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A B S T R A C T

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.

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% 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 ([23] 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

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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 Ref. [24]. 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 [12], LEAP [13], TIMES [17], or PRIMES [10] 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. Ref. [22] 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 - [8], GEM-E3 [7] or ENV-Linkages [9]. 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 [6], NEMESIS [1,11].) or GINFORS [18] 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 [3,5]. ThreeME is now been applied to other national contexts such as Indonesia [21], Mexico [15] 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 when their relative prices change. Consumers can substitute between energy sources, between transport choices or between goods and services.
- ThreeME is a CGEM (Computable General Equilibrium Model). It therefore takes into account the interaction and feedbacks between supply and demand (see Fig. 1). The demand (consumption, investment) defines the supply (production). The supply defines in return the demand through the incomes generated by

[1] For full description of ThreeME see Ref. [6].

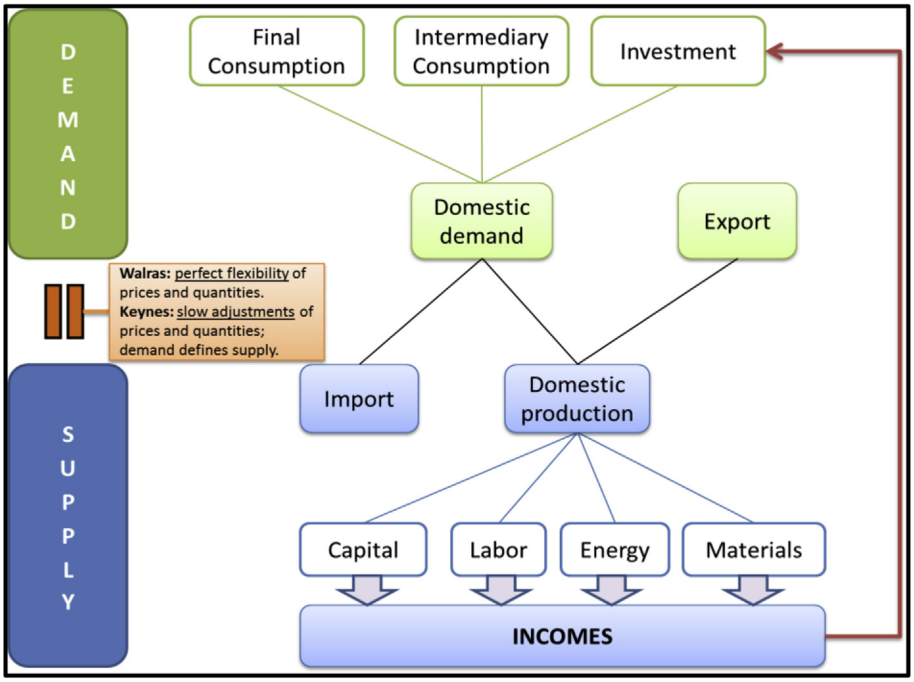


Fig. 1. Architecture of a CGEM.

the production factors (labor, capital, etc.). Compared to bottom-up energy models such as MARKAL [12] or LEAP [13], 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 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 Fig. 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 modeled 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]

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

[2] Econometric models such as 3EME [3,5], NEMESIS [1]; ERASME, n.d.) and MESANGE [14] 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 Ref. [4] for a comparison of ThreeME with MESANGE for France.

[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.

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	

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]

Fig. 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.

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 Fig. 3). The first level assumes a technology with four production factors (capital, labor, energy and material), using a Variable Output Elasticities Cobb-Douglas function [20]. 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.

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).

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 [24]. 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 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

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

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

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

		SUPPLY															
		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, Geothermal	Energy other	Taxes	Margins	TOTAL SUPPLY = TOTAL DEMAND
COMMODITIES	Agriculture	24.7	0.2	0.0											0.5	9.4	34.8
	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
	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
	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
	Energy other	0.2	3.6	2.7			0.2	2.4	0.0				0.2	66.3	12.7	4.2	92.5
PRODUCTION	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
	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
	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

	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, Geothermal	Energy other	CONSUMPTION (Households + Government)	INVESTMENT	EXPORTS - IMPORTS
Agriculture	4.9	15.9	1.3									0.1	0.0	6.1	0.4	6.1
Industry	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	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	0.3	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	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	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
CO2 emissions (million tonne)														56.5		

GDP = VA + TAX = C + I + EXP - IMP	586.8

Fig. 2. Equilibrium between supply and demand in 2010 (in billion euros).
Source: Authors' calculations.

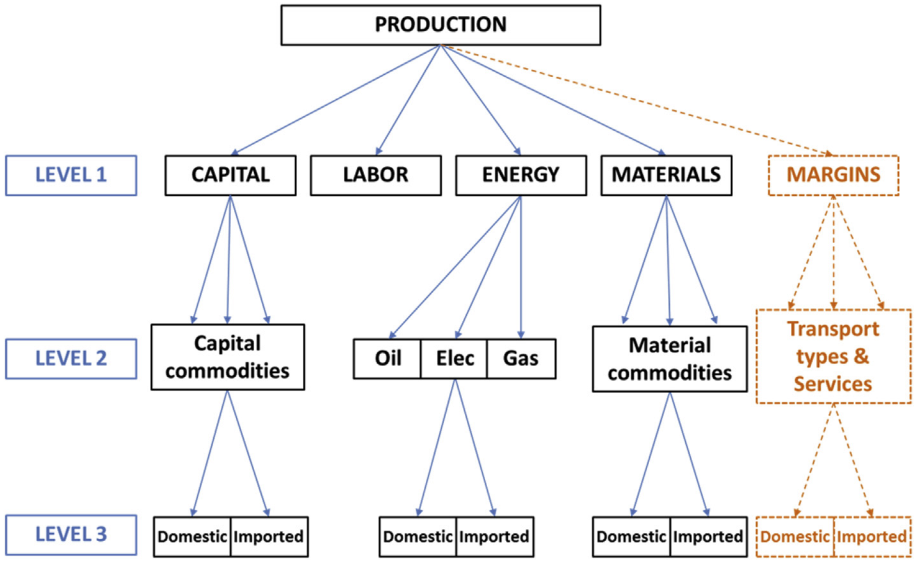


Fig. 3. Production structure.

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

the energy system. Here we omit the description of the demand side since it has not been used in the ThreeME calculations. Fig. 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.

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.

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. Fig. 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, Fig. 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 Fig. 5. This is logical since we assume that the Dutch gas not consumed nationally is not exported.

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 Fig. 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 Fig. 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.

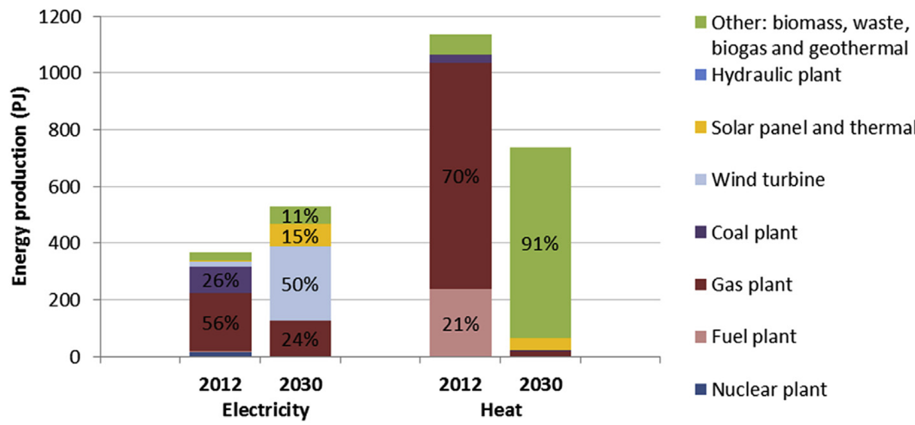


Fig. 4. Structure of electricity and heat supply in 100% renewable scenario.
Source: ETM results as accessed on 30 October 2015, authors' calculations.

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	1103	2420	4467	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.

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 Ref. [2]. 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 Ref. [16] 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 Ref. [19]). 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:

$$Y = AY + C + I \tag{1}$$

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):

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

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:

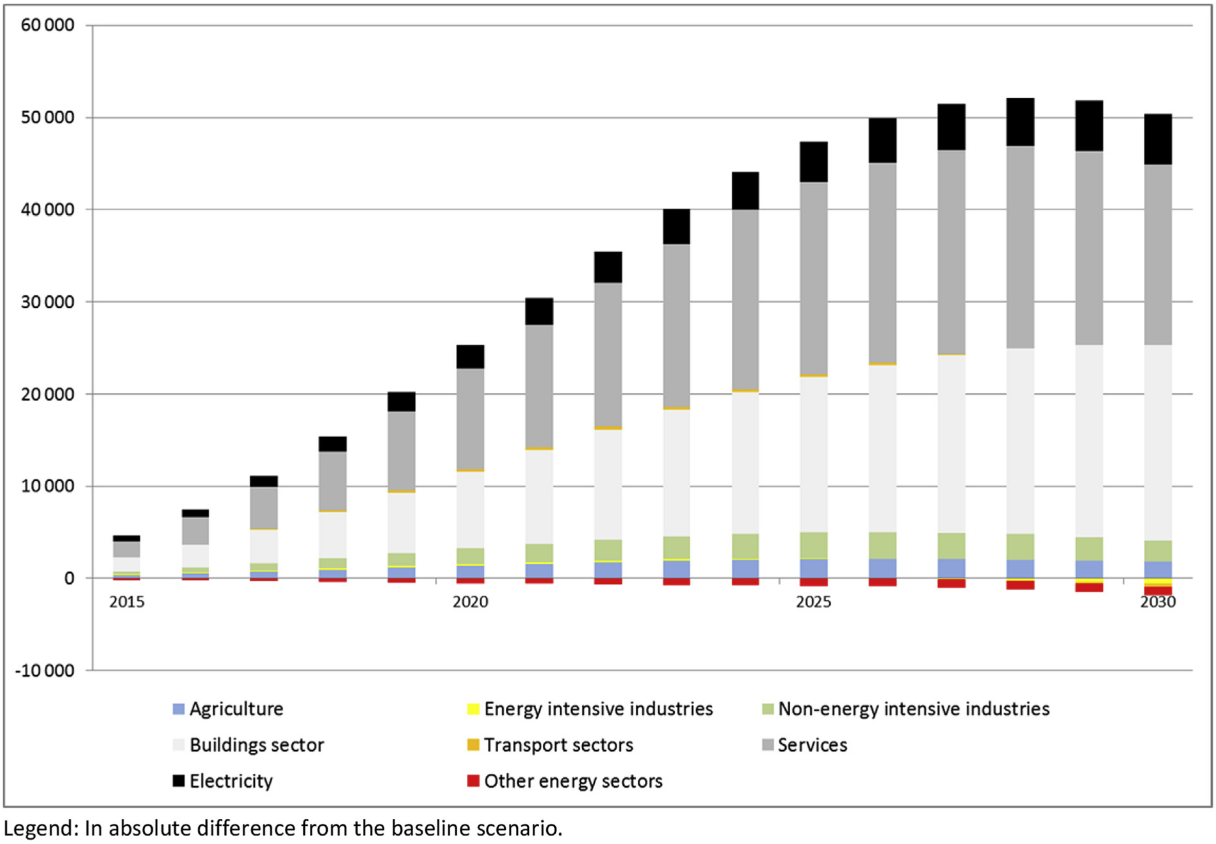


Fig. 5. Employment per sector (in FTE). Legend: In absolute difference from the baseline scenario.

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

where K is the capital stock, δ its depreciation rate. $f(\cdot)$ is a function increasing with production. A 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.

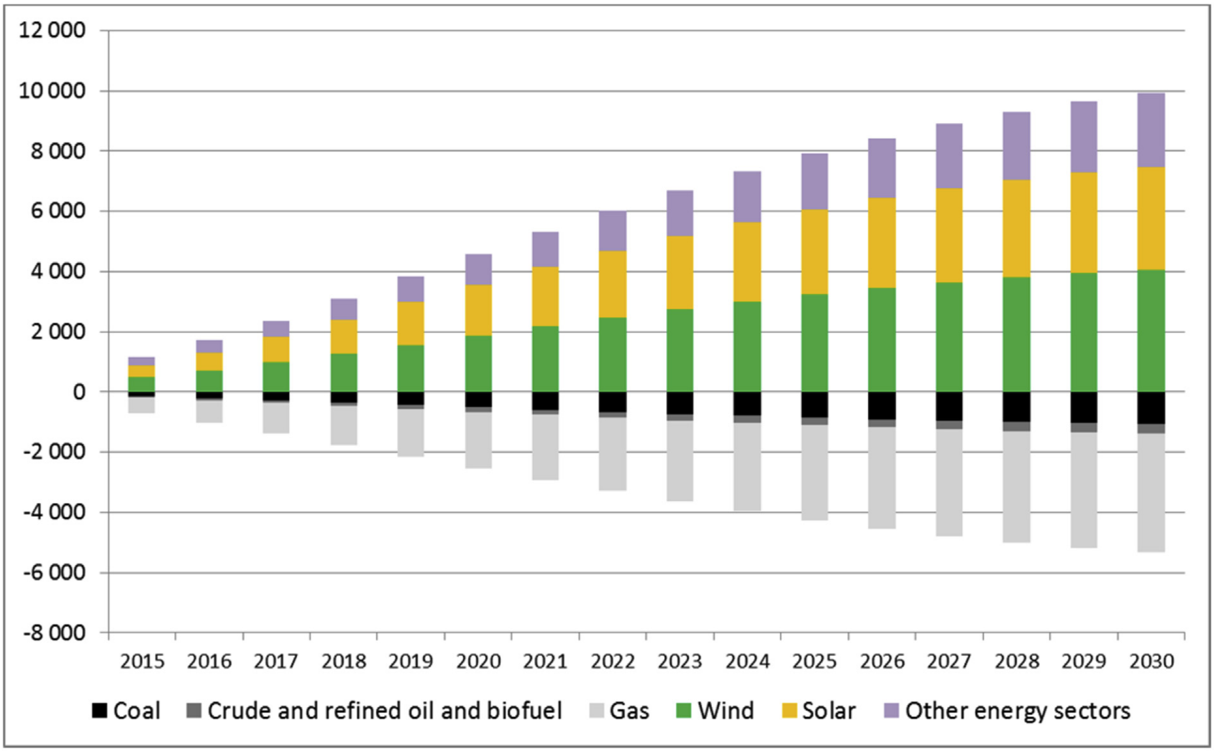
- **Step 2: Effects Step 1 + Multiplier of intermediaries, transport & trade margins**

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**



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.

Fig. 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.

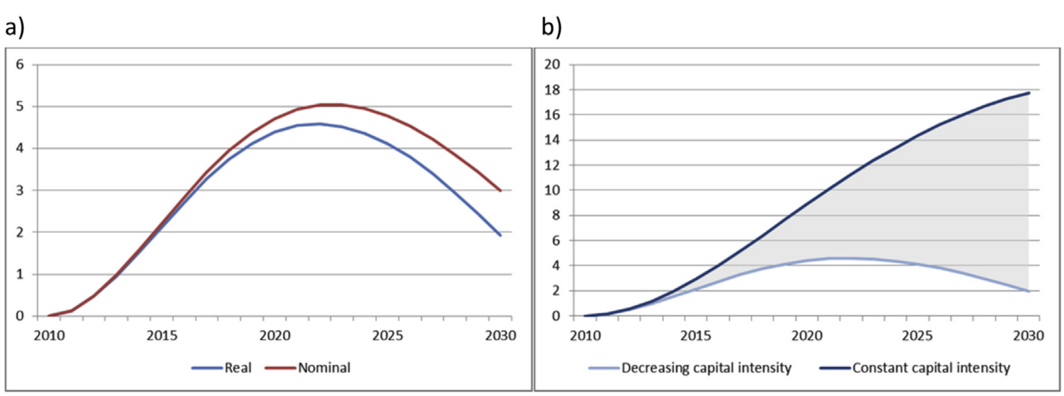


Fig. 7. Electricity price. Legend: in % difference from the baseline scenario. a) shows relative path of electricity price in nominal and real (corrected for difference in inflation between the baseline and the scenario) terms. b) shows the interval for relative path of the real electricity price between 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).

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

Fig. 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 3000 jobs are created in agriculture and 1700 and 900 jobs are lost in services and other energy sectors accordingly. But including the impact on

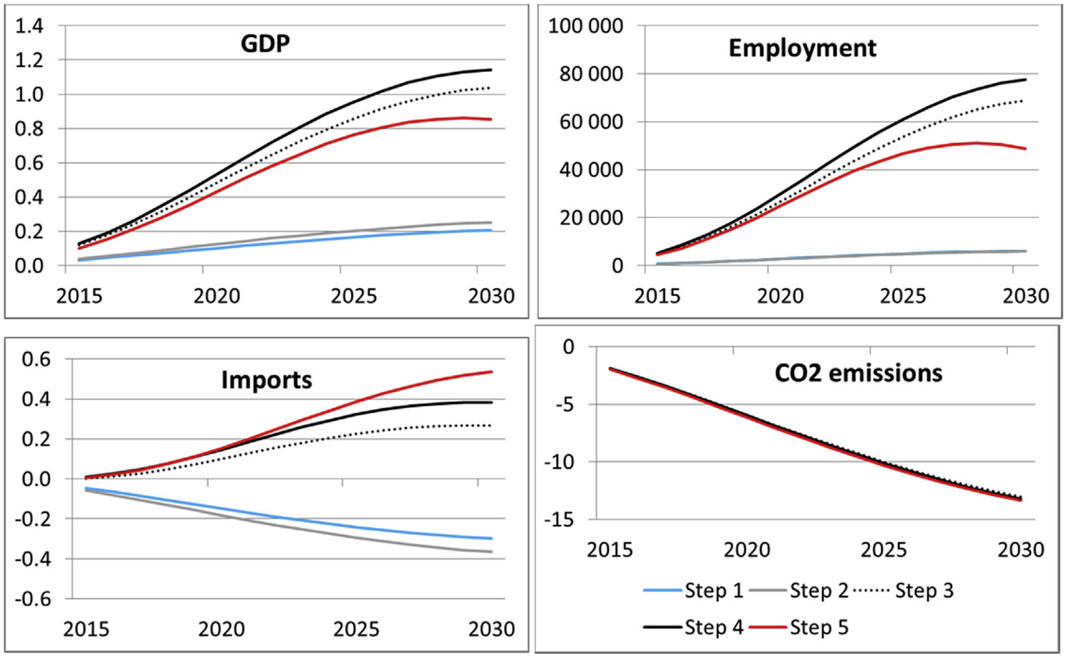


Fig. 8. Decomposition of impact on GDP, employment, import and CO2. Legend: % deviation relative to baseline for GDP, imports and CO2 emissions; absolute deviation relative to baseline for employment (expressed in FTE).

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.

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

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).

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%).

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.

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 modeling and analysis lays in finding the right combinations of physical and micro models, which give the 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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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.renene.2017.09.039.

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