most of these assumptions are also maintained in the renewable scenario, except for the generation mix. The consistency of assumption between the baseline and the scenario allows us to focus on the effects of a single policy change (here a change in the electricity mix).

[5] These value follow the assumptions taken by ETM model of Quintel, as extracted on 7 April 2016.

Figure 3. Production Structure



4.2 Renewable electricity scenario for the Netherlands

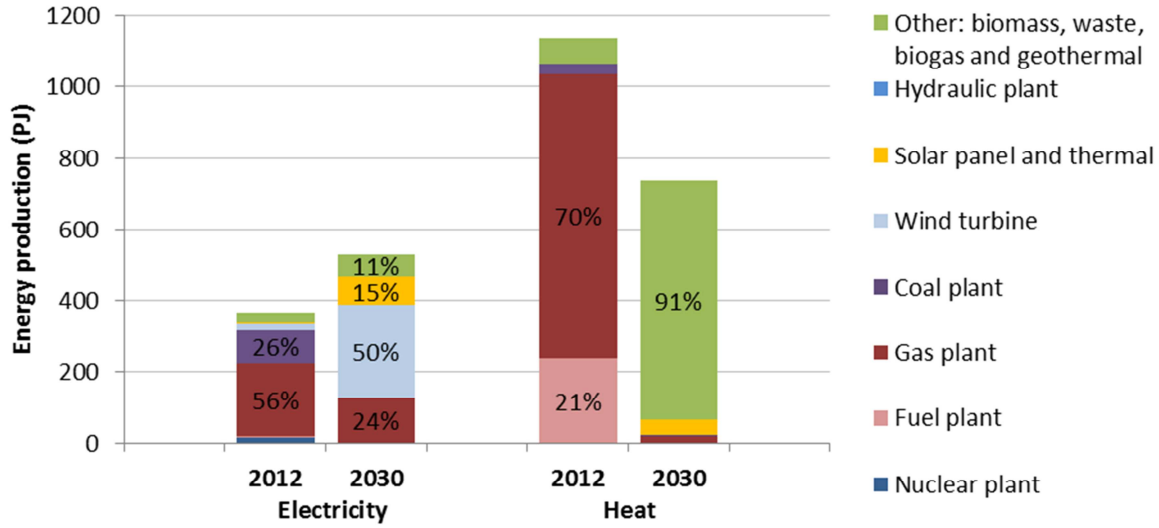
In this paper we analyze the scenario in which the Netherlands replaces coal and more than half of gas plants by solar panels and wind turbines, and therefore achieves 75% renewable electricity mix by 2030. The original and more comprehensive vision for this scenario has been developed by Urgenda, a Dutch foundation that promotes transition towards sustainable society. The scenario of Urgenda considers the situation of (almost) 100% renewable energy mix, but here we focus only on the part of the scenario related to electricity and heat generation. Urgenda also supports its vision with an action plan that requires a number of changes in consumers' behavior and in the way the energy is produced (Urgenda, 2014). This scenario has been already quantified by the open source Energy Transition Model (ETM) developed by Quintel Intelligence[6]. ETM represents the energy system in the Dutch economy. It is an interactive online tool that allows users to play with assumptions regarding energy supply and demand and see what would be the effect on the energy use, share of the renewables, emissions and the associated costs of the transition. Due the partial nature of the model, ETM is not able to show how energy transition would affect other sectors of the economy. Another shortcoming is that the model produces only one final state of the economy in the future, but does not show the path towards this point. Here we are taking advantage from the

[6] https://github.com/quintel/documentation

strong points of ETM, such as the technological and behavioral detail, and feed them into the neo-Keynesian CGEM ThreeME in order to overcome the aforementioned drawbacks.

The 100% renewable future of Urgenda is achieved by introducing substantial changes both on the demand and supply side of the energy system. Here we omit the description of the demand side since it has not been used in the ThreeME calculations. Figure 4 gives the overview from the supply side of the technologies used for central generation of electricity and heat. As the name of the scenario already suggests, renewables are playing the major role in the mix by 2030. 65% of the electricity is generated by wind and solar technologies. They are supported by dispatchable plants based on biomass and gas. As opposed to the assumption in the original Urgenda scenario, we do not take into account a possibility of replacing natural gas with green gas. Over 90% of heat is generated from biomass, with small share given to solar thermal

Figure 4. Structure of electricity and heat supply in 100% renewable scenario



Source: ETM results as accessed on 30 October 2015, authors' calculations.

5 *Simulations results of a change in the electricity mix*

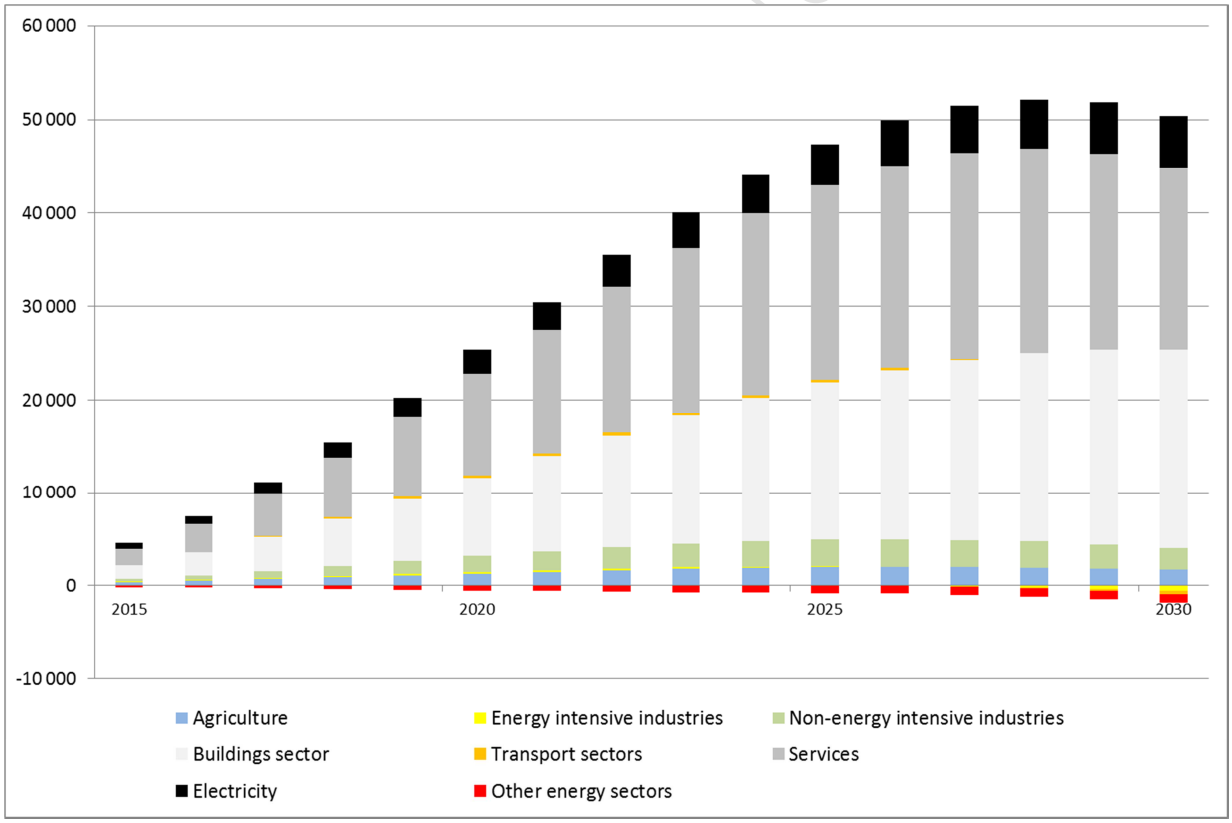
The key macroeconomic impacts of the analyzed scenario are shown in Table 3. Most of the results are given in comparison to the baseline scenario, unless otherwise indicated in the legend. The overall effect on the Dutch economy of shifting toward a more renewable electricity mix appears to be positive. Gross domestic product is 0.85% higher by 2030 and 48 500 additional jobs are created, which corresponds to approximately 0.7% of the total number of jobs today. The relative increase in investments of 6.5% is explained by the higher capital intensity of renewable generation technologies.

Table 3. Macroeconomic impacts

		2010	2011	2012	2013	2014	2015	2020	2025	2030
Real GDP	(a)	0.00	0.00	0.01	0.03	0.06	0.10	0.43	0.76	0.85
Household consumption	(a)	0.00	0.00	0.00	-0.01	0.00	0.00	0.20	0.59	0.94
Investments	(a)	0.00	0.02	0.08	0.20	0.40	0.67	3.00	5.45	6.55
Exports	(a)	0.00	0.00	0.00	0.00	-0.01	-0.02	-0.10	-0.25	-0.46
Imports	(a)	0.00	0.00	0.00	-0.01	0.00	0.01	0.15	0.39	0.54
Unemployment rate (%)	(b)	0.00	0.00	0.00	-0.01	-0.03	-0.05	-0.24	-0.43	-0.44
Employment - % difference	(a)	0.00	0.00	0.01	0.02	0.03	0.06	0.34	0.63	0.65
Employment - numbers of jobs	(b)	0	81	386	1 103	2 420	4 467	24 800	46 598	48 616
Real wage	(a)	0.00	0.00	-0.01	-0.02	-0.03	-0.04	0.06	0.47	1.08
Price	(a)	0.00	0.00	0.01	0.03	0.05	0.08	0.31	0.64	1.05
Public Debt (% of GDP)	(b)	0.00	0.00	-0.02	-0.04	-0.08	-0.12	-0.53	-1.05	-1.49
Public deficit (% of GDP)	(b)	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	-0.04	-0.06
GDP Index	(c)	100	102	104	106	109	111	122	135	148
Emissions Index	(c)	100	102	103	104	105	106	109	112	117
Emissions	(a)	0.0	-0.1	-0.4	-0.8	-1.3	-2.0	-6.1	-10.3	-13.3
Electricity production price	(a)	0.0	0.1	0.5	1.0	1.6	2.2	4.7	4.8	3.0

Legend: (a) in % difference from reference scenario, (b) in absolute difference from reference scenario (see unit next to the variable name), (c) 100 in 2010. The electricity production price includes the transmission and distribution costs. As in Urgenda report, we do not assume additional transmission and distribution costs in the 100% renewable scenario.

Figure 5. Employment per sector (in FTE)



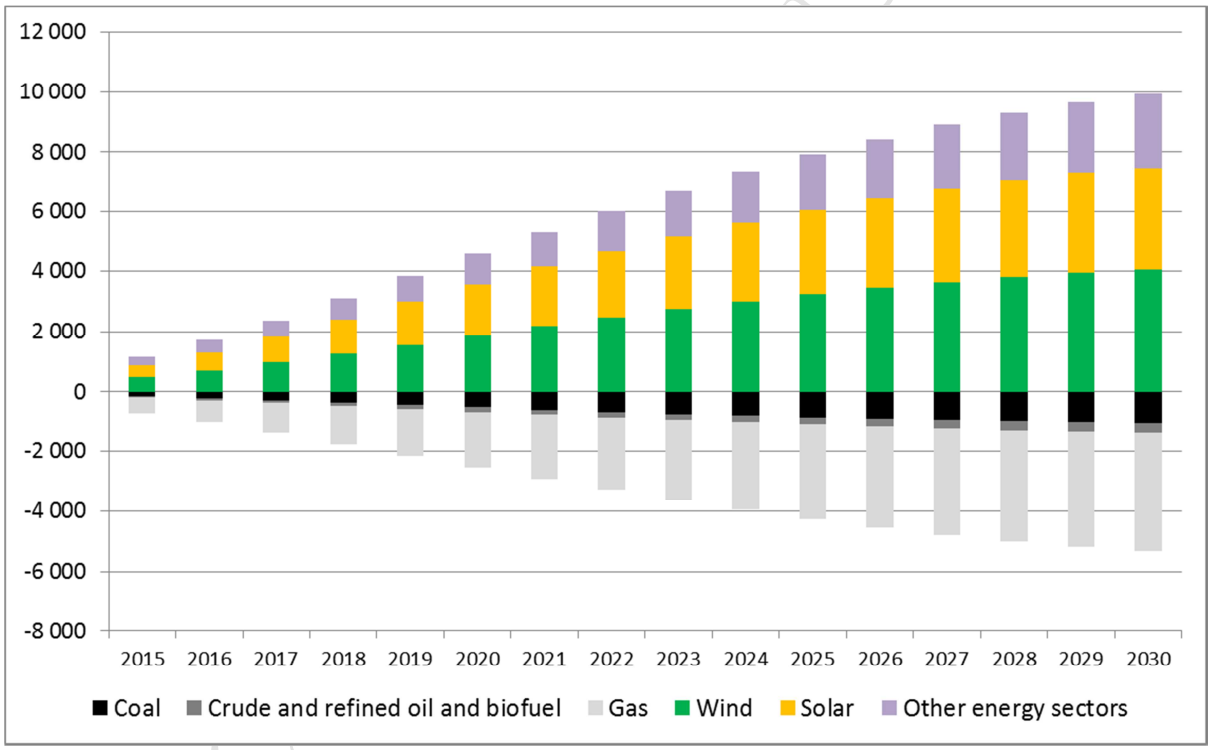
Legend: In absolute difference from the baseline scenario.

The relative reduction in carbon dioxide emissions is quite low (13.3%) because thermal plants represent only 17% of the today emissions. Notice that the emission index shown in Table 3 is expressed in absolute value (not in comparison to the baseline). It increases because we do not

assume here any exogenous improvement in energy efficiency. This indicator is however interesting when compared to the GDP index to show the decoupling between GDP and carbon emissions allowed by the penetration of renewable energy.

It is also interesting to see how the change in employment is decomposed across sectors. If the aggregate effect is positive, employment decreases in certain sectors. Figure 5 shows that jobs are created mainly in the building and service sector and to a lesser extend in electricity sectors, non-energy intensive industries and agriculture. The job destructions are mainly expected in other energy sectors and also in the end of the simulation period in energy intensive industries and transport. Zooming in the energy sectors, Figure 6 shows that jobs are created in wind and solar production of electricity whereas the highest job destructions are in the gas sectors, which are part of other energy sectors in Figure 5. This is logical since we assume that the Dutch gas not consumed nationally is not exported.

Figure 6. Employment in energy sectors (in FTE)

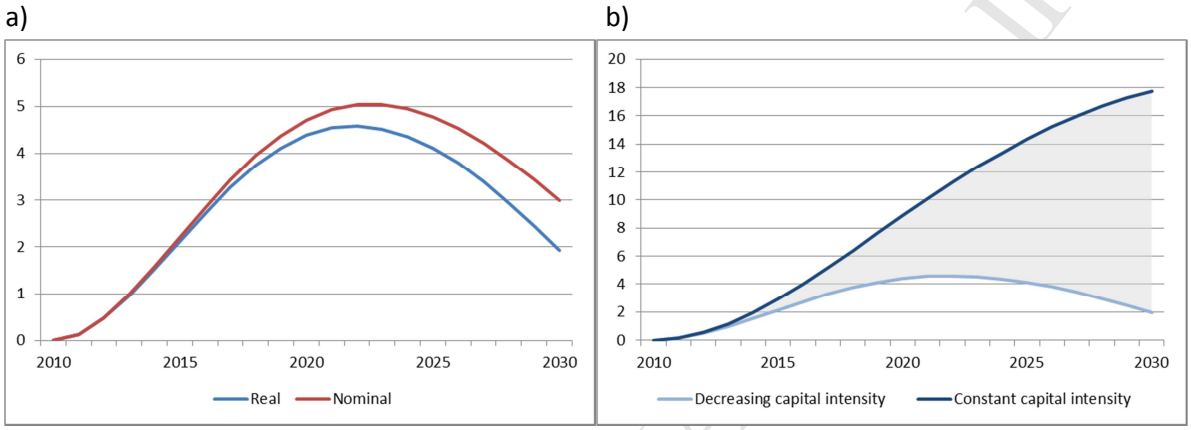


Legend: In absolute difference from the baseline scenario. Gas, coal, fuel electricity plants are respectively put together with the sectors gas, coal, crude and refined oil and biofuel.

Further we take a look at how the electricity price develops as the result of the transition towards renewable technologies. On the left part of Figure 7, the path of the price, relative to the baseline, is shown both in nominal and in real terms. The nominal price of electricity in the scenario is 3% higher than in the baseline by 2030, reaching the difference of 5% between 2020 and 2025. When corrected with the difference in inflation rates, the real difference in price is slightly lower: 2%

by 2030. The downward trend in the price difference starting from 2022 is explained by the decreasing capital intensity of renewable technologies, their costs are getting closer and closer to the cost of non-renewable ones. The assumption regarding decreasing investment costs of renewable technology is debatable and there is no consensus on this point. The importance of this assumption is illustrated on the right part of Figure 7. The upper boundary on the graph gives the relative electricity price path when the investment costs associated with renewable technologies are assumed constant over the whole period. In this case, the effect on the electricity price in substantially higher, +18% by 2030, and the grey area can be interpreted as the uncertainty interval.

Figure 7. Electricity price



Legend: in % difference from the baseline scenario. a) shows relative path of electricity price in nominal and real (corrected for difference in inflation between the baseline and the scenario) terms. b) shows the interval for relative path of the real electricity price between the cases of constant capital intensity and of decreasing capital intensity of renewable technologies (-1.8% annually for wind and -3.1% annually for solar).

5.1 Decomposition of effects

In order to improve our understanding of projected effects of energy transition on economy and environment, we have performed additional dynamic Input-Output (IO) analysis. ThreeME can run both IO and CGEM analysis and decompose results into various multiplier effects by adopting the same approach used in Bulavskaya et al. (2016). In this section, we firstly give some background information on IO analysis and the different types of multipliers. Then we show how CGEM results for gross domestic product, employment, trade balance and emissions can be decomposed into 5 steps.

The IO analysis developed by Leontief (1936) can be used to measure the impact on the different sectors of the economy of such a change in the structure of electricity production. Based on national account data, IO analysis can measure the economic dependence between activities (for an overview see Miller & Blair, 1985). IO models have the advantage to account for indirect effects via the impact of one sector to another. Formally, an IO model can be derived by defining the supply-use equilibrium:

$$Y = AY + C + I \quad (1)$$

Where $Y = (Y_a)$, $C = (C_a)$, $I = (I_a)$ are respectively the vectors of production, final (households and government) consumption and investment. To simplify the presentation and without loss of generality, we assume that each activity a produce only one commodity. AY is the matrix of intermediary consumption. $A = (\alpha_{a',a})$ is the matrix of technical coefficients where $\alpha_{a',a}$ are the Leontief technical coefficients, that is the share of product a' into the production of activity a. $\mathbb{I}$ being the matrix identity, production can be expressed as a function of final demand (final consumption plus investment):

$$Y = [\mathbb{I} - A]^{-1}(C + I) \quad (2)$$

The Leontief matrix $[\mathbb{I} - A]^{-1}$ gives the multiplier of intermediary consumption: because of the technical link between activities, the increase in production is higher than the increase in final demand (final consumption and investment).

Although IO models are very useful to capture the dependence between sectors, they neglect important economic effects. First, they do not taken into account other important multipliers. Because final demand is assumed as exogenous, the multipliers of investments and of final consumption are generally not considered. In reality an increase in production requires a higher level of capital and therefore a higher level of investment. This can be taken into account by endogenizing investment and the demand for capital:

$$I_t = \Delta K_t + \delta K_{t-1} \text{ with } K = f(Y) \quad (3)$$

Where *K* is the capital stock, δ its depreciation rate. $f(.)$ is a function increasing with production. An higher production leads to a higher employment and therefore to a higher consumption level. Endogenizing consumption and labor demand leads to a positive relation between consumption and production, $C = f(Y)$, and therefore a multiplier of final consumption.

Although it is technically possible to endogenize investment and final consumption within an IO framework, this is rarely done in practice for several reasons. With all the multipliers, an increase in final demand can lead to large effects on production and eventually to unstable (explosive) solution. It can also lead to economic inconsistency with for instance a negative unemployment rate. These results points out an important limit of IO models: they do not account for limits on supply or demand. In particular, the limit on production imposed by the availability of production factors is not taken into account. By concentrating on relation in volumes between economic variables, IO models omit prices, and therefore price effects which are however crucial in economics. Because of the absence of prices, technical coefficients are constant and there is no substitution between production factors, consumption goods, foreign and domestic production. In economics, price effects are also important because they act as a regulator in case of disequilibrium between supply

and demand. Prices are at the center of mechanisms allowing the economy to stay within the limits of production factors. Accounting for price effects requires extending the IO model into a CGEM by endogenizing final demand and prices.

In order to decompose GCEM results into various multiplier effects, we proceed to several simulation steps with ThreeME. In coherence with IO analysis, Step 1 to 4 assume that prices are constant, whereas Step 5 performs a CGEM simulation:

- ***Step 1: Direct effect (without multipliers)***
  This simulation accounts only for the effects on the electricity and heat producing sectors and assumes that the production of the other sectors, investment of all sectors and final consumption remain unchanged compared to the baseline scenario.
- ***Step 2: Effects Step 1 + Multiplier of intermediaries, transport & trade margins***
  In addition to the direct effects from Step 1, this simulation accounts also for indirect effects by taking into account the change in the production of the other sectors induced by the change in the electricity mix production. Investment of all sectors and final consumption remain unchanged compared to the baseline scenario.
- ***Step 3: Effects Step 2 + Multiplier of investment***
  In addition to the effects from Step 2, this simulation includes the effects related to the change in investments. Consumption remains unchanged compared to the baseline scenario. Change in the composition of sectors from Step 1 and changed demand for intermediate inputs from Step 2 creates an impulse for change in the amount of investment needed.
- ***Step 4: Effects Step 3 + Multiplier of consumption***
  In addition to the effects from Step 3, this simulation includes the effects related to the change in final consumption. Employment change induced by Steps 1-3 changes the disposable income for households and therefore changes the volume of consumption.
- ***Step 5: Effects Step 4 + Price effects***
  In addition to all the volume effects of Step 1 to 4, Step 5 includes the price effects by assuming prices as endogenous. This means that the equations defining prices are activated and that ThreeME is used as a CGEM.

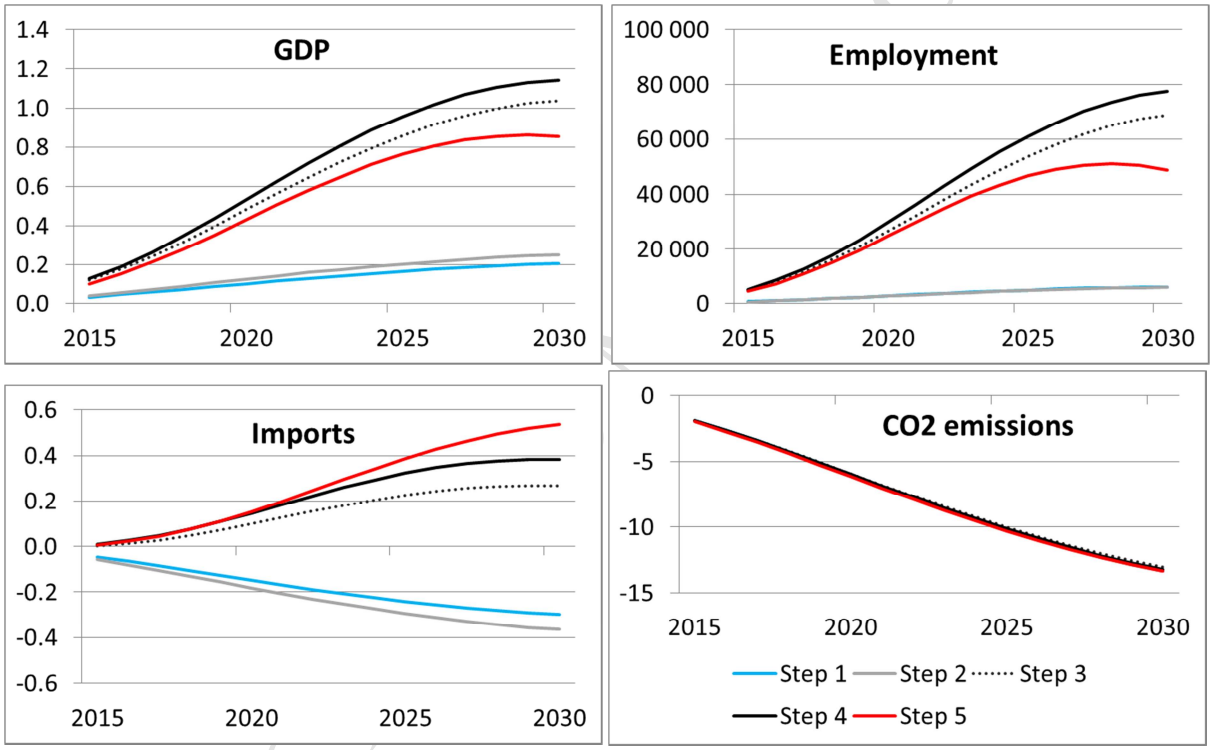
5.2 Results of the decomposition of effects

Figure 8 compares the simulation results of the different steps. Changing the electricity mix toward more renewable sources would lead to 6.1 thousand direct jobs by 2030 (Step 1) because solar and wind technologies are more labor intensive than fossil technologies (see Table 4). If we account for the multiplier of intermediaries (Step 2), that is for the effect on the sectors supplying electricity sectors, the number of job creations stays almost the same (5.9 thousand), the difference with Step 1 is that 3 000 jobs are created in agriculture and 1 700 and 900 jobs are lost in services and other energy sectors accordingly. But including the impact on investment (Step 3) has a strong positive effect with almost 70 thousand job creations. The reason is the higher capital intensity of

wind and solar technologies (see Table 4). These extra jobs (measured in Step 3) lead to an increase of the revenue of households which leads to more consumption. Accounting for this effect on consumption (Step 4) leads to 9 thousand additional job creations compared to Step 3 by 2030.

By accumulating all the volume effects, Step 4 estimates that this change in the electricity mix would generate 77.6 extra jobs. We can suspect that this positive impact in terms of employment is overestimated because price effects are excluded. If the impact of solar in terms of investment is high, this leads also to a higher electricity price that has a reverse effects on the economic activity. A higher level of employment tends to generate inflation which decreases the competitiveness of the economy. This limits the positive impact measured in Step 4. Indeed, by accounting for price effects, Step 5 measures that the positive impact on employment is limited at 48.6 thousand extra jobs by 2030.

Figure 8. Decomposition of impact on GDP, employment, import and CO2.



Legend: % deviation relative to baseline for GDP, imports and CO2 emissions; absolute deviation relative to baseline for employment (expressed in FTE)

The analysis of the different steps on GDP provides a similar story than for employment except that the difference between Step 2 and Step 1 for GDP is more visible. This comes from a stronger reduction of imports in Step 2 compared to Step 1. The propensity to import of the sectors supplying renewable electricity production is indeed lower than the one supplying fossil plants.

The impact in terms of CO2 emissions is very similar across all steps. This shows that the impact of direct effects (measured in Step 1) on this indicator is much stronger than the impact of indirect

effects. This shows that the so-called "rebound effect" are relatively small here. This is not surprising given that the carbon intensity of fossil fuel power plants is much higher than the one of other economic activities.

The positive impact in terms of employment in the different steps is explained by the heterogeneity across economic sectors regarding input intensity and the exposition to the foreign competition. Table 4 shows the production factors intensity of sectors. We notice that power generation through wind and solar is more intensive in capital and labor than fossil power plants but less intensive in energy. This is the reason why a power generation system based on renewable sources tends to be more beneficial to the national economy than the ones based on fossil fuel. According to the national account data, the import share of capital goods is relatively low because supplied for nearly 70% by the building and service sector. The import share of these sectors is respectively 2% and 10% which is much lower than the import share for coal (81%), crude oil (98%) and even gas (18%).

Table 4. Production factors intensity of sectors (2010)

Intensity	Agriculture	Energy intensive industries	Non-energy intensive industries	Construction	Rail transport	Transport by road	Air transport	Water transport	Services	Coal and non-energy mining	Crude oil mining	Refinery petroleum products
Capital	178%	102%	44%	30%	240%	240%	240%	240%	239%	152%	152%	19%
Labor	9.72	2.04	3.91	6.37	10.29	10.67	2.97	4.63	7.87	1.32	0.29	0.16
Energy	11%	19%	2%	2%	18%	16%	32%	16%	2%	33%	9%	17%
Material	54%	59%	70%	61%	30%	31%	59%	58%	41%	18%	15%	77%

Intensity	Gas - Transmission and distribution	Natural gas	Electricity - Transmission and distribution	Nuclear plant	Fuel plant	Gas plant	Coal plant	Wind turbine	Solar panel and thermal	Hydraulic plant	Other: Biomass, etc.	All sectors
Capital	99%	152%	99%	295%	130%	55%	130%	375%	2411%	130%	294%	**175%**
Labor	0.65	0.29	0.65	0.61	0.61	0.61	0.61	1.03	2.29	0.65	1.03	**6.26**
Energy	66%	16%	29%	78%	57%	67%	65%	29%	29%	29%	29%	**7%**
Material	14%	8%	14%	14%	14%	14%	14%	14%	14%	14%	27%	**47%**

Legend: expenditures expressed as a % of the production value except for employment (expressed in FTE per Millions of Euros of production)

6 *Conclusion*

In this paper, we have analyzed the potential short and long-term macroeconomic effects of renewable energy in the Netherlands. We have considered a scenario in which, by 2030, electricity is generated mostly by solar and wind power and heat is derived mainly from biomass. This scenario represents a selection of policy measures suggested in the 100% Renewable scenario of Urgenda. Physical and technical feasibility of the scenario has been already assessed by Energy Transition Model (ETM) of Quintel. We take the electricity mix and future generation costs as defined by ETM and feed them into the neo-Keynesian CGEM ThreeME in order to derive macroeconomic effects.

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We find that renewable energy has potential for stimulating growth and jobs for the Dutch economy. We expect that additional 0.85% of gross domestic product will be created by 2030 as a result of shift towards renewable energy mix, with the largest effect seen in investment growth. In terms of job creation, we project around 50 000 new full time job by 2030. This positive impact is explained by a relatively higher labor and capital intensity of wind and solar technologies, compared to gas and coal plants. This creates growth opportunities primarily for domestic, but not imported, products. At the same time, renewable technologies typically require higher investments per unit of output than fossil fuel technologies, which leads to a higher electricity price. We also show that the relative increase in electricity price strongly depends on the projected costs of the technologies, giving the uncertainty range for the relative electricity price increase between 2 and 18%. We have not only shown the projected long-term outcome of the change in the electricity mix, but also the time path towards this outcome.

Furthermore, we have demonstrated how the total effect can be decomposed into a number of multiplier effects using dynamic Input-Output analysis. One of the important conclusions here is that positive impacts on the economy can be overestimated when price effects and feedback loops are not taken into account. General equilibrium models, such as ThreeME, are specifically designed to incorporate price effects and inter-sectoral links.

This paper has only focused on the macroeconomic effects of change in the electricity and heat generation mix. We have limited the scope of the analysis on purpose, in order to be able to lay out the intuition behind the results and demonstrate the possible role of general equilibrium models in the energy transition discussion. But, of course, the question of sustainable and renewable future is much more broad, including many aspects such as energy efficiency, behavior adjustment, biofuels, local energy generation, etc. We therefore believe that the future of energy transition modelling and analysis lays in finding the right combinations of physical and micro models, which give feasibility of a certain energy solution and its effect on the physical system, and of macroeconomic models, which ensure that labor, capital and monetary constrains are also taken into account.

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- A neo-Keynesian model with detailed energy sector for the Netherlands is presented
- Positive long-term effects of renewable energy on growth and jobs
- Decomposition of effects into investment, consumption and prices
- Policy effects are overestimated in models without price and feedback loops

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Supplementary material A: Main equations of ThreeME

1 Specification of adjustment mechanisms

Unlike Walrasian models that assume that equality between supply and demand is achieved through a perfect flexibility of prices and quantities, ThreeME represents more realistically the functioning of the economy by taking into account explicitly the slow adjustment of prices and quantities (factors of production, consumption). In this Keynesian framework, permanent or transitory underemployment equilibria are possible and supply is determined by demand.

ThreeME assumes that the actual levels of prices and quantities gradually adjust to their notional level. The notional level corresponds to the optimal (desired or target) level that the economic agent in question (the company for prices and the demand for production factors, the household for consumption, the Central bank for the interest rate, etc.) would choose in the absence of adjustment constraints. These constraints mainly come from adjustment costs, physical or temporal boundaries and uncertainties. Formally, we assume that the adjustment process and expectations for prices and quantities are represented by the following equations:

$$\ln(X_t) = \lambda_0^X * \ln(X_t^n) + (1 - \lambda_0^X) * (\ln(X_{t-1}) + \Delta \ln(X_t^e)) \quad (1)$$

$$\Delta\ln(X_t^e) = \lambda_1^X * \Delta\, ln(X_{t-1}^e) + \lambda_2^X * \Delta\ln(X_{t-1}) + \lambda_3^X * \Delta\ln(X_t^n) \quad (2)$$

Where X_t is the actual value of a given variable (e.g. the production price, labor, capital, etc.), X_t^n is its notional level, X_t^e its anticipated value at period *t* and λ_i^X are the adjustments parameters (with $\lambda_1^X + \lambda_2^X + \lambda_3^X = 1$).

Equation (1) assumes a geometric adjustment process. Taking into account the anticipations guaranties that the actual variables converge to their notional levels in the long run. Equation (2) assumes that the anticipations are adaptive (« backward-looking »). One can see that Equations (1) and (2) can be reformulated into an Error Correction Model used in the econometric estimations to take into account the non-stationary propriety of some variables: $\Delta \ln(X_t) = \alpha_1 * \Delta\ln(X_{t-1}) + \alpha_2 * \Delta \ln(X_t^n) - \alpha_3 * \ln\left(\frac{X_{t-1}}{X_{t-1}^n}\right)$. For this, the following constraints must hold: $\lambda_0^X = \alpha_3$, $\lambda_1^X = 0$, $\lambda_2^X = \alpha_1/(1-\alpha_3)$, $\lambda_3^X = (\alpha_2 - \alpha_3)/(1-\alpha_3)$.

We also assume that the substitution effects (*SUBST_X*) adjust slowly to the notional substitution effects (*SUBST_X*^{n}):

$$SUBST_X_t = \lambda_4^X * SUBST_X_t^n + (1 - \lambda_4^X) * SUBST_X_{t-1} \quad (3)$$

The three equations above allow a rich set of adjustment as they integrate different types of rigidity (on prices and quantities, on expectations and on substitution mechanisms). For illustrative purposes, we present the full specification of the demand for labor (*L*). For simplicity, the sector index is omitted. The notional labor demand (L^n) is derived by minimizing production costs (see Section 2). It depends positively on the level of the output (*Y*), negatively on the labor productivity (*PROG_L*) and on an element gathering all the substitution phenomena with the other production factors (*SUBST_L*):

$$\Delta\ln(L_t^n) = \Delta\ln(Y_t) - \Delta\ln(PROG_L_t) + \Delta SUBST_L_t \quad (4)$$

We introduce a distinction between the actual and notional substitution effects to account for the fact that labor demand generally responds more quickly to changes in the level of production than to substitution phenomena: while it is "physically" necessary to increase employment to meet rising production, substitutions involve changes to the structure of production whose implementation takes longer. The actual substitution therefore adjusts gradually to the notional substitution ($SUBST_L^n$) which depends on the relative prices between the production factors:

$$\begin{aligned}\Delta SUBST_L_t^n = & -\eta^{LK}\varphi_{t-1}^K \Delta\ln(C_t^L/C_t^K) - \eta^{LE}\varphi_{t-1}^E \Delta\ln(C_t^L/C_t^E) \\ & -\eta^{LMat}\varphi_{t-1}^{Mat} \Delta\ln(C_t^L/C_t^{Mat})\end{aligned} \quad (5)$$

Where η^{LK}, η^{LE}, η^{LMat} are the elasticity of substitution between labor and the other production factors respectively capital, energy, material (i.e. non-energy intermediate consumption). φ^K, φ^E, φ^{Mat} are respectively the capital, energy and materials shares in the production costs. C^K, C^L, C^E, C^{Mat} are respectively the unitary costs of production of capital, labor, energy and material. The next section provides more information on the derivation of factors demands.

Finally, the adjustment mechanisms being defined according to the equations (1), (2) and (3), the three following relationships are used:

$$\begin{aligned}\ln(L_t) &= \lambda_0^L * \ln(L_t^n) + (1 - \lambda_0^L) * (\ln(L_{t-1}) + \Delta\ln(L_t^e)) \\ \Delta\ln(L_t^e) &= \lambda_1^L * \Delta\ln(L_{t-1}^e) + \lambda_2^L * \Delta\ln(L_{t-1}) + \lambda_3^L * \Delta\ln(L_t^n) \\ SUBST_L_t &= \lambda_4^L * SUBST_L_t^n + (1 - \lambda_4^L) * SUBST_L_{t-1}\end{aligned} \quad (6)$$

2 The production function and the production factors demand

The production structure is decomposed into three levels (see **Error! Reference source not found.**). The first one assumes a production function with 4 inputs (or production factors), often referred as KLEM (capital, labor, energy and materials). The first level has a fifth element: the transport and commercial margins. Stricto sensu, they cannot be considered as production factors since they intervene after the production process. Thus they are not substitutable with the production factors. But they are closely related to the level of production since once a good has been processed, it has to be transported and commercialized. At the second level, the investment, energy, material and margins aggregates are further decomposed by type of commodities (e.g. energy sources). At the third level, the demand for each factor or margin is either imported or produced domestically.

The demands for production factors are derived from the minimization of the firm's production costs. We assume a production function with constant returns-to-scale more general than the CES (Constant Elasticity of Substitution) insofar as substitution elasticities may differ between different inputs pair (Reynès, 2011). The production costs minimization program leads to the following equations for the notional factors demand. This holds for every economic activity, but for algebraic simplicity the sector index is omitted here:

$$\Delta\ln\left(FP_{j,t}^{n}\right) = \Delta\ln(Y_t) - \Delta\ln\left(PROG_FP_{j,t}\right) + \Delta SUBST_FP_{j,t} \quad (7)$$

$$\Delta SUBST_FP_{j,t}^{n} = -\sum_{\substack{j'=1 \\ J'\neq j}}^{J} \eta_{j,j'}\,\varphi_{j',t-1}\,\Delta\ln\left(C_{j',t}^{FP}/C_{j,t}^{FP}\right) \quad (8)$$

with $$\varphi_{j,t-1} = \frac{C_{j,t}^{FP} * FP_{j,t-1}}{\sum_j C_{j,t}^{FP} * FP_{j,t-1}} \quad and \quad j = \{K, L, E, M\} \quad (9)$$

Where FP_j^n is the notional demand of input *j* (KLEM), $\eta_{j,j'}$ the elasticity of substitution between the pairs of inputs *j* and *j'*, $PROG_FP_{j,t}$ the technical progress related to input *j*, C_j^{FP} the cost/price of input *j* and *Y* the level of production of the sector under consideration.

According to national accounts data, THREEME assumes that each commodity may be produced by more than one sector. For instance, electricity can be produced by several sectors such as nuclear or wind power. The production of each sector is defined by the following equations:

$$Y_{c,a} = \varphi_{c,a} YQ_c \quad (10)$$

$$Y_a = \sum_c Y_{a,c} \quad (11)$$

Where YQ_c is the aggregated domestic production of commodity c. It is determined by the demand (intermediate & final consumption, investment, public spending, exports and stock variation). $\varphi_{c,a}$ is then the share of commodity c produced by the sector a (with $\sum_a \varphi_{c,a} = 1$) and Y_a is the aggregated production of sector a.

3 Equations for investment & capital

Investment in ThreeME depends on the anticipated production, on its past dynamic, on substitution phenomena and on a correction mechanism, which guaranties that companies reach their level of long-term notional capital stock. The stock of capital is deducted from the investment according to the standard capital accumulation equation:

$$\begin{aligned} \Delta\ln(IA_t) = {} & \theta_1^{IA} * \Delta ln(IA_{t-1}) + \theta_2^{IA} * \Delta\ln(Y_t^e) \\ & + \theta_3^{IA}(\ln(K_{t-1}^n) - ln(K_{t-1})) + \Delta SUBST_K_t \\ K_t = {} & (1-\delta^K)K_{t-1} + IA_t \end{aligned} \quad (12)$$

Where *IA* is the investment, Y^e the anticipated production, *K* and K^n the actual and notional stocks of capital, *SUBST_K* a variable gathering substitution phenomena between capital and the other inputs, and δ^K the depreciation rate of capital. Moreover, we impose the constraint $\theta_1^{IA} + \theta_2^{IA} = 1$ in order to guaranty the existence of the stationary equilibrium path.

This specification is a compromise between the short-term dynamics empirically observed and the consistency of the model in the long run. Like the E-MOD or MESANGE econometric models (Chauvin Valérie;Dupont, 2002; Klein and Simon, 2010), it is common to estimate an investment equation rather than capital stock equation for serval reasons. Firstly, time series capital stock data are often unreliable. Secondly, this approach better represents the short-term dynamics of investment. In particular, it avoids capital destruction phenomena (negative investment) that are in practice unusual, since companies generally prefer to wait for the technical depreciation of their installed capital. Unlike E-MOD or MESANGE, we assume in addition that investment depends on the difference between the actual and notional capital stock. This element ensures that the effective capital stock converges over time towards its notional level. In the long-term, the model is then consistent with the production function theory that establishes a relationship between the levels of production and capital stock (and not with the flow).

4 Wage equation

Several studies have shown that the theoretical arguments and empirical estimates difficultly allow choosing between the two specifications. However, this difference of specification has important implications on the definition of the equilibrium unemployment rate (NAIRU) and thus on the inflationary dynamic and the long-term proprieties of a macroeconomic model (e.g. L'Horty & Thibault, 1998 ; Chagny, Reynès, & Sterdyniak, 2002). In ThreeME, we choose a general specification that includes the Phillips and WS curves. It assumes that the notional nominal wage (W_t^n) positively depends on the anticipated consumption price (P_t^e) and on the labor productivity ($PROG_L_t$), and negatively on the unemployment rate (U_t):

$$\Delta ln(W_t^n) = \rho_1^W + \rho_2^W * \Delta ln(P_t^e) + \rho_3^W * \Delta ln(PROG_L_t) - \rho_4^W U_t - \rho_5^W \Delta U_t \quad (13)$$

This relation can alternatively be identical, either to the Phillips curve, or to the WS curve depending on the value of the selected parameters (Heyer et al., 2007; Reynès, 2010). The Phillips curve corresponds to the case where $\rho_4^W > 0$ whereas the WS curve assumes $\rho_4^W = 0$. For the model to have a consistent steady-state in the long-run, the WS curve must also impose the constraints identified by Layard et al. (2005) : a unit indexation of wages on prices and productivity: ($\rho_2^W = \rho_3^W = 1$) and $\rho_1^W = 0$.

5 Equation of households' consumption

In the standard version of the model, consumption decisions are modeled through a *Linear Expenditure System* (LES) utility function generalized to the case of a non-unitary elasticity of substitution between the commodities Brown & Heien (1972). Households' expenditures for each commodity evolve (more or less) proportionally to their income:

$$(EXP_c^n - NEXP_c).PEXP_c = \beta_c^{EXP}\left[(1 - MPS).DISPINC_VAL - \sum_c PEXP_c * NEXP_c\right] \quad (14)$$

With $\sum_c \beta_c^{EXP} = 1$

Where $EXP_{c,h}^n$ corresponds to the volume of notional consumption (expenditures) in commodity c and $PEXP_c$ to its price. $NEXP_c$ is the incompressible volume of expenditures in commodity *c*, $DISPINC_VAL$ is the households' disposable income and MPS their marginal propensity to save.

In the case of no incompressible expenditures ($NEXP_c = 0$), households aim at allocating a share β_c^{EXP} of their total expenditure (in value), $(1 - MPS).DISPINC_VAL$, to commodity *c*. This share is constant if the elasticity of substitution between the commodities is equal to one (Cobb-Douglas assumption). In this case (Cobb-Douglas utility function without incompressible expenditures), commodity c expenditures stay exactly proportional to income. In the case of a CES function where the elasticity of substitution is η^{LES_CES}, the marginal propensity to spend varies depending on the relative prices according to the following specification:

$$\Delta\beta_{c,t}^{EXP} = (1 - \eta^{LES_CES}) * \Delta\frac{PEXP_{c,t}}{PEXP_t^{CES}} \quad (15)$$

$$PEXP_t^{CES} = \left(\sum_c \beta_{c,0}^{EXP} * PEXP_{c,t}^{(1-\eta^{LES_CES})}\right)^{\frac{1}{1-\eta^{LES_CES}}} \quad (16)$$

6 Equations of prices and of the mark-up rate

The production price for each sector is set at the lowest level by applying a mark-up over the unit cost of production (which includes labor, capital, energy and other intermediate consumption costs) :

$$PY_t^n = CU_t * (1 + TMD_t) \quad (17)$$

$$\Delta\ln(1 + TM_t^n) = \sigma^{TM} * (\Delta\ln(Y_t) - \Delta\ln(Y_{t-1})) \quad (18)$$

$$TMD_t = \lambda^{TM} * TM_t^n + (1 - \lambda^{TM}) * TMD_{t-1} \quad (19)$$

Where PY_t^n is the notional price, CU_t the unitary cost of production and Y_t the level of production. TMD_t and TM_t^n are respectively the desired and notional mark-up.

The equation of notional price is a behavioral equation: by assuming that the addressed demand to a firm is a negative function of its price, one can easily demonstrate that the optimal price corresponds to a mark-up over the marginal cost of production. The mark-up equation reflects the fact that the returns-to-scale are decreasing in the short-term. Therefore, a non-expected increase in production results into a higher marginal cost of production and therefore into a higher notional price.

The other prices are calculated according to their accounting definition and are therefore (directly or indirectly) a function of the producer price. The price of the domestically produced commodity *c* is a weighted average of the production prices of activities (indexed by a) producing

that commodity. For example, the price of electricity is a weighted average of the production prices of the sectors producing electricity. The price paid by the final user (consumer, government, sector, rest of the world) integrates in addition the commercial and transportation margins, and the taxes net from subsidies. Combined with the price of imports, we get the average price for each commodity paid by each end user.

7 Equations of foreign trade

Exports are determined by the external demand addressed to domestic products and the ratio between the export and world prices:

$$\Delta \ln(X_{c,t}) = \Delta \ln(WD_{c,t}) + \Delta SUBST_X_{c,t} \quad (20)$$
$$\Delta SUBST_X^{n}_{c,t} = -\eta^{X} * \Delta \ln(P^{X}_{c,t}/P^{W}_{c,t}/TC_t)$$

Where $WD_{c,t}$ is the world demand, $P^{W}_{c,t}$ its price. $P^{X}_{c,t}$ is the export price that depends on the production costs and which reflects the price-competitiveness of the domestic products. TC_t is the exchange rate; η^{X} is the price-elasticity (assumed constant).

We assume imperfect substitution between domestic and imported goods (Armington, 1969). The demand for domestic and imported products is :

$$\Delta \ln(A^{D}_{c,t}) = \Delta \ln(A_{c,t}) + \Delta SUBST_AD_{c,t}$$
$$\Delta SUBST_AD^{n}_{c,t} = \eta^{A}_{c} * \Delta \ln(P^{AD}_{c,t} / P^{AM}_{c,t}) * \frac{P^{AM}_{c,t-1} * A^{M}_{c,t-1}}{P^{A}_{c,t-1} * A_{c,t-1}} \quad (21)$$
$$A^{M}_{c,t} = A_{c,t} - A^{D}_{c,t}$$

Where $A_{c,t}$ represents the demand for each type of use (intermediary consumption, investment, consumption, public spending, exports, etc.), $P^{A}_{c,t}$ is its price. $A^{M}_{c,t}$ and $A^{D}_{c,t}$ are the imports and the domestic products demanded for each type of use *A*, $P^{AM}_{c,t}$ and $P^{AD}_{c,t}$ are their respective prices. The elasticity of substitution η^{A}_{c} by type of use *A* of a given commodity *c* can potentially be different, which allows a high degree of flexibility.

Supplementary material B: Detail on the scenario calibration calculation

1.1 Base year data

The database for the Netherlands that went into the base year calibration of ThreeME has not been available directly. This paper is the first application of ThreeME Netherlands and here we describe how the base year data has been constructed. Table 1 list the data sources and how they have been used.

Table 1. Data sources of ThreeME Netherlands

Data source	How is was used
Core data	
2010 Supply and Use Tables (SUTs) from Eurostat	The main data source for calibration of supply and demand functions of the model. Sectors/products had to be aggregated and disaggregated, but disaggregated version of the data always adds up to the original Eurostat source. We used 2010 data because these were the most reliable at the moment of the project. The later releases were essentially rescaled projections of the 2010 data. Indeed, the detailed SUT and IO tables are accurately estimated only every 5 or 10 years.
Auxiliary data	
Domestic vs. Imported Input-Output Tables (IOTs)	Relative shares of domestic vs. imported inputs have been used to split the core use table into domestic and imported
2010 SUTs from CBS	Disaggregation of use table where CBS data are more detailed than Eurostat data
Structural Business Statistics / Bedrijfsleven	Shares of output for disaggregated sectors/products
Trade Statistic	Import and export shares of disaggregated products
Energy Balance	Shares of outputs and inputs of disaggregated energy sectiors/products
EXIOBASE 2.2	CO2 emissions
Employment Statistics	Employment per sector in FTE
Capital stock and Investments in fixed assets (groeirekeningen)	Capital stock per sector and investment matrix
Nationale Energieverkenning	Employment by electricity technology
Levelized Cost of Electricity (LCOE) from IEA	Capital stock per sector and investment matrix by electricity technology

As shown in Table 1, sectoral detail of original Eurostat had to be changed. ThreeME model requires relatively high level of sector/product detail for energy, so most of the energy producing and transport sectors had to be disaggregated. At the same time, Eurostat SUTs include 39 different

types of services, and this level of detail is excessive for operational used of the model. In the end, ThreeME Netherlands distinguishes between 23 economic activities, or sectors, and 15 types of commodities (see **Error! Reference source not found.** in the main text). Table 2 gives detailed overview of correspondence between Eurostat and ThreeME level of details. You can see how sectors have classified into Energy Intensive and Non-Energy intensive. We have defined energy intensity of each industry as amount of energy (in TJ) used per unit of output (in million Euro) and the average energy intensity of all industries (2.49 TJ/MEUR) has been used to define the border between energy intensive and non-energy intensive industries.

Table 2. Correspondence between Eurostat and ThreeME sector/product detail

Eurostat SUTs (NACE r.2)	ThreeME Netherland
(A01) Products of agriculture, hunting and related services	Part of 'Agriculture, forestry and fishing'
(A02) Products of forestry, logging and related services	Part of 'Agriculture, forestry and fishing'
(A03) Fish and other fishing products; aquaculture products; support services to fishing	Part of 'Agriculture, forestry and fishing'
(B) Mining and quarrying	Detailed to 'Coal and non-energy mining', 'Crude oil mining' and 'Gas mining'. 'Gas mining' is further merged into 'Gas'(product) and 'Natural and manufactured gas'(sector)
(C10-12) Food products, beverages and tobacco products	Part of 'Non-energy intensive industries'
(C13-C15) Textiles, wearing apparel and leather products	Part of 'Non-energy intensive industries'
(C16) Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	Part of 'Non-energy intensive industries'
(C17) Paper and paper products	Part of 'Energy intensive industries'
(C18) Printing and recording services	Part of 'Energy intensive industries'
(C19) Coke and refined petroleum products	Renamed to 'Refinery petroleum products (oil and biofuel)'
(C20) Chemicals and chemical products	Part of 'Energy intensive industries'
(C21) Basic pharmaceutical products and pharmaceutical preparations	Part of 'Energy intensive industries'
(C22) Rubber and plastics products	Part of 'Non-energy intensive industries'
(C23) Other non-metallic mineral products	Part of 'Energy intensive industries'
(C24) Basic metals	Part of 'Energy intensive industries'
(C25) Fabricated metal products, except machinery and equipment	Part of 'Non-energy intensive industries'
(C26) Computer, electronic and optical products	Part of 'Non-energy intensive industries'
(C27) Electrical equipment	Part of 'Non-energy intensive industries'
(C28) Machinery and equipment n.e.c.	Part of 'Non-energy intensive industries'
(C29) Motor vehicles, trailers and semi-trailers	Part of 'Non-energy intensive industries'
(C30) Other transport equipment	Part of 'Non-energy intensive industries'
(C31-32) Furniture; other manufactured goods	Part of 'Non-energy intensive industries'
(C33) Repair and installation services of machinery and equipment	Part of 'Services'
(D35) Electricity, gas, steam and air-conditioning	On product side: detailed to 'Electricity', 'Heat' and 'Gas manufacturing and distribution'. 'Gas manufacturing and distribution' is further merged into 'Gas'. On sector side: detailed to 'Gas - Transmission and distribution', 'Electricity - Transmission and distribution', 'Nuclear plant', 'Fuel plant', 'Gas plant', 'Coal plant', 'Wind

	turbine', 'Solar panel and thermal', 'Hydraulic plant', 'Other: Wood, Biomass, Waste incineration, Geothermal'.
(E36) Natural water; water treatment and supply services	Part of 'Services'
(E37-39) Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	Part of 'Services'
(F) Constructions and construction works	Renamed to 'Construction of buildings and Civil engineering'
(G45) Wholesale and retail trade and repair services of motor vehicles and motorcycles	Part of 'Services'
(G46) Wholesale trade services, except of motor vehicles and motorcycles	Part of 'Services'
(G47) Retail trade services, except of motor vehicles and motorcycles	Part of 'Services'
(H49) Land transport services and transport services via pipelines	Detailed to 'Rail transport (Passenger and Freight)' and 'Transport by road (Passenger and Freight)'
(H50) Water transport services	Renamed 'Water transport'
(H51) Air transport services	Renamed 'Air transport'
(H52) Warehousing and support services for transportation	Part of 'Services'
(H53) Postal and courier services	Part of 'Services'
(I) Accommodation and food services	Part of 'Services'
(J58) Publishing services	Part of 'Services'
(J59-60) Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	Part of 'Services'
(J61) Telecommunications services	Part of 'Services'
(J62-63) Computer programming, consultancy and related services; information services	Part of 'Services'
(K64) Financial services, except insurance and pension funding	Part of 'Services'
(K65) Insurance, reinsurance and pension funding services, except compulsory social security	Part of 'Services'
(K66) Services auxiliary to financial services and insurance services	Part of 'Services'
(L68) Real estate services	Part of 'Services'
(M69-70) Legal and accounting services; services of head offices; management consulting services	Part of 'Services'
(M71) Architectural and engineering services; technical testing and analysis services	Part of 'Services'
(M72) Scientific research and development services	Part of 'Services'
(M73) Advertising and market research services	Part of 'Services'
(M74-75) Other professional, scientific and technical services; veterinary services	Part of 'Services'
(N77) Rental and leasing services	Part of 'Services'
(N78) Employment services	Part of 'Services'
(N79) Travel agency, tour operator and other reservation services and related services	Part of 'Services'
(N80-82) Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	Part of 'Services'

(O84) Public administration and defence services; compulsory social security services	Part of 'Services'
(P85) Education services	Part of 'Services'
(Q86) Human health services	Part of 'Services'
(Q87-88) Social work services	Part of 'Services'
(R90-92) Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services	Part of 'Services'
(R93) Sporting services and amusement and recreation services	Part of 'Services'
(S94) Services furnished by membership organisations	Part of 'Services'
(S95) Repair services of computers and personal and household goods	Part of 'Services'
(S96) Other personal services	Part of 'Services'
(T) Services of households as employers; undifferentiated goods and services produced by households for own use	Part of 'Services'
(U) Services provided by extraterritorial organisations and bodies	Part of 'Services'

The rows highlighted in orange had created a number of disaggregation issues. Firstly, the lack of economic data on turnover and inputs of detailed mining sectors, detailed electricity technologies and on the size of transmission and distribution sector made detailing of these sectors a challenge. In order to ensure transparence of the calculations, we have used the shares provided by physical data to disaggregate monetary data. In most of the cases, the assumption was that the price per 1 TJ of energy is always the same, independent of product and user. Furthermore, we have assumed that on average transmission and distribution costs amount for around 60% of the price of electricity and gas. Using this ratio, we are able to reproduce the structure of household expenses quite precisely: 36% is spent on electricity, 4% on heat and 60% on gas. Secondly, treatment of natural gas in 2010 Eurostat table is not very consistent: large industrial consumers are buying directly from the mining sector (B) and other commercial and residential locations by the natural gas resold by energy companies (D35). This complication has required us to separate natural gas as a commodity and its transmission and distribution services from (B) and (D35) and then group them into a single 'Gas' product. As far as we know, the statistical practices has been already changed and in the more recent tables natural gas is treated equally by all sectors.

2 Electricity and heat sectors

Exogenous change in the production share:

- For electricity, nuclear, fuel coal plant are closed by 2030. The share of gas plant decrease from 24.8% to 9.5%. This is compensated by an increase in wind turbine, solar panel and thermal and hydraulic plant.

- For heat, solar panel and thermal and biomass, compensate the decrease of fuel gas and coal.

3 Other

The scenario require a huge increase in biomass that cannot be produced in the Netherlands do to land capacity issue. We assume that this biomass in imported by the following sectors: energy intensive industries, non-energy intensive industries, other energy sectors.