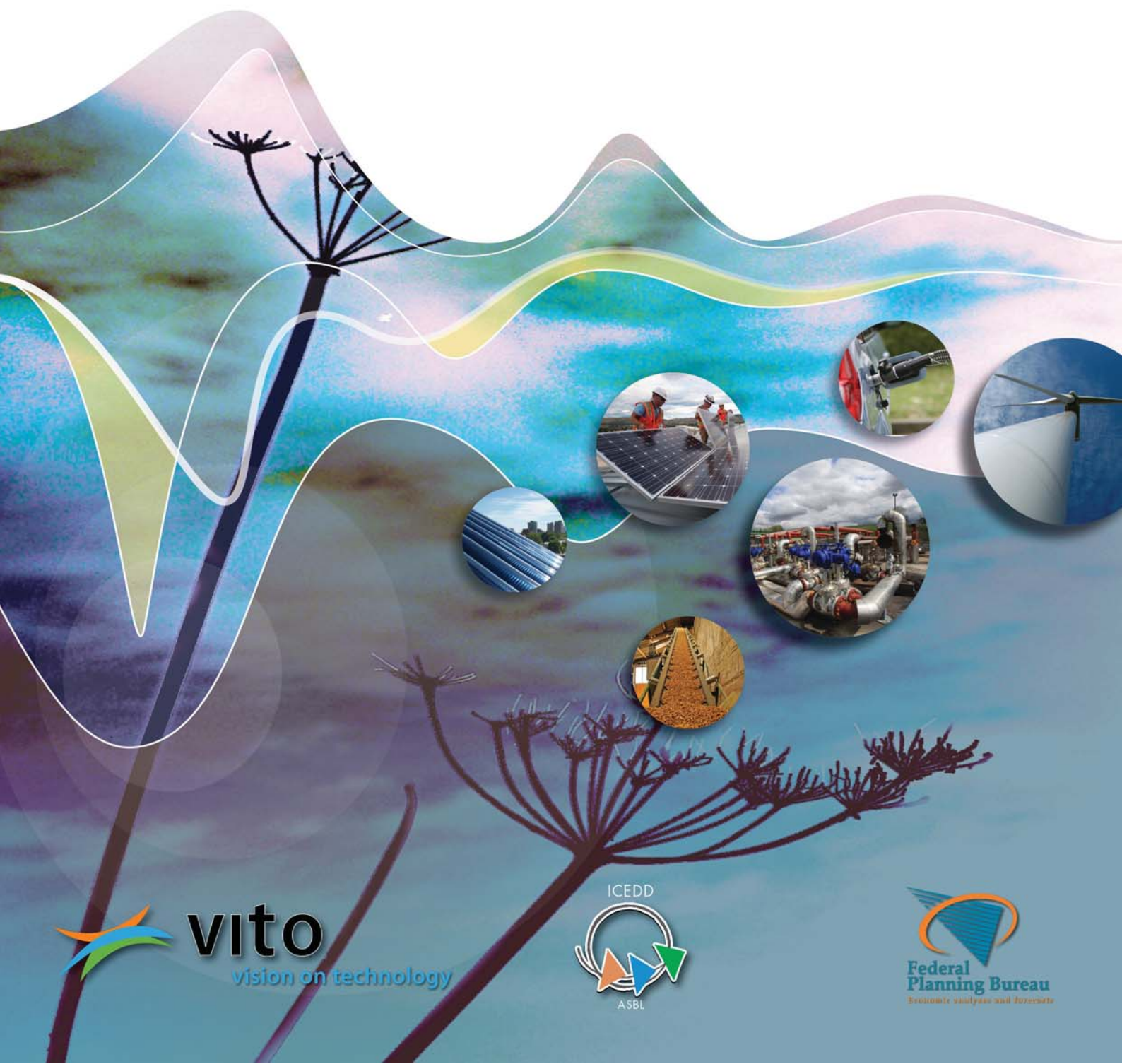


Towards 100% renewable energy in Belgium by 2050



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Abstract – In this report, different long-term evolutions of the Belgian future energy system are drafted, analysed and evaluated. All evolutions are designed to meet the requirement of a 100% renewable based national energy system by 2050. For this purpose, a baseline is developed which depicts an energy system without the stringent renewables' requirement. Next, different trajectories are sketched that lead up to a 100% renewable coverage in 2050. The trajectories show that it is feasible to combine economic growth and comfort with far going deployment of renewable energy sources, provided a number of key options and effective policies and measures are being implemented. These options were deducted from several discussions with stakeholders via an open dialogue process, as well as with national experts, and finally, were presented to the Steering committee. The analysis leads to the undeniable observation that drastic changes in a multitude of areas throughout society are required to obtain the desired level of renewable energy penetration in 2050, but also that such a transition can be realised through various sectoral, technology and inter-temporal choices. In other words, this study describes a vast number of different trajectories leading to a 100% renewable energy system in Belgium in the long term, as well as their socio-economic impacts.

Keywords – roadmap towards 2050, renewable energy, energy system transition

Executive summary (FR)

Vers 100% d'énergies renouvelables en Belgique à l'horizon 2050

Contexte et objectifs de l'étude

En 2011, les quatre ministres belges de l'énergie (un ministre fédéral et trois ministres régionaux) ont chargé un consortium constitué de trois partenaires scientifiques, à savoir le Bureau fédéral du Plan (BFP), l'Institut de Conseil et d'Etudes en Développement Durable (ICEDD) et le Vlaamse Instelling voor Technologisch Onderzoek (VITO), d'étudier la faisabilité et l'impact d'une évolution du système énergétique belge vers un mix énergétique composé exclusivement d'énergies renouvelables à l'horizon 2050. Cet objectif ne s'applique pas seulement au secteur électrique, mais bien à l'ensemble de l'énergie primaire¹ consommée en Belgique, à l'exclusion cependant des carburants pour l'aviation.

Approche méthodologique

La méthodologie mise au point pour l'étude se décline en quatre étapes :

Dans un premier temps, un *scénario de référence* est défini. Ce scénario n'a pas pour objet de prévoir l'évolution la plus probable du système énergétique, mais bien de servir d'étalon pour évaluer, d'une part, le coût de l'objectif des 100% d'énergies renouvelables (SER), et d'autre part, les évolutions technologiques nécessaires pour le réaliser.

Ensuite, *différentes trajectoires d'évolution* du système énergétique belge compatibles avec l'objectif des 100% de SER (source d'énergie renouvelable) à l'horizon 2050 sont explorées par le biais d'une analyse par modélisation et d'une étude de scénarios (voir tableau 1)². Toutes les trajectoires 100% SER exploitent le plein potentiel des sources d'énergie renouvelables qui est limité par des contraintes techniques, sociales et de soutenabilité (par exemple, le potentiel du solaire photovoltaïque (PV) est limité par les surfaces de toitures bien orientées). Dans les scénarios BIO, PV et WIND, ces limites sont néanmoins dépassées. Les trajectoires incluent des objectifs intermédiaires pour les SER au niveau de la demande d'énergie primaire, à savoir 35% en 2030 et 65% en 2040, de manière à éviter une transformation trop brutale du système énergétique au cours des dernières décennies. Dans les scénarios 100% SER, la demande de services énergétiques est sensible à l'évolution des prix ; cette demande de services énergétiques découle de l'évolution déterminée de manière exogène dans le scénario de référence.

¹ Dans les bilans énergétiques d'Eurostat et de l'AIE, la demande d'énergie primaire n'inclut pas les combustibles de soute consommés par le transport maritime ainsi que les combustibles consommés à des fins dites non énergétiques. Le transport maritime est par conséquent exclu de l'objectif des 100% d'énergies renouvelables. En revanche, la demande d'énergie primaire inclut la consommation d'énergie par l'aviation.

² Différentes variantes ont été testées afin d'analyser la sensibilité des résultats à la modification de certains paramètres essentiels, comme le prix du pétrole, le prix de la biomasse ou le coût des cellules PV.

Tableau EX1 : Trajectoires d'évolution du système énergétique belge

Scénario	Description
DEM	La disponibilité insuffisante de sources d'énergies locales induit une augmentation des prix qui elle-même affecte la <u>demande</u> de services énergétiques. Celle-ci diminue jusqu'à un niveau qui est compatible avec le potentiel belge d'énergies renouvelables et avec l'objectif des 100% de SER.
GRID	La disponibilité insuffisante d'énergies renouvelables locales est compensée par une augmentation des importations d'électricité via une meilleure connexion au réseau (<u>grid</u> en anglais) étranger.
BIO	Augmentation des importations de <u>biomasse</u> .
PV	Augmentation de la surface couverte par des panneaux solaires <u>photovoltaïques</u> en Belgique.
WIND	Augmentation des potentiels éoliens (<u>wind</u> en anglais) onshore et offshore.

Le troisième volet de l'étude consiste à évaluer les *impacts socioéconomiques* des trajectoires envisagées. L'exercice se fonde principalement sur les résultats de l'analyse quantitative des scénarios susmentionnés ainsi que sur une étude fouillée de la littérature existante. L'accent est mis sur l'impact au niveau du prix de l'électricité, des investissements et de la facture énergétique extérieure de la Belgique. Ce dernier indicateur permet de mesurer les effets des trajectoires sur la sécurité d'approvisionnement en énergie de la Belgique. Les impacts en matière de création d'emplois sont brièvement analysés à partir d'études existantes.

Enfin, l'étude précise, pour toutes les trajectoires, les mesures à mettre en œuvre pour atteindre l'objectif des 100% de SER.

Les résultats quantitatifs ont été estimés au moyen du modèle TIMES (acronyme de The Integrated MARKAL-EFOM System). Dans le scénario de référence, la demande de services énergétiques (demande de passagers-kilomètres, éclairage résidentiel, niveau de production d'acier, etc.) est une donnée de base. L'approche retenue est basée sur une minimisation des coûts tenant compte des caractéristiques des technologies futures ainsi que de l'offre actuelle et future des sources d'énergie primaire. Partant de ces données, le modèle TIMES détermine comment satisfaire la demande de services énergétiques à un coût minimum en mettant en œuvre simultanément des investissements en équipement et des décisions opérationnelles prises dans un contexte sans incertitude.

Principaux résultats

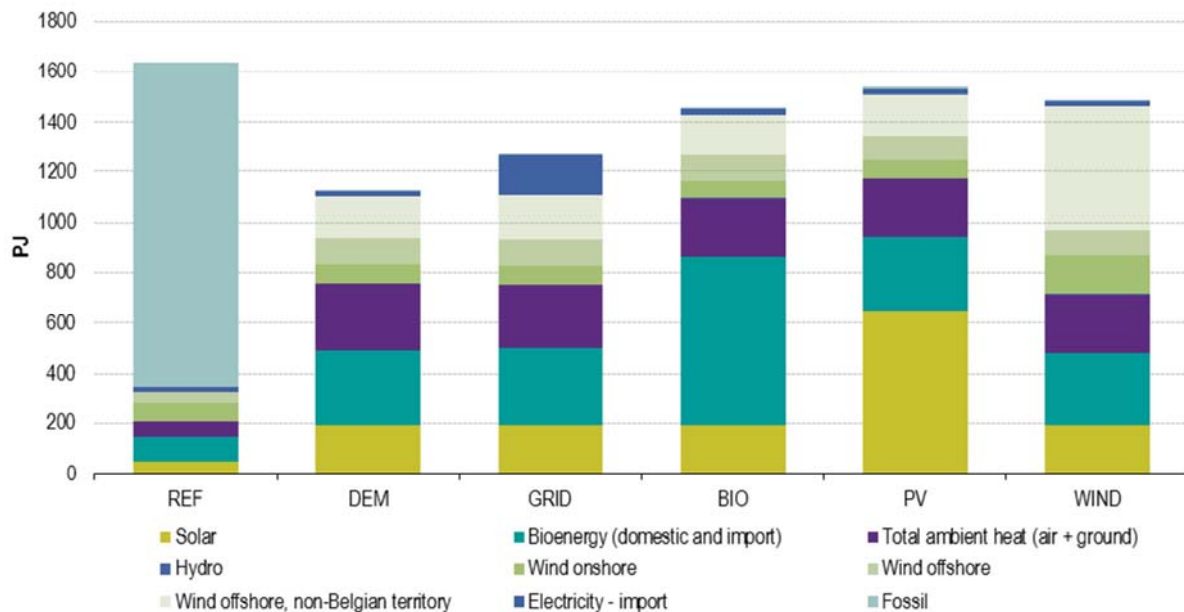
- **Baisse de la demande d'énergie primaire**

Dans l'ensemble des scénarios 100% SER, on observe une baisse de la demande d'énergie primaire par rapport au scénario de référence. En effet, évoluer vers un système énergétique fondé sur 100% d'énergies renouvelables nécessite d'une part, des améliorations de l'efficacité énergétique et des économies d'énergie et implique d'autre part une baisse de la demande d'énergie primaire dans la mesure où la majorité des sources d'énergies renouve-

lables se caractérisent par des rendements de conversion plus élevés (approchant les 100%) que les combustibles fossiles³.

Le graphique 1 présente la demande d'énergie primaire en 2050 dans l'ensemble des scénarios. La baisse par rapport au scénario de référence varie de 6% à 31%. La baisse la plus nette est observée dans le scénario DEM qui se caractérise par une offre locale limitée d'énergies renouvelables. Dans ce cas, une réduction de 31% de la demande d'énergie primaire en 2050 est requise par rapport au scénario de référence.

Graphique EX1 : Demande d'énergie primaire en 2050 dans l'ensemble des scénarios



Source: Résultats du modèle TIMES.

Note: La demande d'énergie primaire correspond à la définition d'Eurostat et exclut la consommation de carburants par l'aviation.

- **Electrification importante et pratiquement 100% d'électricité renouvelable à l'horizon 2030**

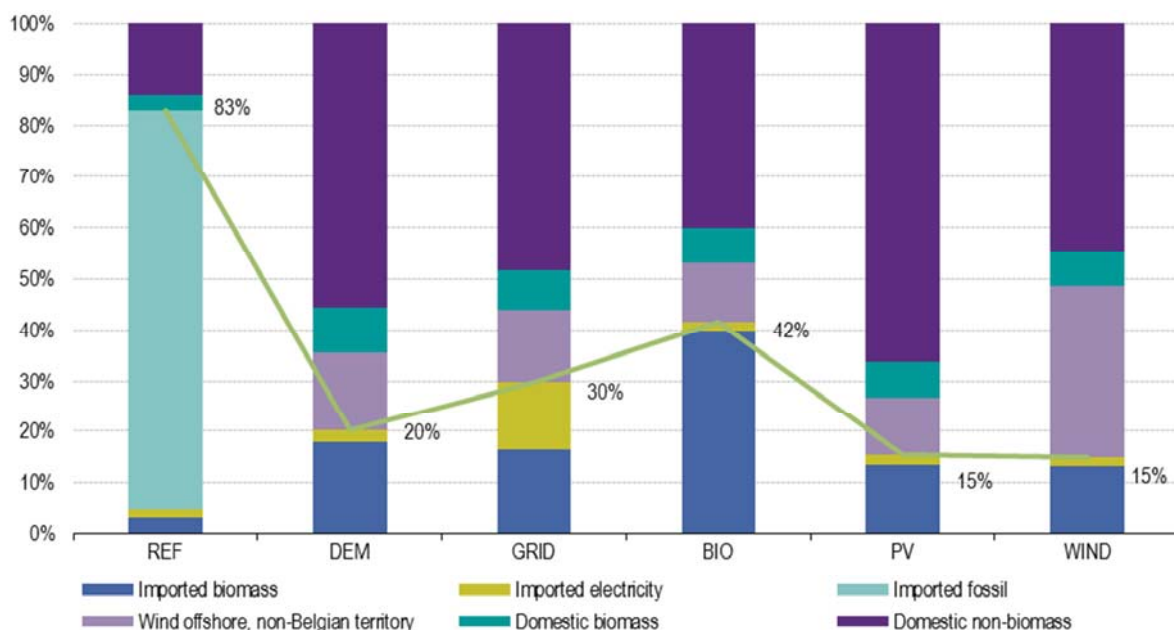
Evoluer vers un système énergétique fondé exclusivement sur les énergies renouvelables implique une mutation de pratiquement tous les secteurs de l'économie. L'analyse montre que la croissance la plus forte des technologies renouvelables se concentre sur la période 2030-2050. Cependant, certains secteurs subissent plus tôt des transformations importantes. On y observe une croissance rapide des technologies liées aux énergies renouvelables. C'est particulièrement vrai pour le secteur de la production électrique qui doit se tourner presque exclusivement vers les énergies renouvelables à l'horizon 2030. En effet, des investissements précoces dans les technologies renouvelables dans ce secteur s'avèrent être la solution la moins chère dans les scénarios SER. En outre, les résultats du modèle montrent qu'un système énergétique fondé exclusivement sur les énergies renouvelables va de pair avec une électrification importante de celui-ci. Il en découle une multiplication par deux, voire par trois du niveau de production électrique à l'horizon 2050.

³ Dans le cadre de la présente étude, l'énergie fossile inclut l'énergie nucléaire.

- **Forte baisse des importations d'énergie**

Une augmentation de la part des énergies renouvelables, conjuguée à une diminution de la consommation d'énergie, entraîne une baisse des achats de combustibles fossiles et partant, une diminution de la facture énergétique extérieure. Certains scénarios se caractérisent par des importations conséquentes de biomasse ou d'électricité produite chez nos voisins. Toutefois, la somme des importations de biomasse et d'électricité n'atteint pas les importations actuelles de combustibles fossiles, y compris dans les scénarios BIO et GRID. Du point de vue de la dépendance aux importations, la Belgique sera gagnante si elle évolue vers un système énergétique à 100% renouvelable. La part des importations d'énergie dans la demande d'énergie primaire chute de 83% dans le scénario de référence à 42% dans le scénario BIO, voire même à 15% dans les scénarios PV et WIND.

Graphique EX2 : Indicateur des importations en 2050 dans l'ensemble des scénarios



Source: Résultats du modèle TIMES.

Note: Hypothèse de 100 PJ de biomasse domestique en 2050, sauf dans scénario REF (50 PJ).

Note: L'indicateur des importations représente la part des importations dans la demande d'énergie primaire.

- **Augmentation similaire du coût du système énergétique dans tous les scénarios SER**

Le coût du système énergétique correspond à la somme de toutes les dépenses énergétiques inhérentes à la production et la consommation d'énergie. Il comprend des coûts fixes, variables et d'investissement. L'augmentation du coût du système énergétique par rapport au scénario de référence avoisinerait 20% en 2050 et représenterait environ 2% du PIB belge en 2050 (PIB₂₀₅₀). Dans la plupart des scénarios, le coût additionnel du système énergétique se compose d'investissements et de coûts fixes additionnels qui représentent quelque 4% du PIB₂₀₅₀ et de réductions des coûts variables qui avoisinent 2% du PIB₂₀₅₀. Ce résultat dépend toutefois de nombreuses hypothèses, la principale étant l'évolution des prix des combustibles fossiles au cours des 40 prochaines années. Les baisses les plus nettes des coûts énergétiques variables sont observées dans les scénarios DEM, WIND et PV, l'économie représen-

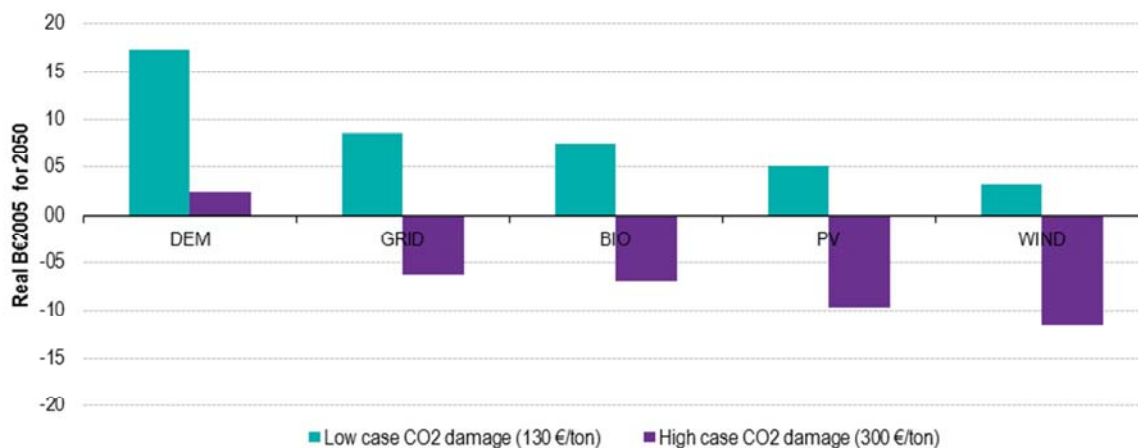
tant plus de 10 milliards d'euros en 2050 (ou 60%) par rapport au scénario de référence. Les investissements à réaliser dans le secteur électrique représentent entre 1,0% (scénario DEM) et 1,7% (PV et WIND) du PIB₂₀₅₀. Les résultats des simulations montrent qu'en Belgique 300 à 400 milliards d'euros d'investissements doivent être réalisés d'ici 2050 si l'on veut évoluer vers un système énergétique fondé exclusivement sur les énergies renouvelables.

- **Impact sur les résultats du coût de désutilité et des coûts évités en termes de dommages liés aux émissions de GES**

Bien que le coût additionnel du système énergétique suite à une mutation vers 100% d'énergies renouvelables soit substantiel, il ne prend en compte ni le coût d'une baisse de la demande de services énergétiques, ni le bénéfice d'une réduction (voire d'une disparition) des émissions de gaz à effet de serre.

Afin d'évaluer le coût associé à la baisse de la demande de services énergétiques, le modèle se base sur le concept de coût de désutilité. L'explication la plus simple que l'on peut donner pour faire comprendre ce concept est qu'une baisse de la demande induit une baisse de la consommation qui génère un certain niveau d'utilité. Lorsque le coût de désutilité est pris en considération, le coût additionnel total (par rapport au scénario de référence) augmente de 30% en 2050. Quand le coût de désutilité et les coûts évités en termes de dommages liés aux GES sont pris en compte, certains scénarios présentent un effet positif net de dix milliards d'euros en 2050, un chiffre qui dépend largement de l'hypothèse de coût des dommages causés par les émissions de GES (valeurs faible et élevée illustrées dans le graphique 3).

Graphique EX3 : Coûts additionnels nets en 2050 dans l'ensemble des scénarios



Source: Projections du modèle TIMES.

Note: Les coûts additionnels nets représentés dans le graphique incluent les coûts de désutilité et les coûts évités en termes de dommages liés aux émissions de gaz à effet de serre

- **Effet positif sur l'emploi**

Si le coût additionnel du système énergétique peut sembler élevé, il ne faut pas perdre de vue qu'augmenter la part d'énergies renouvelables dans notre mix énergétique présente aussi des avantages substantiels. Aux effets positifs déjà cités et qui concernent la facture énergétique extérieure, la dépendance aux importations et les coûts liés aux dommages s'ajoutent

d'autres effets (non analysés), comme une meilleure qualité de l'air, une amélioration de l'état de santé de la population, une exploitation moindre, voire nulle, des ressources naturelles (fossiles) et l'arrêt du processus d'appauvrissement de la planète.

Par contre, l'étude analyse les retombées positives de la mutation du système énergétique en termes de créations d'emplois induites par les filières renouvelables. Les estimations montrent que, comparativement au scénario de référence, 20 000 à 60 000 nouveaux emplois pourraient être créés d'ici 2030. Quelle que soit la période envisagée, les scénarios renouvelables créent davantage d'emplois que le scénario de référence.

- **Nouveau paradigme énergétique**

Un des grands enseignements de l'étude est qu'un nouveau paradigme énergétique doit voir le jour. En effet, dans un système énergétique sans surcapacité excessive de SER intermittentes et où la biomasse et l'énergie géothermique ne sont disponibles que dans certaines limites, le stockage à long terme (saisonnier) d'énergie devient extrêmement onéreux dans les scénarios 100% SER. Dans une approche d'optimisation des coûts, le modèle montre qu'il serait judicieux d'abandonner les équilibres stricts du système énergétique (entre offre et demande d'énergie) et de prévoir une surcapacité d'énergies renouvelables intermittentes. Cette transition énergétique peut avoir des conséquences sur l'organisation de la production industrielle qui, dans certaines branches, devrait être modulée sur base saisonnière de manière à consommer l'énergie nécessaire, comme l'électricité, durant les périodes où elle est la moins chère. Cette flexibilité de l'industrie reviendrait à disposer de l'équivalent d'une batterie géante dans laquelle l'électricité pourrait être stockée par exemple sous la forme d'acier.

- **Domaines d'action prioritaires**

La croissance des énergies renouvelables devra être soutenue par une série de politiques qui viseront à lever les obstacles entravant leur développement. L'étude identifie les domaines prioritaires suivants dans lesquels une action des pouvoirs publics s'impose.

Le prérequis à toute action politique est la création d'un cadre institutionnel définissant l'environnement général dans lequel s'inséreront toutes les politiques et mesures spécifiques visant à atteindre l'objectif des 100% d'énergies renouvelables.

Le soutien à la production d'énergies renouvelables peut être envisagé de nombreuses manières. Toutefois, il conviendra d'accorder une attention particulière au financement des investissements à consentir pour les extensions de réseau et la construction de centrales électriques utilisant les énergies renouvelables, etc.

La réduction de la consommation énergétique, telle que prévue dans les trajectoires 100% SER à l'horizon 2050, nécessitera la mise en œuvre conjointe de plusieurs mesures complémentaires.

L'électrification croissante du système énergétique encouragera tous les acteurs économiques à faire glisser une partie de leur consommation vers des périodes où les prix de l'électricité sont moins élevés. L'introduction d'une nouvelle organisation du travail, largement inspirée

par des considérations de coûts énergétiques, devra nécessairement être négociée par les pouvoirs publics et les partenaires sociaux.

La transition vers un système énergétique davantage orienté vers les énergies renouvelables serait facilitée par une diminution des coûts. A cet égard, le financement de la R&D est primordial puisqu'elle a un rôle moteur à jouer. Pour voir de nouvelles technologies émerger, il faudra également s'appuyer sur la qualification du capital humain. Un des enjeux de la transition énergétique vers 100% d'énergies renouvelables consistera notamment à assurer l'adéquation entre qualifications disponibles et compétences requises.

Prochaines étapes

Les recherches menées dans le cadre de la présente étude étaient centrées autour d'une question principale, à savoir « Comment atteindre l'objectif de 100% d'énergies renouvelables en Belgique à l'horizon 2050 ? » et de trois questions complémentaires « Quelles technologies sont à développer ? », « Quel est le coût d'une telle mutation ? » « Quelles politiques et mesures faut-il mettre en œuvre pour atteindre cet objectif ? ».

Les différents scénarios et analyses présentés dans ce rapport ne constituent pas la fin de l'histoire. Ils apportent des réponses à certaines questions mais en soulèvent d'autres (capacités de stockage, disponibilité de biomasse durable, technologies relatives à l'hydrogène ou implications sociales) qui dépassent le champ initial de l'étude. Il sera nécessaire de poursuivre les recherches dans ces domaines pour mieux comprendre à quoi pourrait ressembler un futur 100% renouvelable.

Executive summary (NL)

Naar 100% hernieuwbare energie in België tegen 2050

Kader en doel van de studie

In 2011 stelden de vier Belgische ministers bevoegd voor energie (1 federale en 3 regionale) een consortium samen van drie wetenschappelijke partners, het Federaal Planbureau (FPB), het Institut de Conseil et d'Etudes en Développement Durable (ICEDD) en de Vlaamse Instelling voor Technologisch Onderzoek (VITO), om de haalbaarheid en de impact te analyseren van een transformatie van het Belgisch energiesysteem naar 100% hernieuwbare energie tegen 2050. Die doelstelling betreft niet enkel de elektriciteitssector, maar alle *primaire energie*⁴ die op Belgisch grondgebied wordt verbruikt, met uitzondering van het brandstofverbruik in de luchtvaart.

Methodologische benadering

De methodologische benadering van de studie omvat vier fasen:

Allereerst wordt een *referentiescenario* opgesteld. Dat scenario is niet bedoeld om de meest waarschijnlijke evolutie van het energiesysteem te ramen, maar doet dienst als benchmark in de evaluatie van de kostprijs voor de toepassing van de 100% hernieuwbare energiedoelstelling en de nodige technologische veranderingen in het energiesysteem.

Vervolgens worden aan de hand van modellering en scenarioanalyse *verschillende trajecten* voor het Belgische energiesysteem verkend die verenigbaar zijn met de doelstelling van 100% hernieuwbare energiebronnen (HEB) tegen 2050 (zie onderstaande Tabel 1)⁵. Alle 100% HEB-trajecten gebruiken het volledige potentieel van de hernieuwbare energiebronnen dat begrensd wordt door zowel technische, maatschappelijke als duurzaamheidsoverwegingen. In de scenario's BIO, PV en WIND worden deze beperkingen deels opgeheven. Ze omvatten intermediaire doelstellingen voor HEB in de primaire energievraag (35% in 2030 en 65% in 2040) en voorkomen zo een te abrupte overgang tijdens de laatste decennia. De vraag naar de verschillende energiediensten is prijsgevoelig in de 100% HEB-trajecten, uitgaande van een exogeen bepaalde evolutie in het referentiescenario.

⁴ Volgens de energiebalansen van Eurostat en het IEA omvat de primaire energievraag niet de maritieme bunkerbrandstoffen en de brandstoffen voor niet-energetische doeleinden. Het maritiem transport valt dus niet binnen het bereik van de doelstelling van 100% hernieuwbare energie. Anderzijds wordt het energieverbruik in de luchtvaart wel opgenomen in de primaire energievraag.

⁵ Verschillende varianten werden getest om de gevoeligheid voor wijzigingen in een aantal belangrijke parameters (o.a. prijs van olie en biomassa, kosten van fotovoltaïsche cellen) te onderzoeken.

Tabel EX1 : Verschillende trajecten voor het Belgisch energiesysteem

Scenario	Beschrijving
DEM	Als gevolg van het tekort aan lokale energiebronnen stijgen de energieprijzen, die op hun beurt de <u>vraag</u> naar energiediensten beïnvloeden. Die vraag daalt tot een niveau wordt bereikt dat verenigbaar is met het Belgisch potentieel aan hernieuwbare energie en de 100% HEB-doelstelling.
GRID	Het tekort aan lokale energiebronnen wordt gecompenseerd door een grotere elektriciteitsinvoer via een verbeterde <u>netwerkverbinding</u> met het buitenland.
BIO	Er kan meer <u>biomassa</u> worden ingevoerd.
PV	<u>Fotovoltaïsche</u> zonnepanelen kunnen over een grotere oppervlakte beschikken in België.
WIND	Het potentieel aan onshore en offshore <u>windenergie</u> wordt verhoogd.

Ten derde beoordeelt deze studie de *socio-economische impact* van de onderzochte trajecten. Die analyse steunt voornamelijk op de resultaten van de kwantitatieve analyse en wordt aangevuld door informatie uit een uitgebreide literatuurstudie. De focus ligt daarbij op de impact in termen van de Belgische elektriciteitsprijzen, kosten, investeringen en de buitenlandse brandstoffactuur. Die laatste indicator maakt het mogelijk de effecten op de Belgische energiebevoorradingzekerheid te meten en op basis van bestaande studies wordt een beperkte analyse gemaakt van de impact in termen van jobcreatie.

Ten slotte geeft de studie voor alle trajecten aan welke *beleidsmaatregelen* genomen kunnen worden om de 100% HEB-doelstelling te bereiken.

Het TIMES-model (The Integrated MARKAL-EFOM System) wordt gebruikt om de kwantitatieve resultaten te ramen. De vraag naar energiediensten in het referentiescenario (bv. afgelegde passagierskilometers, residentiële verlichting, warmtebehoefte in de papierindustrie...) wordt door de gebruiker zelf ingevoerd. Er wordt een benadering van minimale kosten gehanteerd, uitgaande van de kenmerken van toekomstige technologieën, huidige en toekomstige bronnen voor het primair energieaanbod en informatie over prijsgevoeligheid. Op basis van die data poogt het TIMES-model energiediensten aan te leveren tegen minimale kosten waarbij de modelkeuzes omtrent investeringen en het gebruik van installaties gebaseerd zijn op de assumptie van perfecte toekomstplanning.

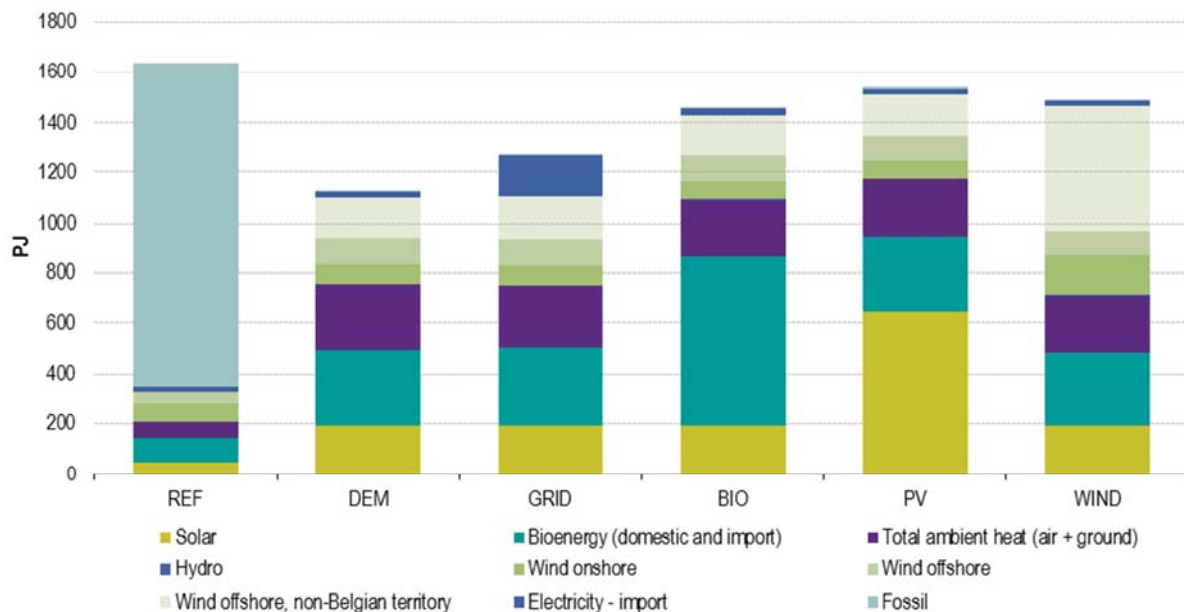
Voornaamste resultaten

- **Primaire energievraag beperkt**

Een daling van de primaire energievraag wordt waargenomen overheen de tijd in alle hernieuwbare scenario's. De transformatie van het systeem naar 100% hernieuwbare energie vereist namelijk enerzijds verbeteringen in energie-efficiëntie en energiebesparingen en anderzijds een lagere totale hoeveelheid primaire energie, aangezien voor de meeste hernieuwbare energiebronnen een omzettingsrendement van 100% gebruikt wordt. Figuur 1 toont de

primaire energievraag in 2050 in de hernieuwbare scenario's vergeleken met het referentiescenario. De afname ten opzichte van het referentiescenario varieert van 6% tot 31%. De grootste daling wordt waargenomen in scenario DEM, dat gekenmerkt wordt door een beperkt (begrensd) aanbod aan lokale hernieuwbare energie.

Figuur EX1: Primaire energievraag, alle scenario's, 2050 (PJ)



Bron: Resultaten TIMES-model.

Opmerking: De primaire energievraag is bepaald volgens de Eurostat-definities maar omvat niet het brandstofverbruik in de luchtvaart.

- **Grootschalige elektrificatie en dicht bij 100% hernieuwbare elektriciteit tegen 2030**

De verandering in een 100% hernieuwbaar energiesysteem veronderstelt een radicale transformatie van vrijwel alle sectoren van de economie. Het model toont dat de sterkste groei in hernieuwbare technologie plaatsvindt over de periode 2030-2050. Niettemin ondervinden bepaalde sectoren al eerder aanzienlijke effecten. Dat geldt in het bijzonder voor de elektriciteitssector, die bijna volledig hernieuwbaar moet zijn tegen 2030, aangezien vroege investeringen in HEB-technologie de goedkoopste oplossing lijken die met de HEB-trajecten in overeenstemming kan gebracht worden. Daarenboven geven de resultaten van het model aan dat een 100% hernieuwbaar energiesysteem een grootschalige elektrificatie vereist, met een verdubbeling of zelfs verdrievoudiging van de huidige elektriciteitsproductie tegen 2050 tot gevolg.

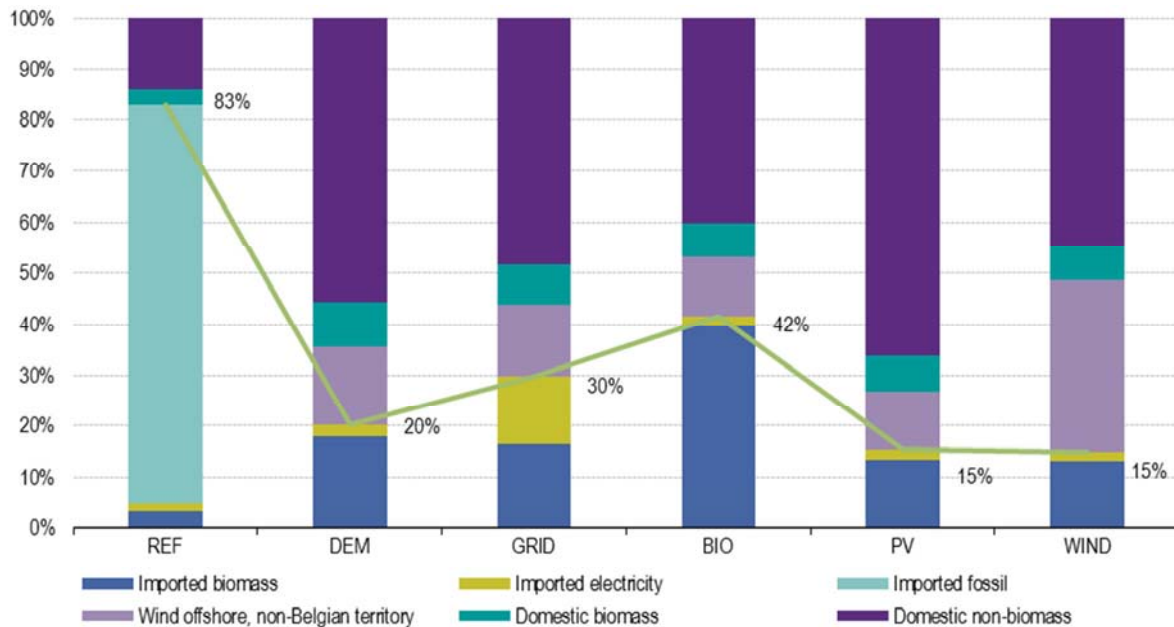
- **Sterke afname van de energie-invoer**

Een groter aandeel hernieuwbare energie en een lager energieverbruik impliceren minder aankoop van fossiele⁶ brandstoffen, waardoor de Belgische buitenlandse brandstoffactuur kan dalen. In sommige scenario's worden grote hoeveelheden elektriciteit uit de buurlanden of biomassa uit het buitenland ingevoerd. Toch stemt de som van ingevoerde biomassa en elektriciteit niet overeen met de huidige invoer van fossiele brandstoffen, zelfs niet in de sce-

⁶ Nucleaire energie wordt onder fossiele energie gecatalogiseerd.

nario's BIO en GRID, zodat België vanuit dit oogpunt waarschijnlijk baat heeft bij de overschakeling naar een volledig hernieuwbaar systeem. Het aandeel ingevoerde energie in de primaire energievraag valt terug van 83% in het referentiescenario tot een bereik tussen 42% in scenario BIO en 15% in scenario PV en WIND scenario.

Figuur EX2 : Invoerindicator, alle scenario's, 2050



Bron: Resultaten TIMES-model.

Opmerking: Voor de binnenlandse biomassa in 2050 wordt 100 PJ verondersteld, met uitzondering van REF (50 PJ).

Opmerking: De invoerindicator vertegenwoordigt het aandeel van de invoer in de primaire energievraag.

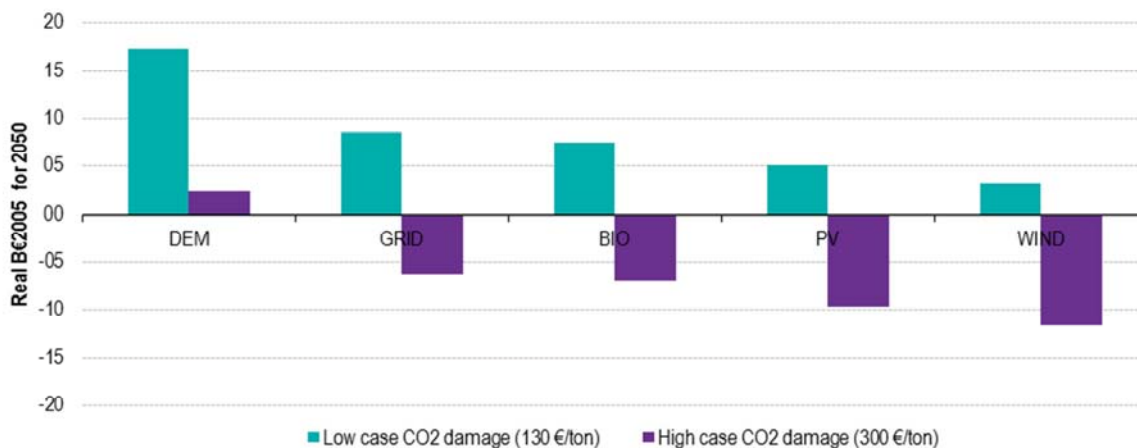
- **Gelijkaardige groei van de energiesysteemkosten in alle HEB-scenario's**

De energiesysteemkosten zijn de som van alle energie-uitgaven opgelopen door de energieproducerende en -verbruikende sectoren. Ze omvatten variabele, vaste en investeringskosten. De stijging van de energiesysteemkosten bovenop het referentiescenario wordt berekend op ongeveer 20% in 2050 of 2% van het Belgisch bbp in 2050 (bbp_{2050}). De aanvullende energiesysteemkosten kunnen voor de meeste scenario's opgesplitst worden in ongeveer 4% van het bbp_{2050} aan bijkomende investerings- en vaste kosten en 2% van het bbp_{2050} aan verlaagde variabele kosten. Dat resultaat is echter afhankelijk van verscheidene aannames, waarvan de evolutie van de fossiele brandstoffenprijzen over de komende 40 jaar de belangrijkste is. De sterkste dalingen van de variabele energiekosten worden waargenomen in de scenario's DEM, WIND en PV, met besparingen van meer dan 10 miljard euro (of 60%) per jaar ten opzichte van het referentiescenario. De noodzakelijke investeringen in de elektriciteitssector variëren van 1.0% (scenario DEM) tot 1.7% (scenario PV en WIND) van het bbp_{2050} . De resultaten tonen dat in België voor 300 tot 400 miljoen euro aan investeringen nodig zijn in de periode tot 2050 om ons huidig energiesysteem om te vormen tot een 100% hernieuwbaar energiesysteem.

- **Impact van 'disutility' kosten en vermeden schadekosten van BKG op de resultaten**

Hoewel de bijkomende energiesysteemkosten van de 100% hernieuwbare energiescenario's aanzienlijk zijn, werden de kosten van een ingekrompen vraag naar energiediensten of het voordeel van lagere (of zelfs geen) broeikasgasemissies daarin nog niet verrekend. Om de verliezen in de vraag naar energiediensten te ramen, gebruikt het model het concept van 'disutility' kosten. Eenvoudig gesteld betekent dit dat een vraagverlies een consumptieverlies inhoudt, terwijl consumptie een bepaald nutsniveau genereert. Wanneer de 'disutility' kosten worden verrekend, stijgen de totale bijkomende kosten (t.o.v. het referentiescenario) met 30% in 2050 of ongeveer 3% van het bbp2050. Wanneer zowel disutility kosten als vermeden schadekosten van BKG in aanmerking genomen worden, hebben sommige scenario's een positief netto-effect van 10 miljard euro per jaar of ongeveer 1.5% van het bbp2050, een cijfer dat sterk afhangt van de gehanteerde aanname voor de schadekosten van BKG (lage en hoge waarden worden voorgesteld in Figuur 3).

Figuur EX3 : Netto bijkomende kosten, alle scenario's, jaar 2050 (real B€2005)



Bron: TIMES-model.

Opmerking: De netto bijkomende kosten in de figuur omvatten 'disutility' kosten en vermeden schadekosten van BKG.

- **Positief effect op de werkgelegenheid**

Hoewel de energiesysteemkosten aanzienlijk kunnen lijken, is het zo dat de verandering van onze toekomstige energievoorziening in de richting van hernieuwbare energiebronnen ook voordelen met zich meebrengt. Het betreft niet enkele kleine bijkomende voordelen, maar belangrijke winsten die mogelijk worden bij de overschakeling naar een volledig hernieuwbaar energiesysteem. Naast de reeds vermelde positieve effecten op de buitenlandse brandstoffactuur, de invoerafhankelijkheid en de schadekosten, zijn er ook andere (nog niet onderzochte) effecten denkbaar, zoals de betere lokale luchtkwaliteit, een significante vermindering van broeikasgasemissies, algemene gezondheidsvoordelen, een veel beperktere en zelfs geen verdere uitputting van de natuurlijke (fossiele) bronnen en de stopzetting van de verarming van de planeet voor toekomstige generaties. Een van die positieve effecten wordt verder geanalyseerd in deze studie: het creëren van extra werkgelegenheid via de hernieuwbare waardeketens. Er werd geraamd dat dit effect tegen eind 2030 20 000 tot 60 000 bijkomende voltijdse equivalente banen zou creëren vergeleken met het referentiescenario. Op elk

ogenblik in de tijd creëren de hernieuwbare scenario's meer voltijdse equivalente banen dan het referentiescenario.

- **Nieuw paradigma voor het 'energiedenken'**

Deze studie leert ons dat er een nieuw paradigma opduikt in de manier waarop we denken over energie. In een wereld zonder overcapaciteit van intermitterende hernieuwbare energiebronnen en met slechts een beperkte toegang tot biomassa en geothermische energie, wordt langetermijn(seizoens)opslag extreem duur met een doelstelling van 100% hernieuwbare energie. Het model suggereert dat, binnen een kostenoptimale modelbenadering, de voorkeur uitgaat naar een transformatie van het energiesysteem waarbij overcapaciteit in intermitterende hernieuwbare energiebronnen wordt geïnstalleerd en dus wordt afgestapt van strikte evenwichten. Daardoor kan de huidige industriële organisatie verschuiven naar meer seizoensgebonden productiegerichte sectoren, die de benodigde energiegrondstoffen zoals elektriciteit alleen tijdens de goedkoopste periodes van het jaar gebruiken. Deze flexibiliteit in de industrie zou dan hetzelfde effect hebben als een grote batterij waarin elektriciteit kan worden opgeslagen in de aggregatietoestand van bijvoorbeeld staal.

- **Kritieke actiedomeinen**

De groei van hernieuwbare energie zal ondersteund moeten worden door een breed scala aan beleidsmaatregelen om de hindernissen die de HEB-evolutie in de weg staan, te overwinnen. De studie identificeert een aantal kritieke actiedomeinen voor de overheid:

Een institutioneel kader dat de algemene context definieert waarin alle specifieke beleidslijnen en maatregelen (PAM) opgenomen zijn om de doelstelling van 100% hernieuwbare energie te realiseren, is een basisvereiste voor elk ander beleid.

Hernieuwbare energieproductie kan op verschillende manieren ondersteund worden. Toch moet bijzondere aandacht worden besteed aan de financiering van de nodige investeringen in de uitbreiding van het net, hernieuwbare energie-installaties, enz.

Om te komen tot de vermindering van het energieverbruik zoals voorzien in de trajecten tot 2050, zal de grootste impact afkomstig zijn van de gemeenschappelijke uitvoering van een aantal complementaire maatregelen.

Een belangrijke verschuiving naar elektrificatie zal alle economische actoren aanmoedigen om een deel van hun verbruik te verplaatsen naar periodes met lagere elektriciteitsprijzen. De beslissing over en de implementatie van een nieuwe werkstructuur die grotendeels steunt op overwegingen over de energiekosten moeten worden bevorderd door brede onderhandelingen tussen regering, werkgeversorganisaties en vakbonden.

Aangezien de kosten verder moeten dalen om de hernieuwbare overgang te vergemakkelijken, is de financiering van O&O een cruciale factor. De opkomst van nieuwe technologieën vereist ook betere arbeidskwalificaties, daar de beschikbaarheid van werknemers met de juiste vaardigheden een essentiële rol zal spelen in de transitie naar 100% hernieuwbare energie.

Volgende stappen

Het onderzoek in deze studie was opgebouwd rond één hoofdvraag: "Hoe kan het streefdoel van 100% hernieuwbare energie in België in 2050 bereikt worden?" en drie deelvragen "Welke technologieën zijn nodig?", "Wat zijn de kosten om dat doel te bereiken?" en "Welke beleidsmaatregelen zijn nodig?". Hoewel dit rapport verschillende trajecten beschrijft en analyseert, is het niet het einde van het verhaal. Er zijn een aantal antwoorden gegeven, maar er blijven ook veel nieuwe, open vragen die niet binnen de draagwijdte van de oorspronkelijke opdracht vallen (bijv. opslagcapaciteit, duurzame beschikbaarheid van biomassa, waterstof-technologie en sociale implicaties). Deze onderwerpen moeten verder uitgespit worden, omdat ze cruciaal zijn voor een beter begrip van hoe een 100% hernieuwbare toekomst er zou kunnen uitzien.

Executive summary (EN)

Framework and purpose of the study

In 2011, the four Belgian ministers (1 federal, 3 regional) in charge of energy commissioned a consortium consisting of three scientific partners, being the Federal Planning Bureau (FPB), the Institut de Conseil et d'Etudes en Développement Durable (ICEDD) and the Vlaams Instituut voor Technologisch Onderzoek (VITO) to analyse the feasibility as well as the impact of a Belgian energy system transformation towards 100% renewable energy by 2050. This target is not focalized on the sole power sector; it applies to all *primary energy*⁷ consumed on the Belgian territory, excluding fuel consumption for aviation.

Methodological approach

The methodological approach of the study consists of four steps:

Firstly, a *reference scenario* is built. This reference scenario does not aim at forecasting the most likely evolution of the energy system, it rather serves as a benchmark to evaluate the cost of implementing the 100% renewable energy target and the technological changes required in the energy system.

Secondly, *different evolutionary pathways* of the Belgian energy system compatible with the fixed objective of 100% renewable energy sources (RES) by 2050 are explored using modelling and scenario analysis (see Table below)⁸. These pathways include intermediate targets for RES in primary energy demand: 35% in 2030 and 65% in 2040. Regarding the demand for the different energy services, the 100% RES trajectories rest on the exogenously determined evolution in the Reference scenario.

Table EX1 : Different pathways of the Belgian energy system

Scenario	Description
DEM	The insufficient availability of local energy sources raises energy prices which in its turn affects energy service demand. The latter is reduced until a level is reached that is compatible with the Belgian renewable energy potential and the 100% RES target.
GRID	The lack of local renewable energy is compensated by larger imports of electricity.
BIO	A higher quantity of biomass can be imported.
PV	A larger surface can be covered by solar panels in Belgium.
WIND	Onshore and offshore potentials are increased.

⁷ According to the Eurostat and IEA energy balances, primary energy demand does not include maritime bunker fuels and fuel consumed for non-energy uses. Maritime transport is thus excluded from the scope of the 100% renewable energy target. On the other hand, primary energy demand includes energy consumption for aviation.

⁸ Different variants have been tested in order to analyse the result sensibility to variations of some important parameters, e.g. oil prices, biomass prices or PV cell costs.

Thirdly, the study evaluates the *socio-economic impacts* of the investigated trajectories. This analysis is mainly based on the results of the quantitative analysis. It is complemented by information coming from an extensive literature review. The focus is put on the impact in terms of electricity prices, investments and the external fuel bill for Belgium. The latter indicator allows measuring the effect on Belgium’s security of energy supply. A limited analysis of the impact in terms of job creation is realised on the basis of existing studies.

Finally, the study sets out, for all trajectories, which *policies and measures* could be taken to reach the 100% RES target.

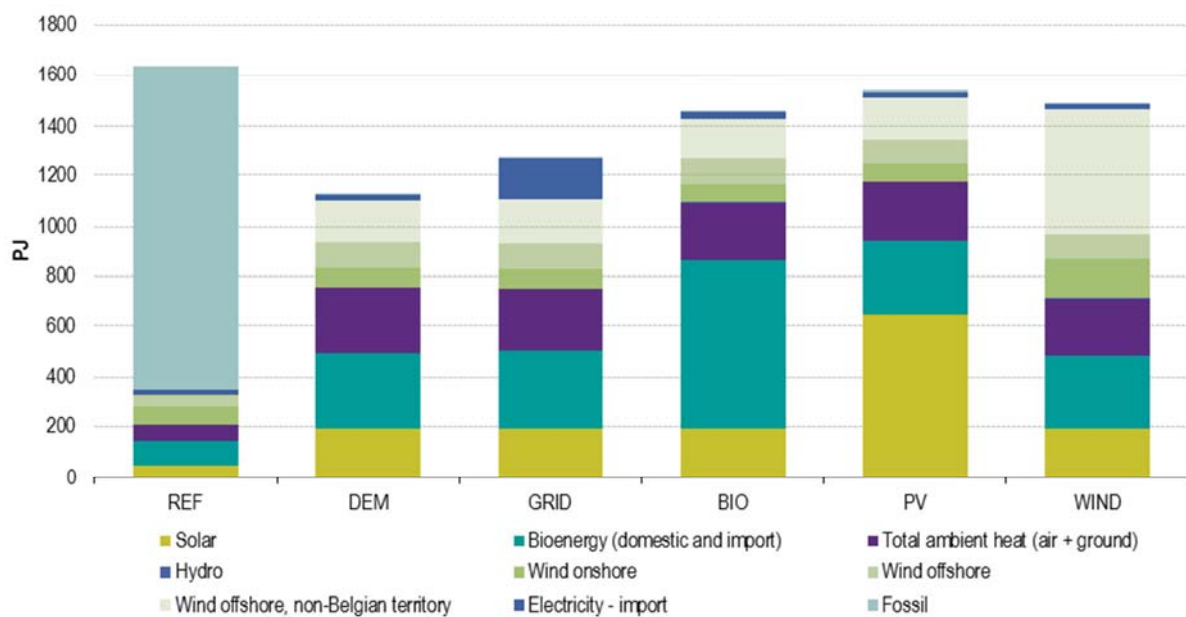
For the estimation of the quantitative results, the TIMES (an acronym for The Integrated MARKAL-EFOM System) model is used. It is based on a cost minimisation approach using an energy services demand concept (e.g. passenger-kilometres demand, households’ comfort level, steel production level), characteristics of future technologies as well as present and future sources of primary energy supply and their potentials. Using these data as inputs, the TIMES model aims to deliver all required energy services at minimum cost by simultaneously making equipment investment and operating decisions under perfect foresight.

Main results

- **Primary energy demand confined**

A decrease in primary energy demand over time is noticeable in all renewable scenarios. Indeed, transforming the system towards 100% renewable energy necessitates, on the one hand, energy efficiency improvements and energy savings, on the other, lower total amounts of primary energy.

Figure EX1 : Primary energy demand, all scenarios, year 2050 (PJ)



Source: TIMES model results.

Note: Primary energy demand is defined following Eurostat definitions but excludes fuel consumption by aviation.

This is because the majority of renewable energy sources have higher conversion efficiencies (reaching 100%) than fossil fuels⁹. Figure 1 shows the primary energy demand in the renewable scenarios compared to the reference scenario in 2050. The decline compared to the reference scenario ranges from 6% to 31%. The steepest decrease is registered in the DEM (and) scenario. This can be explained by the fact that this scenario can only count on a limited (restricted) local renewable supply that has to cover all (residual) demand. Shrinking demand to a level that is 31% beneath the reference level in 2050 seems to be required.

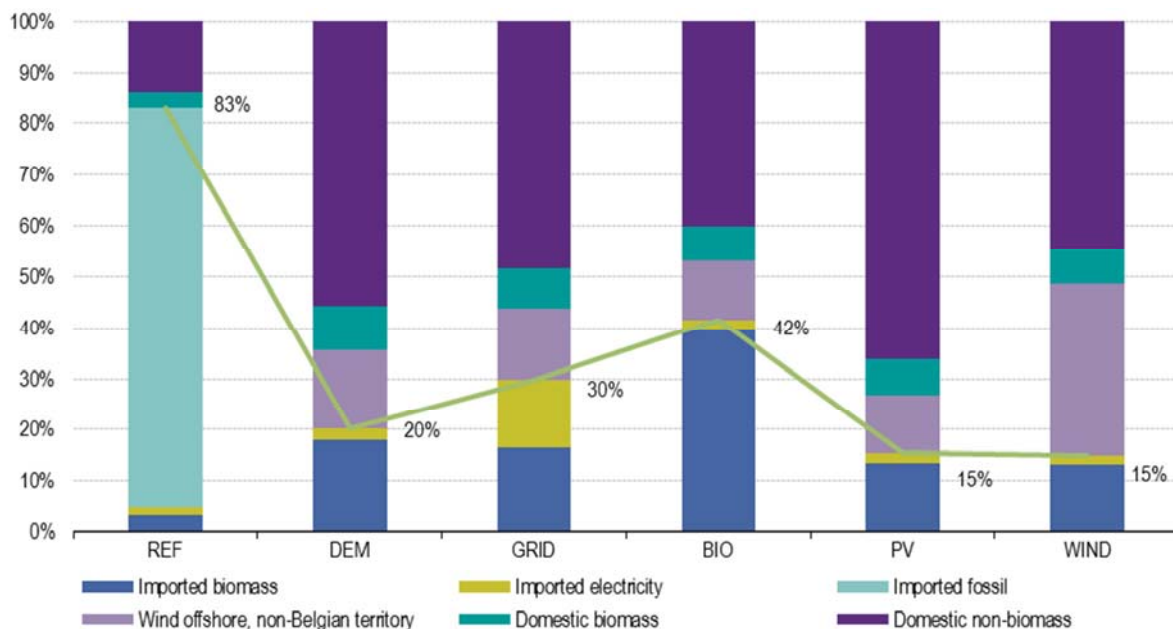
- **Extensive electrification and close to 100% renewable electricity by 2030**

Turning into a 100% renewable energy system implies a radical transformation of almost all sectors of the economy. The model shows that the strongest growth of renewable technologies is concentrated in the period 2030-2050. Notwithstanding that, some sectors experience thorough impacts earlier on through high growth rates of renewable energy technologies. This is particularly the case in the electricity production sector which has to be almost completely transformed into a renewable based one by 2030, since early investments in RES technologies appear to be the least expensive solution in line with the RES trajectories. Furthermore, the results of the model indicate that a 100% renewable energy system needs an extensive electrification causing a doubling or even tripling of the current electricity production level by 2050.

- **Strong decrease in energy imports**

A higher share of renewable energy combined with reduced energy consumption implies less fossil fuel purchases which may reduce the national external fuel bill.

Figure EX2 : Import indicator, all scenarios, year 2050



Source: TIMES model results.

Note: 100 PJ is assumed for the domestic biomass in 2050, except in REF (50 PJ). The import indicator represents the share of imports in primary energy demand.

⁹ Fossil energy is meant to include nuclear energy.

Some scenarios import large amounts of electricity produced in neighbouring countries or biomass shipped from abroad. Nonetheless, the sum of the biomass and electricity imports does not equal the current imports of fossil fuels, not even in the BIO and GRID scenarios. This means that Belgium stands to gain from switching to an all renewable system from this point of view. The share of energy imports in primary energy demand tumbles down from 83% in the reference scenario to a range between 15% in the PV and WIND scenario and 42% in the BIO scenario.

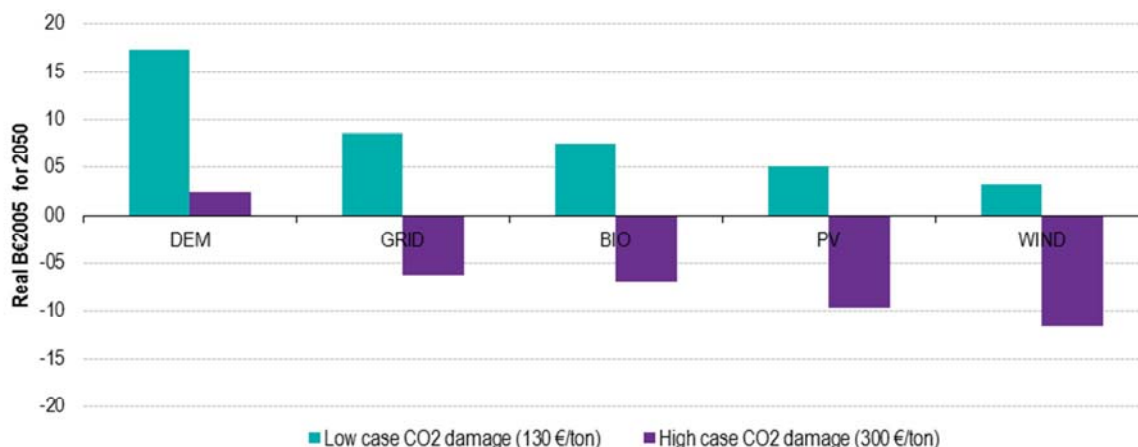
- **Similar increase in the energy system cost in all RES scenarios**

The energy system cost is the sum of all energy expenses incurred by the energy producing and consuming sectors. It consists of variable, fixed and investment costs. The increase in the energy system cost on top of the reference scenario is calculated to be around 20% in 2050 or about 2% of the Belgian GDP in 2050 (GDP_{2050}). The additional energy system cost for most scenarios can be decomposed into additional investment and fixed costs of around 4% of GDP_{2050} added to reduced variable costs of around 2% of GDP_{2050} . This result depends, however, on various assumptions of which the evolution of fossil fuel prices over the next 40 years is the most important. The highest reductions of variable energy costs are observed in the DEM, WIND and PV scenarios with savings of more than 10 billion € (or 60%) a year compared to the reference scenario. The necessary investments in the power sector vary between 1.0% (DEM scenario) and 1.7% (PV and WIND) of GDP_{2050} . The results show that 300 to 400 billion € of investments are needed in Belgium from today up to 2050 to transform our current energy system into a 100% renewable energy system.

- **Impact of disutility and avoided GHG damage costs on results**

Although the additional energy system cost of the 100% renewable energy scenarios is substantial, it does not include the cost of having energy service demand reduced or the benefit of having greenhouse gas emissions decreased (or even eliminated).

Figure EX3 : Net additional costs, all scenarios, year 2050 (real B€2005)



Source: TIMES model runs.

Note: Net additional costs shown in the graph include disutility costs and avoided damage costs of greenhouse gas emissions.

To assess the energy service demand losses, the model uses the disutility cost concept. The easiest way of looking at it, is that a loss in demand represents a loss of consumption, consumption generating a certain level of utility. When disutility costs are taken into account, the total additional cost (compared with the reference scenario) increases by 30%. When both disutility costs and avoided damage costs of greenhouse gas emissions are included, some scenarios have a net positive effect of 10 billion € per year, a number that strongly depends on the assumption used for the GHG damage cost (low and high values are used in Figure 3).

- **Positive effect on employment**

Although energy system costs may appear to be considerable, one has to bear in mind that changing our energy future towards renewable energy sources also entails benefits. Not some minor side benefits, important gains can and will be created when switching to an all renewable energy system. The positive effects on the external fuel bill, on import dependency and on damage costs already being cited, other (not analysed) effects can be thought of as to local air quality, significant reductions in greenhouse gas emissions, general health benefits as well as lesser to no depletion of natural (fossil) resources and halted future generations' planet impoverishment. One of those positive effects is further analysed in the course of this study: the creation of additional employment through the renewable value chains. It was estimated that this effect would, by the end of 2030, create an extra 20 000 to 60 000 full time equivalent jobs compared to the reference scenario. At any point in time, the renewable scenarios create more full time equivalent jobs than the reference scenario.

- **New paradigm on energy thinking**

This study teaches us that a new paradigm is arising in the way we think about energy. In a world without excess overcapacity of intermittent renewable energy sources and with only limited access to biomass and geothermal energy, long term (seasonal) storage becomes extremely expensive. The model suggests that, in a cost optimal modelling approach, a transformation of the energy system towards abandoning strict equilibria and replacing it by installing overcapacity in intermittent renewable energy sources is to be preferred. This can have an impact on the current industrial organisation towards more seasonal production oriented sectors, using the necessary energy commodities like electricity only during the cheapest periods of the year. This flexibility within industry can then be perceived as having the same effect as a giant battery in which electricity may be stored in the aggregation state of e.g. steel.

- **Critical areas for action**

The growth of renewable energy will need to be supported by a wide range of policies designed to overcome barriers to renewable energy adoption. The study identifies critical areas where governments will need to act:

An institutional framework defining the general context where all specific policies and measures (PAMs) for reaching the 100% renewable target should be included is a prerequisite to any other policy.

The support of renewable energy production can be achieved in multiple ways. However, special attention should be given to the financing of the investments the country will need in grid extensions, renewable energy plants, etc.

In order to achieve the reduction in energy consumption which is foreseen in the pathways to 2050, the greater impact will come from the joint implementation of several complementary measures.

A major shift towards electrification will encourage all economic players to move some parts of their consumption to low electricity price periods. The decision on and implementation of a new working structure largely inspired by energy cost considerations will need to be facilitated by broad negotiations between governments, employers' federations and trade unions.

Since costs need to further decrease to make the renewable transition easier, financing research and development is a crucial driver. The emergence of new technologies will also require the improvement of labour qualifications as the availability of workers with the right skills will play a critical role in allowing the transition to 100% renewable energy sources.

Next steps

The research performed in this study was centred around an attempt to answer one main question: "How to achieve a 100% renewable energy target in Belgium in 2050?" and three related sub-questions "Which technologies are needed?", "What are the costs of achieving the target?" and "Which PAMs are needed?". Although different trajectories are described and analysed in the present report, this study is not the end of the story. Although it has provided some answers, it also concludes with many new, open questions which fall out of the scope of the initial assignment (e.g. storage capacities, sustainable biomass availability, hydrogen technologies or social implications). These topics certainly deserve to be further analysed since they are crucial to gain a better understanding of what a 100% renewable future might look like.

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1. Framework and purpose of the study

This study is the result of a 12 months' mandate the four ministers (1 federal, 3 regional) in charge of energy on the Belgian territory gave to a consortium consisting of three scientific partners, being the Federal Planning Bureau (FPB), the Institut de Conseil et d'Etudes en Développement Durable (ICEDD) and the Vlaams Instituut voor Technologisch Onderzoek (VITO) to analyse the feasibility and the impact of a Belgian energy system transformation towards a 100% renewable energy by 2050. The 100% target applies to the *primary energy* demand excluding fuel consumption for aviation¹⁰.

This study logically sticks to the context and continuity of the targets formulated in the legislative Climate-Energy Package, as well as of the European Commission's Roadmaps 2050 (the Roadmap for moving to a competitive low carbon economy of March 2011 and the Energy Roadmap of December 2011). However, the design and analysis of the energy trajectories that will allow Belgium to (mainly) break its dependence on fossil¹¹ fuels focus on the Belgian energy system only and have no European scope.

In this context, the methodological approach of the study consists of four steps:

- Firstly, a *reference scenario* is built. The reference scenario does not aim at forecasting the development of the energy system. It serves as a benchmark to evaluate the cost of implementing the 100% renewable energy target and the technological changes required in the energy system. The reference scenario does not include any renewable energy or greenhouse gas reduction target except those listed in the legislative Climate-Energy Package¹² for the year 2020. Consequently, the reference scenario cannot be seen as a low carbon scenario.
- Secondly, different evolutionary pathways of the Belgian energy system compatible with the fixed objective of 100% renewables (RES) by 2050 are explored using modelling and scenario analysis. Regarding the demand for the different energy services, the 100% RES trajectories rest on the exogenously determined evolution in the Reference scenario. This means that the study does not investigate the possibility of drastically reducing the energy service demand in order to reach the 100% RES target.
- Thirdly, the study evaluates the socio-economic impacts of the investigated trajectories. This analysis is for the most part based on the results of the quantitative analysis. It is complemented by information coming from an extensive literature review. The focus is put on the impact in terms of electricity prices, investments and the external fuel bill for

¹⁰ According to Eurostat and IEA energy balances, primary energy demand does not include maritime bunker fuels and fuel consumed for non-energy uses. As a consequence, maritime transport is also excluded from the scope of the 100% renewable energy target.

¹¹ Fossil energy is meant to include nuclear energy in the rest of the document.

¹² The climate and energy package is a set of binding legislation which aims to ensure the European Union meets its climate and energy targets for 2020. These targets, known as the "20-20-20" targets, set three key objectives for 2020 :a 20% reduction in EU greenhouse gas emissions from 1990 levels; raising the share of EU energy consumption produced from renewable resources to 20%; a 20% improvement in the EU's energy efficiency.

Belgium. The latter indicator allows measuring the effect on Belgium's security of energy supply. A limited analysis of the impacts in terms of job creation is realised on the basis of existing studies. However, it is important to stipulate beforehand that this study will not address competitiveness issues in the economy. Such an analysis is not possible without taking into account the energy trajectories of our main commercial partners.

- Finally, the study presents, for all the trajectories, possible policies and measures in order to reach the 100% RES target.

This study covers most of the technological challenges and opportunities, costs and the reduction of greenhouse gases that go hand in hand with the envisaged transition in an energy intensive country like Belgium. However, some aspects are excluded from this study. Energy needs for the production of goods for export are included but indirect energy use from imported goods is excluded. Another important limit of the study is that it does not cover external effects, except for global damage caused by greenhouse gases, the most important energy related externality.

2. Introduction

To date, a variety of studies have been published on the topic of long term energy system transition. Most studies on future energy systems, however, have a shorter time frame (e.g. 2030, see for example Devogelaer and Gusbin, 2011) or adopt a supranational focus (e.g. the Energy Roadmap, 2011 or the World Energy Outlook, 2011). It then constitutes a sincere challenge to perform a national energy system transition study with as time horizon 2050 and covering a far-reaching transformation of the energy system. This was the objective of the mission to be realised in a mere 12 months period (the time imparted for the study).

This study then has one main mission: to scrutinise the transition of the Belgian national energy system towards a future mix entirely based on renewable energy sources. The focus on renewable energy sources and on building a national energy system completely running on renewable energy can be traced back to three main concerns:

- Climate change. Renewable energy sources (RES) are a major instrument in the fight against climate change as RES do not release (net) greenhouse gas emissions. Although these RES can contribute in a substantial way to tackle global warming through greenhouse gas emission reductions, several studies (a.o. Federaal Planbureau, 2006; Devogelaer and Gusbin, 2009) have demonstrated that putting a constraint solely on greenhouse gases does not suffice to prompt a massive renewable deployment which is obligatory for a 100% RES based society. Additional RES specific incentives are thus needed.
- Security of supply. Most renewable energy sources make use of technologies that ultimately derive energy from natural phenomena like wind, wave, tidal, sun, water, etc. Renewable electricity can be generated from wind power, wave, solar photovoltaics (PV), hydro, geothermal and biomass. Since most RES are then cultivated or naturally available within a nation's territory, RES can help to reduce Belgium's (and Europe's) growing dependence on imported fossil fuels. As a 100% RES based system is independent of imported fossil fuels, it goes without saying that security of energy supply should benefit from a transition to a 100% RES based system.
- Economy/competitiveness. In times of economic crisis, creating or expanding a renewable "filiale" with a considerable number of direct and indirect jobs can seem appealing. Moreover, an energy system entirely based on renewable energy presupposes considerable efforts in the field of energy savings to drastically diminish the amount of energy needed, which in its turn instigates the activity of a.o. the building sector (through e.g. isolation, heat pumps, etc.). Not only job creation can prompt economic growth, also cost cutting does. As to costs, (most) RES, once in operation, have no fuel costs and less maintenance is needed to keep them functioning (IEA, 2005). However, it is also worth noting that most RES today need subsidies to compete with other technologies. These subsidies should nonetheless decrease steadily over time because of the "learning by doing" process and economies of scale so as to reach a level playing field with the "old" fos-

oil fuels whose prices, due to scarcity issues, will likely not stop increasing in the coming decades if no global action is taken.

Transforming into a 100% renewable system can then be an answer to those concerns, and may be the way forward in a world where sustainability, national/European self-reliance and economic growth are amongst the top priorities.

Before discovering how the pathways towards a fully renewable energy mix look like, the methodology and the main assumptions used in this analysis should first be described. The methodology, which is based on the Belgian TIMES model, is outlined in Chapter 3 while Chapters 4 and 5 set out the assumptions used for the renewable production technologies and other supporting technologies (as for example storage technologies, industrial processes based on renewables, demand side technologies, etc.), as well as the more general assumptions and policy framework underpinning the analysis. Chapter 6 describes the reference and the 100% renewable scenarios. The effects of the different 100% renewable trajectories on the Belgian energy system are summarized and compared in Chapter 7 whereas the socio-economic impacts are dealt with in Chapter 8. Chapter 9 examines which policies and measures could be implemented to meet the 100% RES target, and finally, Chapter 10 provides some key conclusions.

3. Methodology

3.1. Modelling approach: the Belgian TIMES model

TIMES (an acronym for The Integrated MARKAL-EFOM System) is an economic model generator for energy systems, which provides a technology-rich basis for estimating energy dynamics over a long-term, multi-period time horizon. The model has been developed and maintained by ETSAP, an implementing agreement of the IEA and its history goes back to 1981 with the development of the first MARKAL model. The Belgian TIMES model was developed from 2006 onwards by VITO and the University of Leuven (KU-Leuven) within different projects, mainly for the Belgian Science Policy.

Reference case estimates of end-use energy service demands (e.g. car travel; residential lighting; steam heat requirements in the paper industry; etc.) are provided by the user. In addition, the user provides estimates of the existing stock of energy related equipment in all sectors and the characteristics of available future technologies, as well as present and future sources of primary energy supply and their potentials.

Using these as inputs, the TIMES model aims at supplying energy services at minimum global cost (more accurately at minimum loss of surplus) by simultaneously making equipment investment and operating decisions. For example, an increased demand for electrical appliances in the residential sector due to population growth leads to a number of reactions. First, it involves a choice of appliances as the market provides different types corresponding to different energy efficiency levels (energy labelling) at different costs. Second, the increased demand for electricity has to be met and either existing generation equipment is used more intensively or new – possibly more efficient – equipment must be installed. The choice of the model of the generation equipment (type and fuel) is based on the analysis of the characteristics of alternative generation technologies, on the economics of the energy supply, and on environmental criteria.

Table 1 gives an overview of the costs and benefits, both included in and excluded (in *italic*) from this study.

The TIMES approach aims at identifying explicitly suitable technologies for the delivery of energy services to the community. However, at a certain level there is a trade-off between exhaustiveness and explicitness. For instance, behavioural and organisational changes are hard to express as technologies. Price reactions on energy service demand are represented in TIMES in a more generic way (see annex 1 for an exhaustible explanation on this issue), but behavioural changes or policies that involve no costs can never be addressed with TIMES. Typical examples of such policies are policies aiming at reducing mobility demand (teleworking, car-pooling)

The cost minimisation approach covers the full time horizon, which involves comparing different costs at different points in time. For this purpose all costs are discounted to the base

year, using a uniform (social) discount rate. Basically TIMES calculates the amount of money that should be placed on an interest bearing account to be able to pay all the expenses of the energy system over the whole period. Usually a social discount rate is applied for reasons of intergenerational equity. Discounting affects investment costs and operational costs differently as operational costs are spread over time.

The TIMES model is less suited as a projection tool. The main purpose of TIMES is the analysis of alternative scenarios, i.e. the impacts of measures are evaluated by comparing two scenarios which have been constructed in a transparent and consistent manner. The approach is more normative from the point of view of the public authorities (prescribing what optimally should happen). Transparency is guaranteed by the explicitness.

Table 1 : Total additional (wrt REF) energy system costs, year 2050

		Costs	Benefits
Private effects		Additional investments	Avoided investments
		Additional biomass fuel costs	Avoided fossil fuel costs
		Transportation and distribution	Avoided transport and distribution costs
		<i>Dismantling costs</i>	
Externalities	<u>Environmental</u>	<i>Land use for biomass</i>	Avoided GHG
			<i>Avoided local air pollutants</i>
			<i>Avoided impacts on mining</i>
	<u>Socio-economical</u>	Disutility costs of reduced energy service levels	<i>Employment</i>
			<i>Avoided congestion costs</i>
	<u>Technological</u>	<i>Spill over effects of technology development (the value of technology knowledge that becomes available for other sectors or other parties).</i>	
	<u>Socio-political</u>	<i>Risks and costs associated with overdependence on a too limited choice of energy sources, fuels or materials.</i>	

Note: *Italic* means not included in the analysis of this study

3.2. Challenges of intermittent energy

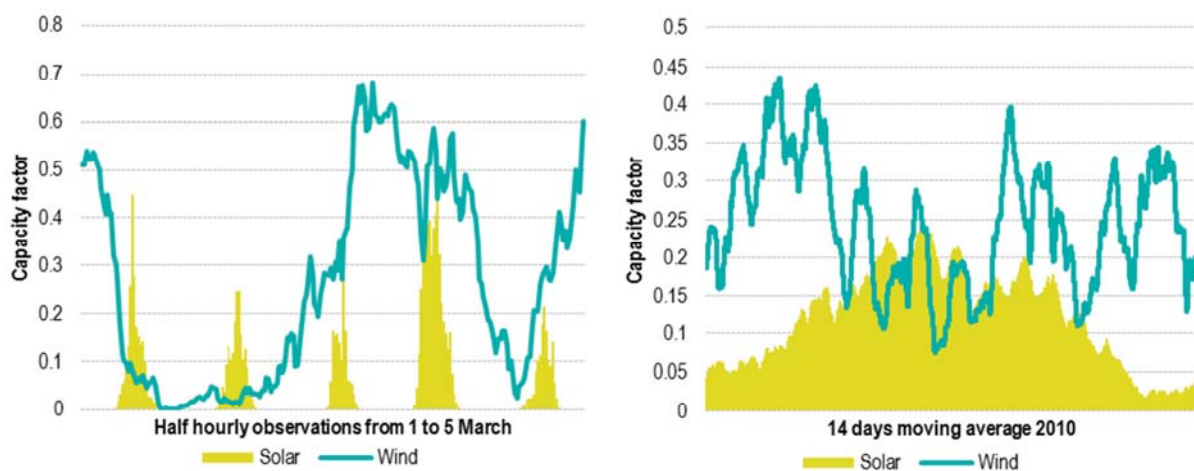
When dealing with high penetrations of intermittent renewable energy sources like wind and solar, fluctuations in supply occur and prevail over demand fluctuations. In the case of solar energy, the decomposition of the yearly production profile comprises 3 components: first, day/night fluctuations, second, a long wave starting at close to zero levels in January, peaking in the summer months and ending at similar close to zero levels by the end of the year, and third, a pattern that looks purely random.

In traditional energy modelling, a distinct approach is used for fuels and electricity. For fuels, which can easily be stored, a simplified time representation is used and the costs of storage are often ignored. For electricity, a more detailed time representation is required in order to be able to take daily and seasonal demand fluctuations into account. The time structure in TIMES is illustrated in Figure 34 (in annex), in which one year is divided into 16 rep-

representative periods. This time representation is sufficient to accurately model daily and seasonal demand fluctuations and dispatching of different production facilities in order to meet demand at any point in time, given that all capacities are controlled by operators and coordinated by a network regulator.

The production of electricity by intermittent renewable energy sources is of a different nature as they are not controlled by an operator and balancing the network can only be done by the non-intermittent sources. Figure 1 illustrates the intermittent nature for wind and solar energy. On the left hand side the picture shows a detail for a 5 day period, from 1 to 5 March 2010. On the right hand side a 14 day moving average is plotted which allows identifying longer periods with low availability of wind and solar energy. Compared to fluctuations in demand, these fluctuations are of another size of magnitude. Indeed, whereas demand in Belgium fluctuates between 6 GW and 13 GW, the production of wind and solar fluctuates between zero and the installed capacity.

Figure 1 : Illustration of the intermittent nature of solar and wind energy.



Sources: Elia production figures for wind, Vito research for sun.

Figure 1 also illustrates another characteristic, namely that solar creates one long cycle, with high capacity factors in summer and low capacity factors in winter months. Some relevant statistics are summarised in Table 2. These figures clearly illustrate that it is not sufficient to characterise renewable energy sources by their average capacity factors, as average capacity factors over a period of 14 days fluctuate with a factor 6 for wind and 14 for solar energy. The good news from this picture is that the low capacity factor for solar in the winter months seems to be compensated by a higher capacity factor for wind. In 2010, the lowest combined 14 day average capacity factor was observed around the 15th of December. In 2010, we calculated over a 14 day period that the minimum capacity factor for wind was 7.6% and 1.7% for PV. This means that there exists a period of 14 days in which the wind was only available on average for 7.6% of the time and that PV only reached 1.7% of its maximum capacity (not the same weeks however).

Table 2 : Some relevant statistics on the intermittent nature of wind and solar energy

	Wind	Solar
Average capacity factor	0.244	0.121
Minimum capacity factor in 14 days	0.076	0.017
Maximum capacity factor in 14 days	0.436	0.239
Minimum combined 14 days capacity factor	0.131	0.029

Source: wind: ELIA statistics; solar: detailed observations by VITO

Note: capacity factor is defined as: actual average production / (maximum capacity * 8760 hours)

Dealing in a correct way with the intermittent nature of wind and solar energy is a major challenge for developing renewable energy scenarios and the high share of renewable energies required several model improvements which are discussed below.

3.3. Model improvements for dealing with intermittency

Different approaches for dealing with intermittent energy can be thought of: a better integration of the Belgian network in a European network, installing back-up installations, implementing smart grids, using storage technologies, adapting demand to supply. These solutions, which had to be represented in the model, posed some limitations. For instance, the integration in a European network requires a European model. This section describes the various model improvements that have effectively been implemented.

3.3.1. Storage options

Storage options are included in order to represent different alternatives in dealing with the volatility of energy supply. So far, the only mass storage available in Belgium is the pumped water storage facility in Coe, representing a capacity of 5 GWh, allowing producing electricity at a power rate of 1.2 GW. Additional storage facilities are included in the model: day/night and seasonal storage options for electricity, electricity to hydrogen and hydrogen to electricity options (electrolysis and fuel cells) and hydrogen storage options.

Implementing electricity storage options in TIMES requires some basic understanding of the technical characteristics of storage technologies (as described in Table 3). A storage technology is characterised by a power rate for charging, a power rate for discharging (both expressed in kW or MW), a capacity expressing the volume of energy storage (expressed in kWh) and the efficiency, which is the ratio between input and output energy. The terminology is often misleading as for electricity producing technologies capacity often refers to power. The C rate is the ratio between the power and the capacity of a battery. A high C rate indicates a storage facility that can supply high power for only a limited period of time. The ideal storage facility has a high C rate, a high capacity, a high efficiency and a low price. Unfortunately this ideal storage facility does not exist and the choice of a storage device involves a difficult trade off analysis between the investment cost, efficiency, C factor and ca-

capacity whereas the choice for an electricity production technology involves only cost, efficiency and power.

Figure 1 illustrates that solar creates one long wave per year. The cost of storing electricity in summer periods for use in winter using lithium-ion technology is 50 €/kWh, being prohibitively high. Even when the price of lithium-ion battery would drop to 10 €/kWh (a factor 100), it would still be too expensive. Consequently, although storage options might contribute significantly to matching demand and supply of electricity, alternative solutions should be looked at as long-term storage seems to be too expensive.

For the TIMES model, we use a more generic representation of storage technologies (see chapter 4.4.1). However, the relevant modelling parameters such as the C-rates, efficiencies and investment costs are based on existing technologies.

Table 3 : Electricity storage technologies

Technology	Power (MW)	Typical C-rates	Efficiency	Lifetime	Capital costs \$/kW
Pumped Hydro	250-1000	0.3	70-80	> 30	2000-4000
CAES	100-300	0.3	45-60	30	800-1000
Fly wheels	0.1-10	240	>85	20	1000-5000
Super capacities	10	100	90	50000 cycles	1500-2500
Li-ion batteries	5	4	90	8-15	1000-2500
Lead-battery	3-20	100	75/80	4-8	1500-2000

Source : IEA-ETSAP and IRENA © Technology Policy Brief E18 - January 2012.

3.3.2. Extending the temporal resolution

Standard TIMES models consider 12 sub-periods in one year, representing 4 seasons and 3 daily levels: night, day and peak. Usually this distribution in twelve time slices is chosen to represent the variability in demand and one peak demand slice simulates a peak close to historical levels. Empirically it has been found that this level of detail is sufficient for dealing with fluctuations in demand when supply is steerable.

However, when dealing with high penetrations of intermittent renewable energy sources like wind and solar, fluctuations in supply occur and prevail over demand fluctuations. In the case of solar energy, the decomposition of the yearly production profile comprises 3 components: first, day/night fluctuations, second, a long wave starting at close to zero levels in January, peaking in the summer months and ending at similar close to zero levels by the end of the year, and third, a pattern that looks purely random. For wind we observe many cycles, defining periods with low availability extending from a couple of days to a couple of weeks. In order to represent this in the model the number of time periods within one year has been extended to 78 periods, equivalent to 26 two-week periods and 3 daily levels.

3.3.3. Demand profiles for all energy services

For fossil fuel based energy services, modelling detailed demand patterns is not very relevant as the cost of storage represents only a minor fraction in the use. A 100 % renewable scenario necessarily involves the electrification of many energy services (like electric cars, electric space heating based on heat pumps or electric resistance, electric cooking, electric processes in industry). Therefore detailed demand profiles have been introduced for all energy service levels. These demand profiles have been built on a number of assumptions which are listed in Table 4.

Table 4 : Principles for deriving demand profiles for energy services

Sectors / technologies	Principles for deriving demand profiles for energy services
Heavy industries	Continuous operation
Small industries	Closing down at night, week-end and holidays
Space heating	Based on daily heating degree days statistics for 2010
Residential lighting	Comprises a seasonal component and a daily component with higher demand in evening hours
Residential cooking	Concentrated at noon and in early evening
Refrigeration	Continuous process
Other residential appliances	Continuous process
Commercial lighting	At night only 20 % of daily requirements
Commercial appliances	At night only 20 % of daily requirements
Commercial cooking	Similar as residential cooking
Public lighting	Only at night
Transport	Comprises a week /week-end component and a morning- and evening peak

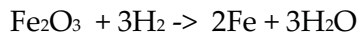
3.3.4. Allowing excess capacity of PV solar and wind - smart curtailment

An alternative to expensive electricity storage is excess capacities of intermittent electricity so as to meet the demand for electricity during less favourable periods. Consequently under more favourable circumstances supply might exceed demand, requiring curtailment of excess capacities. In such periods, the marginal cost of electricity is zero. In TIMES excess capacity is part of the standard formulation and curtailment is assumed to involve no costs.

3.3.5. Industrial demand-side management

Alternative solutions should be thought of as for dealing with excess electricity supply in the summer and with shortage of supply in the winter, in particular for scenarios that largely rely on solar energy. Industrial demand-side management has been taken into account in the model for the steel industry. Steel industry is one of the largest energy consumers in Belgium, consuming more than 5% of the final energy. Demand-side management has been implemented by allowing the model to determine when steel is produced and to shut down

production in periods of low availability of renewable electricity. This involves a considerable cost as steel production capacities should be expanded but this cost is compensated by cheap electricity. The implementation in the model is based on the following principles. The main process in steel production is the reduction of iron ore. In the model the reduction will be based on the following chemical reaction in which hydrogen is used as reducing agent instead of CO like in the current blast furnace process:



Hydrogen is produced by electrolysis; it is also stored for day/night fluctuations and optionally for seasonal fluctuations. Cost optimization determines the optimal balance between hydrogen storage and production capacity over dimensioning. In a typical renewable scenario, steel production is stopped for a couple of months in the winter as it proves to be cost efficient.

To illustrate the relevance of this approach we notice that the production of 4 Mton steel requires 25 TWh electricity, corresponding to 30% of the final electricity consumption in 2010. Similar non-energy storage options could be considered for other industrial sectors but so far these have not been taken into account in the model.

3.3.6. Transmission and distribution network

Another model extension is related to the transmission and distribution grid. In the traditional approach, transmission and distribution costs are implemented as energy based delivery costs to final consumers (i.e. transmission and distribution costs as they appear on the energy bill). This approach does not include any capacity consideration. In a 100 % renewable scenario, irregular supply conditions and an intense electrification require extending the capacity of the transmission and distribution network and the requirements depend on the options chosen. For instance, a scenario mainly based on solar energy will put more pressure on the distribution and transmission systems than a scenario based on biomass. In the model transmission and distribution costs have been replaced by the necessary investment cost for the required capacity. The cost of the transmission and distribution network largely depends on the length, the capacity, the number of connections and local circumstances (e.g. higher costs for high voltage underground cables compared to pylons). However, as the geographical dimension is not represented in TIMES, a simplified representation is used, in which the global capacities of the transmission and distribution networks are determined and investment costs are expressed per unit of capacity. The capacity requirements are determined by the highest energy flows observed over the 78 sub-periods.

3.3.7. Smart grids

Smart grids will be designed to shift demand from periods with low availability to periods with high availability. For network load, smart grids have a similar function as storage facilities. Major differences are that the efficiency can be very high, the cost of implementing can be low, but the potential capacity is limited by the consumption of a number of appliances.

3.3.8. Security of supply

Security of supply is a major concern for policymakers and industrial organisations. In a 100% renewable scenario, security of supply is both related to the availability of imported energy (biomass and electricity) and to the intermittent character of wind and solar energy. In the standard TIMES' formulation capacity requirements are evaluated in 78 time slices, i.e. 78 different combinations of electricity consumption and favourable or unfavourable conditions for renewable electricity production. However, for the reason that it is not possible to evaluate more than one set of time slices, some other actions have been taken to guarantee the security of supply. These actions are related to three requirements which are:

- (1) Real delivery requirement without intermittent sources. We simulate one particular period of 14 consecutive days with zero availability of sun and wind, compensated by another 14 day period with very high availability of sun and wind.
- (2) Virtual delivery requirement without intermittent sources. One particular problem with action (1) is that the model runs under a perfect foresight modus. This means that the model is able to anticipate this situation and fully charge all available storage options in the previous period. To cover this, another requirement has been introduced stating that the non-intermittent electricity production capacities + 10% of the import capacity + 50% of the storage capacities must be sufficient to cover 14 days of electricity consumption.
- (3) Capacity reserve requirement. The sum of the capacities of biomass plants, geothermal plants and the power of storage facilities is sufficient to meet the highest peak in final electricity demand¹³. This is a typical capacity requirement as the peak lasts only for a short period.

¹³ There might arise some confusion on the wording 'capacity' and 'power'. For production facilities, capacity relates to the maximum power that can be delivered, both are expressed in the same unit (MW). For storage facilities the capacity stands for the energy stored and is expressed using an energy unit (for instance MWh).

4. Assumptions for renewable and supporting technologies

4.1. Renewable technologies' potentials and characteristics

Major transitions are needed to reverse current trends in GHG emissions and ensure energy security without compromising other needs, including maintenance of food and water supplies and biodiversity. As a result greater sustainability will be achieved.

It is generally recognised that no single sector or technology can address the entire challenge of meeting the increasing demand for energy supplies while mitigating climate change. Therefore, it is necessary to develop a diversified portfolio of available options and to implement all those that can contribute to sustainable development (IPCC, 2007).

4.1.1. Biomass potential

a. Introduction

The use of biomass for energy (i.e. bio-energy) is considered to be a very promising option for meeting the increasing demand for energy services while mitigating climate change (IEA Bioenergy 2007), mainly because of its substantial growth potential. At present, global bio-energy use amounts to approximately 50 EJ/yr, about 10% of humanity's primary energy supply (Haberl et al., 2010).

Different types of biomass are to be considered to achieve this goal and biomass is defined as 'the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste' (European Commission, 2009). It is a versatile energy source; and its uses are as different as its types: it can be used to produce heat and power as well as solid, liquid and gaseous fuels.

Using biomass has many advantages over conventional energy sources, as well as over other renewable energies, e.g. often relatively low costs, promotion of regional economic structures and additional income for farmers (EEA, 2006). However, growing concerns exist on the additional pressures an increased production of biomass for energy could cause, mainly related to socio-economic (e.g. human condition, property rights, working conditions) and environmental issues (e.g. agricultural and forestry biodiversity, soil and water resources or air quality).

b. Mid-term biomass supply potentials and sustainability criteria

Numerous studies have tried to assess the potential supply of energy from biomass at different scales and time frames (e.g. Beringer et al., 2011; Dornburg et al., 2010; Haberl et al., 2011; Hoogwijk et al., 2005; van Vuuren et al., 2009; Wolf et al., 2003) and several reviews have at-

tempted to summarise their findings (e.g. Bentsen and Felby, 2012; Berndes et al., 2003; Dornburg et al., 2008; Haberl et al. 2010; IEA Bioenergy, 2007; IEA bioenergy, 2009; Koch, 2010, Offerman et al., 2011; Smeets et al., 2007). These studies differ on several aspects, partly due to methodological considerations (e.g. assumptions on future yields of food and energy crops, feed conversion efficiencies in the livestock system), and partly due to constraints and criteria taken into account to estimate biomass potentials. These criteria and constraints play for instance an important role in determining the availability of land for bio-energy production accounting for the fact that the growing worldwide demand for food must be met, or also that biodiversity must be protected, soils and water reserves sustainably managed.

In an attempt to categorise these studies, Koch (2010) distinguished four types of biomass potentials: theoretical potential, technical potential, economic potential, implementation potential and introduced the concept of a fifth type of potential: "the sustainable implementation potential". There has indeed been an increasing demand for inclusion of sustainability aspects in bioenergy potential, especially after bio-energy in general and biofuels in particular entered the food versus fuel debate and increased the awareness on land use competition and (in)direct land use changes. Defining sustainability criteria and indicators has therefore become an important prerequisite when trying to assess biomass potential by 2050.

Various sets of sustainability indicators and criteria have been developed but when investigating the sustainability of biomass energy production, the environmental and socio-economic impacts that are taken into account relate to GHG emissions (there has to be a significant contribution to GHG mitigation), competition with biomass for food production (food security shall be ensured), biodiversity (the loss of biodiversity shall be prevented), water use (negative impacts on water shall be minimised), nutrient balance of soils (negative impacts on soils shall be minimised), resource efficiency (resource use shall be minimised), welfare and social well-being (adequate social conditions shall be ensured) (Van Dam, 2009; Koch, 2010).

Between the various envisaged frameworks for sustainability and between the approaches of various countries and stakeholder groups, differences are evident in the strictness, extent and level of detail of the proposed social, economic and environmental criteria (Van Dam, 2009). A range of content-related issues have yet to be resolved, including the precise formulation of sustainability principles and criteria and the selection of indicators. This process is highly complex, because many stakeholders are involved and a wide variety of biomass production systems and settings must be taken into account.

Furthermore, even if some criteria are well agreed upon, the lack of data may hinder their inclusion in mathematical models. For instance, the role played by high nature value farmlands, which include low-intensity agriculture, in European biodiversity is recognised but no consolidated database exist on where they are. Their surfaces are therefore often included in land that is considered available for bio-energy production. Similarly, the possible effect of future climate change on yields of bio-energy crops or on the entire food system has seldom been assessed and included in models.

The future potential of biomass energy production, even if limited to the “sustainable implementation potential” category cannot therefore be presented as one simple figure (Dornburg et al., 2008), and published estimates of this potential in 2050 differ by a factor of almost 50 (Haberl et al., 2010). According to Haberl et al. (2010), no scientific study is at present available that would satisfactorily resolve the many scientific issues related to future bio-energy potentials. The most pressing uncertainties relate to the availability and suitability of land for energy crops, the development and potential of yield increases, future area demand for food, conservation and other purposes, trade-offs with other environmental goals (e.g., biodiversity), water availability and climate impacts. This does not even take into account uncertainties related to bio-energy policies and socio-economic aspects (e.g. the influences of food, feed and land prices on direct and indirect land-use changes are still poorly understood) of bio-energy production or even the almost impossible to predict human behavioural patterns - e.g. diets through changes in meat consumptions patterns.

c. Study hypotheses

The wide range of abovementioned uncertainties related to current bio-energy mid-term potential estimates led us to adopt a precautionary approach in defining the potential we would use in this study.

The conservative number proposed by Haberl et al. (2010), suggesting a global primary bio-energy potential in 2050 in the range of 160 to 270 EJ/yr, has been chosen; which is about 15-25% of the world's primary energy demand in 2050 (IEA, 2009). It has to be noted that dedicated bio-energy crops contribute 81 (44 to 133) EJ/yr in the range proposed, which is at the lower end of the potentials found in previous assessments. Haberl et al. (2010) review mentioned a large range of global bio-energy potentials (~30 to 1000 EJ/yr), which was quite similar to the range described in IEA bioenergy (2009) (40 to 1100 EJ/yr) but chose to narrow down the range, mainly because the high end of the range seemed implausible. According to Haberl et al. (2010), this implausibility was mainly due to an overestimation of the area available for bio-energy crops due to insufficient consideration of constraints (e.g. area for food, feed or nature conservation) and too high yield expectations. A more recent study made by the same leading author (Haberl et al., 2011) and taking into account sensitivity to climate change, diets and yields provides even more restrictive ranges (64 to 161 EJ/yr).

An almost equivalent range to that of Haberl et al. (2010) was proposed by Beringer et al. (2011): 130 to 270 EJ/yr. The authors mentioned however that exploiting these potentials would still incur significant additional human interventions in the environment as newly established energy crop plantations are responsible for a large share of global biomass production. They emphasise that even though the current models preserve the most important hotspots of biodiversity and carbon reservoirs through the use of sustainability constraints, the ecological, economic and social value of natural areas that remain potentially available for energy crop cultivation can still be very high. Therefore, taking any number higher than the range here above mentioned seemed to be in opposition with the precautionary principle.

In order to distribute this global worldwide biomass potential and attribute its share to Belgium on a fair basis, two different “pre-emptive rights” were chosen, according to De Ruyck (2009): (i) distribution on the basis of the predicted inhabitants in 2050, i.e. per capita, without taking into account the local specific use/need of biomass and (ii) distribution according to the share of Belgian 2050 GDP in the world 2050 GDP, which is a way of approaching a distribution that accounts for the higher need of Belgian population as compared to the world’s average need.

The first hypothesis divides the Belgian 2050 population (13 million inhabitants) by the world estimated population at that time (9,31 billion) to obtain the share of Belgium in the world’s population (0.14%). The second hypothesis takes the share of Belgian 2050 GDP (837 billion \$05) in the world’s 2050 GDP (164 000 billion \$05) (European Commission, 2007), i.e. 0.51%. These percentages are then multiplied by the lower and higher numbers of the bio-energy potential range chosen (160-270 EJ/yr), and the averages between the lower and higher number of the range taken. The biomass input in the model was therefore 300 PJ/yr for the first hypothesis and 1 097 PJ/yr for the second hypothesis. These numbers take into account both Belgian production and imports.

4.1.2. Wind energy potential

a. Onshore wind energy potential

Over the last decade, onshore wind capacity has been highly developed in Belgium and across Europe. In the European context, it seems to be one of the most energy and cost efficient renewable technologies. While investment costs have decreased by 20% over the last 5 years, they are still supposed to decrease to 862 €/kW by 2035 (CASES, 2008).

Table 5 : Investments costs for onshore wind technology (€/kW)

	2006	2010	2015	2025	2035
Onshore	1407	1140	1140	921	862

Source: CASES (2008)

In 2010, the Belgian onshore wind production capacity equalled 730 MW. The typical Belgian utilisation rate of wind generators is around 2135 hours full capacity equivalent¹⁴.

Partially due to the rapid development of this energy source, anti-wind lobbies are against a further development of new capacities arguing that wind turbines have a negative impact on landscape quality. In response to these criticisms, regional authorities have tried to determine where new windmills could be built.

At present, windmills can only be installed in some restricted areas. Due to their size and their possible impact on inhabitants’ well-being and to bad wind conditions in urban areas,

¹⁴ The utilisation rate has been derived from ELIA production and capacity statistics but in the model it is implemented as a load profile over 78 time slices. ELIA provides production statistics on a quarterly basis. These data have been used to determine the time slices for wind availability.

they are not allowed in those zones. Thus, they have to be installed at least a few hundred meters away from any urban zone. Furthermore, the difficulty of access to forest zones, the turbulence caused by trees and the possible impact on wild life imply that windmills are not permitted to be installed in forest areas in Belgium. Many other criteria also limit the technical potential (such as military constraints, civil aviation, nature protection, etc.). Finally, a more subjective criterion of 'co-visibility' is implicitly applied in Belgium. This means that if some windmills are installed in one determined zone, no others can be constructed nearby in order to avoid an encircling feeling.

Studies about renewable energy potential have been conducted both in the Flemish and Walloon regions in order to assess the maximum onshore wind capacities (ICEDD, 2009 and VITO, 2011). In so far as Brussels is an almost exclusively urban region, no significant wind potential can be installed there. The Flemish and Walloon studies have taken into account the exclusion criteria listed above. Applied to the Belgian case, these criteria give a potential of slightly less than 9 GW. However, if some constraints were relaxed such as forest area exclusion or if some societal priorities changed (e.g. priority to energy production over co-visibility constraints), the maximum onshore capacity could be more important. In this study, the onshore potential is supposed to increase up to 20 GW.

b. Offshore wind energy potential

Even if the Belgian maritime area is small compared to those of neighbouring countries, it represents an interesting zone where substantial electricity production capacity can be developed. In this study, the only potential for renewable energy that has been taken into account is offshore wind even if some other renewable technologies are being currently considered by researchers (such as wave, tidal and ocean current energy).

The utilisation factor of offshore windmills is higher compared to onshore installations due to more constant and higher wind speeds. In this study, the utilisation factor of offshore turbines equals 3484 hours full capacity equivalent¹⁵.

A dedicated area of the Belgian continental shelf has already been divided into 7 concessions able to receive about 2200 MW until 2020. By the end of 2012, the total offshore capacity is expected to be around 380 MW.

Different studies have tried to estimate the offshore potential of the Belgian maritime area. The most ambitious one has estimated a global offshore potential of 21 GW that can be installed in the Belgian exclusive economic zone (EEZ)¹⁶ (Mathys et al, 2010). This study indicates the maximum energy potential given that the Belgian continental shelf is covered by wind turbines except in some specific zones reserved for maritime navigation and environ-

¹⁵ This figure is based on literature review. For offshore, production profiles have been derived from the onshore profiles as ELIA provided the required statistics for the simple reason that Belgian offshore production is very recent. Basically the onshore production profiles have been increased in a linear manner.

¹⁶ A zone where a country has sole exploitation rights over all natural resources.

mental protection. Considering that this 21 GW figure is an upper limit that is unlikely to be achieved, a lower offshore potential of 8 GW¹⁷ has been taken into account.

The Belgian exclusive economic zone (EEZ) is very small since it is surrounded by those of neighbouring countries (see the B zone in Figure 2 below). However, a higher offshore capacity can be assumed reflecting the possibility to import offshore wind energy from outside the Belgian territorial waters. This complementary offshore capacity is presumed to be installed in exclusive economic zones (EEZ) of other North Sea countries (the Netherlands, UK, France, Germany, etc.).

Figure 2 : North Sea exclusive economic zones (EEZ)



Source: Unité de Gestion du Modèle Mathématique de la mer du Nord
<http://www.mumm.ac.be/FR/Management/Atlas/map.php?NorthSeaBelgianArea>

By 2050, new offshore technologies can be expected such as floating windmills. Therefore, the available construction zone may be extended and the potential of the North Sea might be increased dramatically. The Grand Design scenario from Veum et al. (2011) gives an offshore potential of 135 GW in the Central and Southern North Sea. However, relaxing the constraints (spatial allocation priorities, technology costs) taken into account in this study, the North Sea potential could increase in a range that is comparable to the maximum world potential of wind energy. This equals 400 TW for wind turbines placed on Earth's surface

¹⁷ It is important to notice that the study of Mathys et al. (2010) has had a controversial reception. According to numerous Belgian experts, the Belgian offshore potential estimated in this study is too optimistic and has to be reduced. Nonetheless, assuming that some societal priorities may be relaxed (energy production versus other criteria) this potential is supposed to equal 8 GW.

(Marvel et al, 2012). Since the North Sea surface equals almost 0.15% of the Earth's surface, its wind potential is assumed to equal 600 GW. It is important to note that this potential does not take into account an additional offshore potential of the Atlantic Sea in front of the French coasts. Thus, the additional "import" offshore capacity is supposed to be "free of constraints" compared to the Belgian energy demand.

4.1.3. Solar energy potential

In Belgium, solar radiation can be transformed into two major useful energy forms. On the one hand, heat at a relatively low temperature can be produced by thermal solar panels for sanitary hot water or other heat purposes. On the other hand, electricity can be produced directly from photovoltaic panels. Thermoelectric solar power stations have not been considered in this study insofar as Belgian climatic conditions seem to be unfavourable to the development of this technology.

In all our scenarios, solar technologies play a major role in achieving the 100% renewable target by 2050. Even if Belgium is not the sunniest country of the European Union, there exist many opportunities to install large solar capacities.

In this study, solar panels are supposed to be installed on roofs of existing buildings. Different studies have analysed the regional solar energy potential assessing available well oriented roof surfaces (ICEDD, 2010 and VITO, 2011). Well oriented roof surface is defined as the projection on the ground of the building minus the loss of surface due to poor roof orientation and roofs that are in the shadow of another building, a chimney, etc. plus the gain of surface size due to roof inclination.

Considering all the existing buildings in Belgium, the potential roof surface that can be used to install solar panel equals around 250 km². This figure is injected in the model as an upper limit of the solar energy potential for the production of electricity or heat in all scenarios except for the PV scenario. In the PV scenario, a higher upper bound is fixed corresponding to 10% of the Belgian territory. Even if this upper limit is never reached in the various model runs, a higher potential implies that solar panels are also installed on non-built areas (parking lots, gardens, fields, etc.).

The efficiency of the PV panels is presumed to increase by 50 % over the next 40 years.

4.1.4. Geothermal potential

The geothermal potential has been quantified by the Consortium. This quantification is based on an underground heat map that is currently under construction. The quantification is based on a wells' depth of 6000 m and a water temperature of 197°C. In the northern Limburg region, 280 individual installations of 11 MWe could be installed on an available surface of 540 km², reaching 3100 MW. As no detailed data for Wallonia were available, the potential for Belgium has been augmented only to 4000 MW.

4.1.5. Hydroelectricity

In 2010, hydroelectric net capacity equals 110 MW in Belgium. The hydroelectric potential is already largely used in Belgium and no important development is foreseen in the future. Therefore, the power capacity of this technology is supposed to equal 120 MW in all scenarios. It is important to notice that this figure does not include storage facilities such as Coe.

4.1.6. Levelised fixed costs of the main renewable technologies

A typical indicator to compare electricity costs is the levelised costs. When one only includes the fixed costs (CAPEX and FIXOM), we get an indicator that is fuel price independent. Table 6 shows the CAPEX and FIXOM of renewable energy technologies for 2020 and 2050.

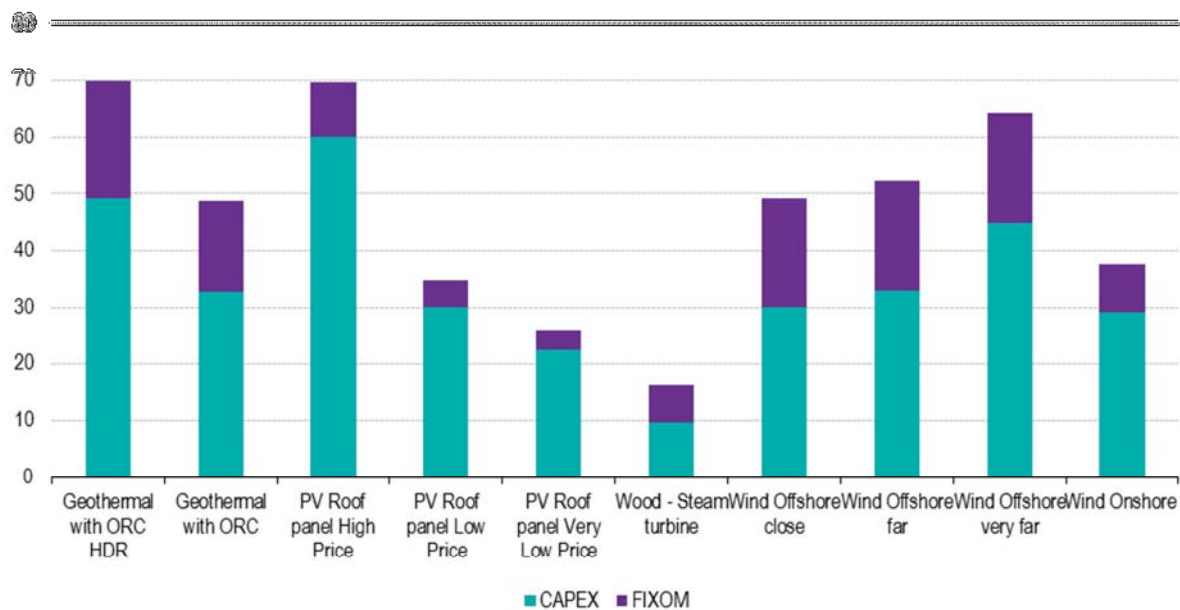
As can be seen in Figure 3, the levelised fixed costs vary widely. It is important to notice that all costs are discounted with the same discount rate as in the Belgian TIMES model. However, this is not a model input but a stand-alone calculation, based on inputs of CAPEX and FIXOM, maximum operating hours and lifetime. The concept of levelised costs does not fully cover all costs, even if fuel costs would be included. Ueckerdt et al. (2012) shows that important costs are not included and that a system approach is necessary to draw accurate conclusions from the results.

Table 6 : CAPEX and FIXOM of renewable energy technologies (€2005 per kWe)

	CAPEX 2020	CAPEX 2050	FIXOM 2020	FIXOM 2050	Lifetime
Geothermal with ORC HDR (hot dry rock)	6248	5742	207	153	25
Geothermal with ORC	4166	3828	157	119	25
PV Roof panel High Price	1000	1000	10	10	25
PV Roof panel Low Price (PV scenario)	1000	500	10	5	25
PV Roof panel Very Low Price	500	371	5	4	25
Wood - Steam turbine	1396	1236	50	50	30
Wind Offshore close	1807	1441	68	68	20
Wind Offshore far	1988	1585	68	68	20
Wind Offshore very far	2711	2161	68	68	20
Wind Onshore	1031	862	22	18	20

Source: model assumptions.

Furthermore, there is a great uncertainty regarding the evolution of PV performance in the future especially regarding investment costs and efficiency. Therefore, 3 PV scenarios have been defined characterised by three different PV prices (HP for high prices, LP for low prices and VLP for very low prices). The efficiency of PV panels is presumed to increase by 50 % over the next 40 years.

Figure 3 : CAPEX and FIXOM of renewable energy technologies in 2050 (€2005 per kWe)

Source: model assumptions.

4.2. Technological options in industry

4.2.1. The steel industry

The steel industry is one of the most important and energy intensive industrial sectors in Belgium. Traditionally the sector has been developed on so-called “integrated routes” fed with raw materials like iron ores and coal and is based on the blast furnace (BF) technology using hard coal previously transformed into coke. During the last few decades, electric arc furnaces (EAF) consuming almost exclusively scrap have progressively been introduced in order to exploit an increasing scrap potential and to produce steel at lower energy costs. Indeed, BF consumes more energy (EU27 average = 21 GJ/t; benchmark = 17 GJ/t of hot rolled coils - HRC) since the raw material of this production chain is iron ore while the specific energy consumption of EAF using scrap iron equals 4,5 GJ/t HRC (EU27 average) or 3,5 GJ/t HRC (benchmark). The current share of EAF (about 40% in the EU in 2005) is supposed to increase up to more than 50% in Belgium by 2030.

Besides BF, companies use an alternative way of producing steel from iron ore: direct reduction, whose specific energy consumption is almost the same as that of BF but in this case, coal and coke can be replaced by natural gas. This fuel is used as an energy source as well as a reducing agent to transform iron ore into steel (see for example MIDREX technologies powered by CH₄).

Moreover, the steel industry undertakes a lot of research to be able to cope with climate challenge and the expected increase in fossil fuel prices e.g. ULCOS project aimed at reducing the emissions of today’s best technologies by at least 50% (Birat, 2010).

Since our study assumes that the general economic paradigm will remain unchanged, steel production is presumed to stay constant at around 8 million tons over the whole period (until 2050) even if recent news suggest that it could also drop to around 6 million tons (like in 2012). In order to turn the steel industry into a 100 % renewable sector, it may seem that closing down all BF and replacing them with EAF would be the simplest option. However, in reality it does not seem to be a realistic option due to problems of scrap availability and of EAF steel quality. On the one hand, almost all available good quality scrap is already recycled requiring the exploitation of additional ore to fulfil the global demand for steel. On the other hand, even if the recycling sector is improving its process quality, it will probably always remain impossible to purify the scrap iron feeding the EAF as far as needed for the highest added value steel products (e.g. flat products for the automobile, white goods and packaging industries) in an economically viable way. Therefore, it seems almost certain that a ‘tool’ directly transforming iron ore into steel will remain necessary (at a volume to be defined). The question then is: “How can these tools be powered exclusively by renewable energy sources?”. BF fed with charcoal is of course easy to imagine but the availability of biomass will certainly limit the development possibilities of such a solution. A breakthrough solution could be to adapt the MIDREX process in order to replace CH₄ with H₂. Doing so would make it possible to avoid the consumption of fossil fuel (CH₄) and to resort to a 100% renewable fuel since H₂ can be produced from the electrolysis of water using renewable electricity.

From literature and according to experts, it seems that this highly technological option is conceivable. Even if numerous challenges need to be tackled before the steel industry can move to such a renewable energy supply, there does not seem to be any insurmountable technical obstacle to achieve this target. It is difficult to find relevant technical-economic figures about these breakthrough technologies but according to experts in the field, a H₂ consumption of 1000 Nm³/t HRC and a CAPEX of 1.5 b€ to produce 4 Mt HRC can be assumed. Since the raw material in this process is iron ore, the specific energy consumption roughly equals the specific benchmark consumption of the blast furnace technology (about 17 GJ/t HRC).

Table 7 : Characteristics of H₂ MIDREX technology

Characteristic	Value	Unit of measure
Iron ore	1.5	ton/ton steel
Hydrogen	17	GJ/ton steel
Electricity	0.7	GJ/ton steel
Capex	400	€ /ton steel
Fixom	10	€ /ton capacity
Varom	2	€/ton steel
Lifetime	40	years
Available	2030	

Source: Based on data from Birat (2011) and personal communication from the steel industry.

Since the EAF option could not cover all of Belgium's demand for steel (presumed to remain constant at 8 Mt/year), the long-term steel production is assumed to be achieved with a mix of 50% EAF and 50% H₂ based MIDREX. The MIDREX technology is assumed to be available from 2030 onwards.

4.2.2. Cement production

The cement industry is a very energy intensive sector only present in Wallonia. Today's production equals almost 7 million tons of clinker per year. Following the general assumption of stability in the general economic paradigm, this production level should increase slightly over the next 40 years.

Currently, cement can be produced in two different ways (the 'wet' and the 'dry' processes). The first one (the wet process) consumes more energy (almost 8,5 to 9 GJ/t clinker) while the second one (the dry process) is more energy efficient (almost 3,3 to 3,8 GJ/t). This difference in energy efficiency explains why cement companies are gradually phasing out the wet process. The clinkering process requires very high temperatures (oven temperature above 1400 °C and flame temperature of around 2000°C). During the last few decades, the cement industry has used more and more alternative fuels such as industrial or organic waste (used tires, contaminated meat and bone meal, etc.) but the more alternative fuels are used, the less energy efficient the process becomes.

In theory, electrical arc furnaces could achieve the clinkering temperature but in practice, there are no electrodes able to support this temperature without melting. Therefore at this stage, it seems that the cement industry still needs classic ovens requiring a combustion process. Due to the high temperature, high net calorific value (NCV) fuels (above 20 GJ/t) are necessary in the clinkering process while typical NCV of biomass is around 14 GJ/t (wood, etc.). However, it is possible to transform biomass in order to increase its NCV by preparing liquid biofuels with the same calorific characteristic as diesel or charcoal globally equivalent to coke.

So converting the cement industry implies powering it with a biomass mix of 50% wood or waste and 50% "prepared" biomass such as liquid biofuels or crushed charcoal. This option is available in the model from 2030 onwards

4.2.3. Lime production

The same raw material (limestone) is used by both the lime and cement industries. But unlike the cement industry, the required temperature to produce lime is lower because the basic process is limited to the calcination of the carbonates included in limestone. This chemical transformation is achieved at around 900°C. Due to this lower temperature and even if no industrial appliance already exists, it is technically possible to manufacture such an electric lime kiln using microwave or indirect heating processes. In fact, lime kilns for research purposes are already electrically heated. Thus, the study presumes that the lime industry can

be electrically powered in the future. This option is available in the model from 2020 onwards.

4.3. Demand side Technologies

4.3.1. Mobility

The energy service demand for mobility is expressed in passengers-kilometres for cars and ton-kilometres for freight. An important technology characteristic is the fuel consumption.

The plug-in hybrid and pure electric vehicles (PHEVs/EVs) in our model are only consuming electricity for charging and do not have the possibility to be discharged for delivering electricity to other consuming appliances. That is the reason why they are not shown in the model's fast reacting reserves as they do not play an extended role in the day/night storage processes. This is based on the fact that our calculations showed that it is not trivial to know when and how much energy can be taken from PHEVs/EVs assuming that they always need to have a certain minimum reserve available during the day (without saying it is inconceivable either).

This holds even for the very short-time span: since cars often stand still, the fast reacting batteries of the electric cars could take over when the supply of PV/wind suddenly drops. Here too, the PHEVs/EVs are not included in the equation of the model's fast reacting reserves. We opted for a more cautious approach by summing only the biomass, geothermal and other storage technologies.

4.3.2. Building sector

Energy consumption in buildings is for heating and the use of electrical appliances. The heating of existing and new buildings is to satisfy a constant comfort level per dwelling. For the residential sector, required energy service levels are based on population projections, income elasticities and the evolution of the number of inhabitants per dwelling. Furthermore, the model considers the existing stock of dwellings and its energy characteristics as well as the policies which have been implemented to improve the energy efficiency of dwellings.

TIMES differentiates between the energy service demand in existing houses and in new houses. Demolition of existing houses is represented exogenously in the energy service demand for existing houses. The model considers different options for saving energy in existing houses: roof insulation, wall and floor insulation and replacing windows. However, the potential of saving energy by insulation is limited by the historical building concept and it is difficult to reach similar energy efficiency levels like in new houses. To increase the saving potential in the residential sector, an additional 'demolishing and rebuilt as passive' option has been implemented in the model. This option is implemented for houses that in 2040 will reach the age of 80 years or more. When this option is chosen, the residual value of the existing house is considered as an additional cost element.

4.4. Energy networks

4.4.1. Residential smart grids

The assumption here is that the capacity is based on a controllable daily energy consumption of 3.72 kWh per family, corresponding to a storage capacity of 15 GWh and a total potential shifted consumption of 5.4 TWh per year, approximately 1.8% of the estimated 2050 consumption¹⁸. These figures are only rough estimates and are surrounded with uncertainty. To give an example: an additional volume of a 200 l electric boiler would allow “storing” 10 kWh electricity, but a detailed assessment should consider the family’s behaviour as regards hot water consumption. For modelling purposes we have assumed that implementing smart grids involves an investment cost of 200 € per family. Technically smart grids have been implemented as a day/night storage technology (see next section).

4.4.2. Day/night and seasonal electricity storage options

Today, various technologies for electricity storage exist and are being further developed. Rather than pick and choose (arbitrarily) which technology will be used, we opted for a more generic representation (see Table 8 below). However, the relevant modelling parameters such as the C-rate, efficiency and investment costs have been quantified according to existing technologies (see chapter 3.3.1). For instance, the parameters for high efficiency day/night storage are inspired by Li-Ion technology whereas the low efficiency seasonal storage options could be based on technologies similar to lead-acid batteries. Smart grids have been implemented as a storage option – equivalent to a storage capacity of 15 GWh, almost 3 times the capacity of the pumped storage facility in Coe.

Table 8 : Characteristics of storage technologies

Storage technology		Characteristics					
		Efficiency	C -rate	Investment €/kWh		Life	Max cap.
2010	2050						
Electricity	High efficiency Day-Night	0.9	0.3	500	400	10	
	Low efficiency Day-Night	0.7	0.3	200	160	5	
	High efficiency - seasonal	0.95	0.03	500	400	10	
	Low efficiency - seasonal	0.55	0.03	20	10	10	
	Smart grids	0.98	0.03	53	53	10	15 GWh
	Pumped storage	0.74	0.25	N.A.	N.A.	50	5 GWh
Hydrogen	Day-night	0.8	/	3	2	20	
	Seasonal	0.75	/	3	2	20	

Source: model assumptions.

¹⁸ In comparison, Meunier and Vidalence (2011) estimate the potential shifted consumption for France as 1.3% of the total consumption in 2008.

For hydrogen, only the costs for storage are shown, covering only a part of the total costs of hydrogen production and distribution chain. The storage costs are typically lower than for electricity, but the costs for producing hydrogen are higher. Stored hydrogen can be used by the model in different ways, but typically the direct use of hydrogen is preferred.

4.4.3. Cost assumptions for the transmission and distribution network

The cost of developing a distribution grid largely depends on the local circumstances. Relevant literature data are scarce. The derivation of investment costs for the distribution and transmission network is illustrated in Table 9. Revenues from distribution are calculated by multiplying electricity delivered and the distribution costs. The present value of distribution revenues is assumed to be representative for the historical investment costs and is calculated from the revenues, a commercial profit rate and an assumed lifetime of 50 years. The capacities of the distribution networks are the unknown variable. TIMES' reference scenarios have been used for quantifying the peak capacity factors.

In the model, we use a 5000 €/kW for the distribution network and 650 €/kW for the transmission network.

Table 9 : Derivation of investment costs for the distribution and transmission network

	Distribution	Transmission
Electricity delivered 2010 (TWh)	55	85
Peak capacity factor (fraction of average)	1.3	1.4
Capacity distribution network (GW)	8.8	13.6
Costs of distribution and transmission (€/kWh)	0.06	0.0085
Yearly revenues (B€)	3.30	0.723
Lifetime (years)	50	50
Commercial profit rate	8%	8%
Present value of revenues (B€)	40	9
Capacity costs (€/kW)	4946	651

Source: model assumptions.

ELIA et al. (2012) have quantified the necessary investment costs for grid expansion to meet the EU20-20-20 requirements. This study reports 445 M€ investments for the transmission network and 356 M€ for the distribution network. However, these figures are hard to compare with the estimates made here as they are based on smart solutions, i.e. making use of locally existing overcapacities and are only valid in the context of the EU20-20-20, i.e. only 20% renewable energy target by 2020. In a 100% renewable scenario, we assume that these local existing overcapacities represent only a small fraction of what will be needed.

4.4.4. Hydrogen distribution

Hydrogen can be produced in different ways and the Belgian TIMES model covers transformation technologies with different energy commodity inputs. The cost of transformation is

included in the model and so the cost of hydrogen is a model result. Nevertheless, the cost of hydrogen is typically determined for a large part by the cost of the input energy vector of which hydrogen is created from. The price of hydrogen will strongly depend on the scenario and the period in the year. The Belgian TIMES model also covers the costs of hydrogen distribution. Some losses and electricity input are foreseen in the model. The determining factors in the cost are the sector for which the hydrogen is produced and the physical states of hydrogen, being gaseous or liquid.

Table 10 : Hydrogen technologies' costs

Sector	Supply	Filling station	Electricity input	Losses	Cost (€/05/GJ)	Cost (\$'08/boe)
Industry and electricity	Gaseous	Gaseous	1%	2%	2	13
Commercial and residential sector	Gaseous	Gaseous	1%	4%	9	58
Transport urban	Gaseous	Gaseous	7%	4%	7	50
Transport rural	Gaseous	Gaseous	6%	1%	12	82
Transport	Liquid	Gaseous	5%	1%	7	50
Transport	Liquid	Liquid	2%	1%	5	35

Source: CASCADE MINTS, Case Study Comparisons And Development of Energy Models for INTe grated Technology Systems (2007)

5. General assumptions and policy framework

As all scenarios (described in the next chapter) share common assumptions, this chapter covers the most important general assumptions and the policy framework. In order to elaborate long-term energy projections, the first step is to define the hypotheses which are afterwards fed into the TIMES model as input variables. For the hypotheses to be specified, a vast literature review was performed culminating in a large number of diverse assumptions. We went ahead analysing these in order to make a sound proposal based on best available knowledge and consistency. Subsequently, the hypotheses were presented to the Steering Committee, after which the different model runs could be launched.

The hypotheses used in this exercise relate to a number of variables, more specifically the international fuel prices, economic activity, demography, implemented policy measures, imports and energy service demand. As it proved not to be trivial to find forecasts up to the year 2050 on a national (Belgian) level, several sources could nonetheless be gathered, the first always being the figures used in the TUMATIM project¹⁹. The next sections give a concise overview of the main assumptions.

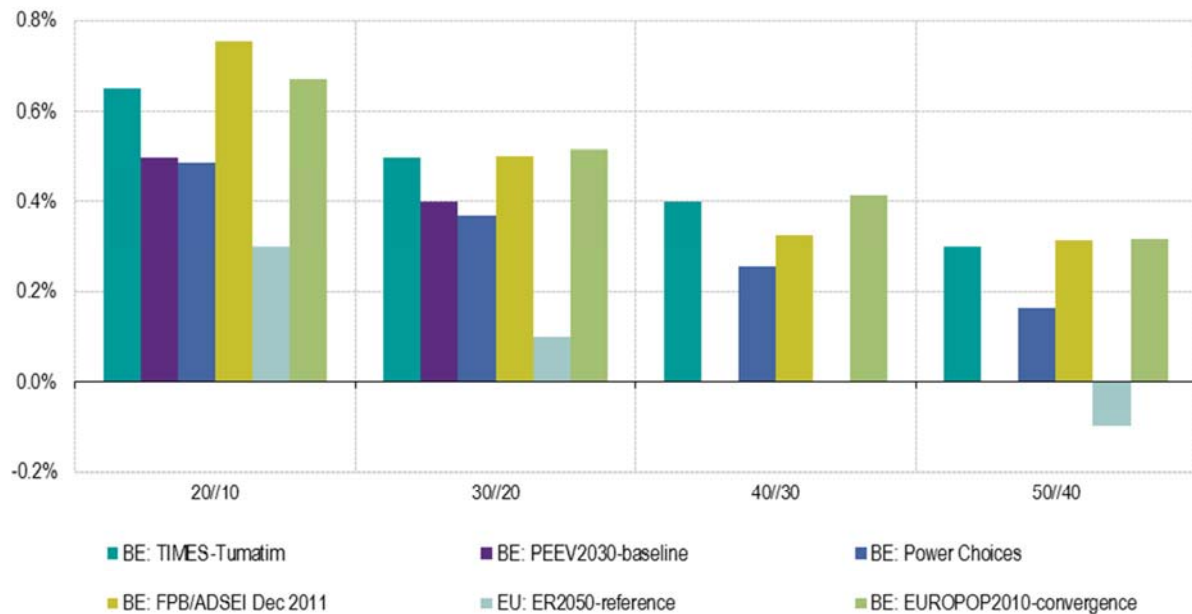
5.1. Demographic and macroeconomic assumptions

As regards the hypotheses on demography and economic growth, both main determinants for the estimation of the future energy services demand, different sources on different geographic levels (being the Belgian or European level) were assembled. The consulted demographic studies (ranked according to the legend depicted in Figure 4) are the cited TUMATIM project (2011), the most recent energy outlook for Belgium established by the Federal Planning Bureau (abbreviated: PEEV2030) (2011), the Power Choices study by Eurelectric (2010), the joint FPB/ADSEI publication on long-term population forecasts (2011), the EUROPOP2010-convergence scenario (EUROPEAN POPulation Projections) from Eurostat (2010) which is also the basis for the 2012 Ageing Report (European Commission, DG Economic and Financial Affairs, 2011) and, rather as a benchmark, the annual average population growth rate for the EU27 as applied in the Energy Roadmap towards 2050 of the European Commission²⁰ (2011).

¹⁹ The TUMATIM report is the culmination of a 3-year joint assignment between the KU-Leuven, VITO and HUB for the Belgian Science Policy Office with horizon 2050 and scope the Belgian energy system.

²⁰ Which itself is based on the EUROPOP2008-convergence scenario from Eurostat.

Figure 4 : Comparison of the evolution of population growth between different sources (annual average growth rate per decade, %)



Source: FPB, own calculations.

Note: BE stands for Belgian figures, EU stands for European figures.

Looking at the different studies, it becomes obvious that the general trends are similar (apart from the European evolution which seems to follow a different growth path): growth rates peak during the first decade and seem to slow down afterwards. Since the joint exercise performed by the FPB and ADSEI, published in December 2011, is based on the latest trends and statistics and that these figures highly converge with the ones put forward in the other studies covering the 2050 horizon (e.g. TUMATIM, the EUROPOP2010-convergence scenario, ...), we decided to take as demographic hypotheses the FPB/ADSEI forecasts for Belgium, of which the annual average growth rates are depicted in Table 11.

Table 11 : Annual average growth rate of the Belgian population according to the FPB/ADSEI publication (%)

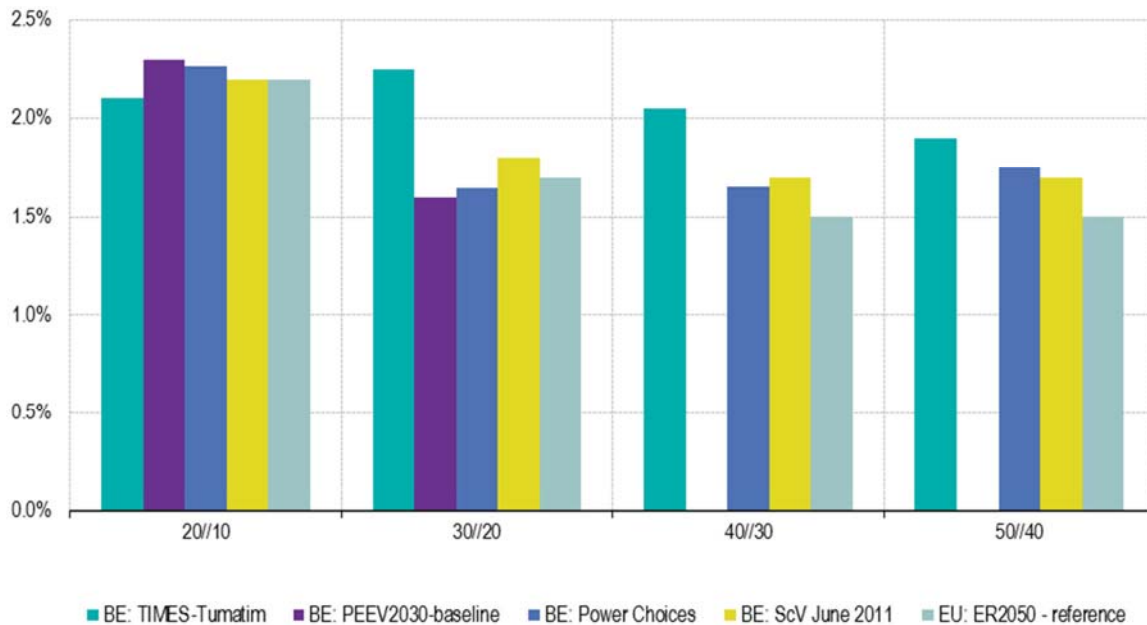
	20//10	30//20	40//30	50//40
FPB/ADSEI	0.8	0.5	0.3	0.3

Source: FPB/ADSEI (2011).

Turning to GDP, the same approach of comparing different sources was adopted. Only difference is that the FPB/ADSEI publication is now replaced by the annual report of the Study Committee on Ageing of the High Council of Finance, which was published in June 2011. Both studies are however interlinked through common assumptions, a common model (the use of the FPB's MALTESE model) and common authors (the FPB is co-author of both studies). In a concern to be coherent, encouraged by the fact that overall, the GDP projections (except for TUMATIM) converge, we decided to, in what follows, work with the GDP outlook

as found in the annual report of the Study Committee on Ageing (ScV). This publication takes track of the fact that the recent economic crisis has long-lasting effects leading to a permanent loss in GDP. The recovery from the crisis is not expected to be vigorous enough to compensate for lower GDP growth rates during the crisis.

Figure 5 : Comparison of the evolution of GDP between different sources (annual average growth rate per decade, %)



Source: FPB, own calculations.

Note: BE stands for Belgian figures, EU stands for European figures.

In the table below, the annual average growth rate that will be used in the framework of the 100% RES study is summarized.

Table 12 : Annual average growth rate of Belgian GDP according to the annual report of the Study Committee on Ageing (%)

	20/10	30/20	40/30	50/40
ScV	2.2	1.8	1.7	1.7

Source: High Council of Finance (2011).

5.2. International energy prices

The projection of the fossil fuel price evolution up to 2050 is a tricky exercise since this, next to fuel reserves and production rates, not only depends on potential economic recovery and possibly a resuming GDP growth (or not, or not soon), but also on the global climate action initiatives. Conditional on the fact that the whole world follows our example of transforming into a 100% renewable society or decides to take drastic actions in the fight against climate change, the resulting fossil fuel demand will be (largely) impacted as the need for fossil fuels shrivels and prices then will be driven down. Nevertheless, in this study we suppose that

this outset will not take place and that fossil fuel demand on a global scale will continue to grow following the vast and increasing energy needs of the emerging economies, culminating in high future prices. These high price assumptions have non-negligible consequences on the subsequent energy projections, as well as on the height of the carbon value required to meet the GHG emission reduction targets (cfr. infra).

Three studies are scrutinised for their international energy prices, being the TUMATIM study, the energy outlook for Belgium up to 2030 sketched by the FPB (abbreviated: PEEV2030) and the Commission's Energy Roadmap 2050 which contains two diverging views on future international energy prices conditional on the baseline²¹ perspective or the decarbonisation²² point of view as depicted in Figure 6. The three studies have in common that prices are derived with world/global energy models (POLES and PROMETHEUS), showing largely parallel developments of oil and gas prices whereas coal prices remain at much lower levels. We notice that international fuel prices are projected to grow steadily over the whole period with oil prices reaching around 88 \$'08/barrel in 2020, around 106 \$'08/barrel in 2030 and around 127 \$'08/barrel in 2050²³.

Now given that the TUMATIM, PEEV2030 and Energy Roadmap 2050-reference price projections converge (except for gas which follows a similar evolution but starts at a lower level in TUMATIM), that PEEV2030 projections only run up to 2030 and that we have a preference to subscribe both to the most recent as to the wider European context in a desire to be coherent with the work done by the Commission, we implemented the (evolution of the) energy prices taken from the Energy Roadmap 2050-reference (and current policy initiative – CPI - scenario) in our work.

Table 13 : Evolution of international energy prices according to the Energy Roadmap 2050, CPI scenario (\$'08/boe)

	2020	2030	2040	2050
ER2050-CPI oil	88,4	105,9	116,2	126,8
ER2050-CPI natural gas	62,1	76,6	86,8	98,4
ER2050-CPI coal	28,7	32,6	32,6	33,5

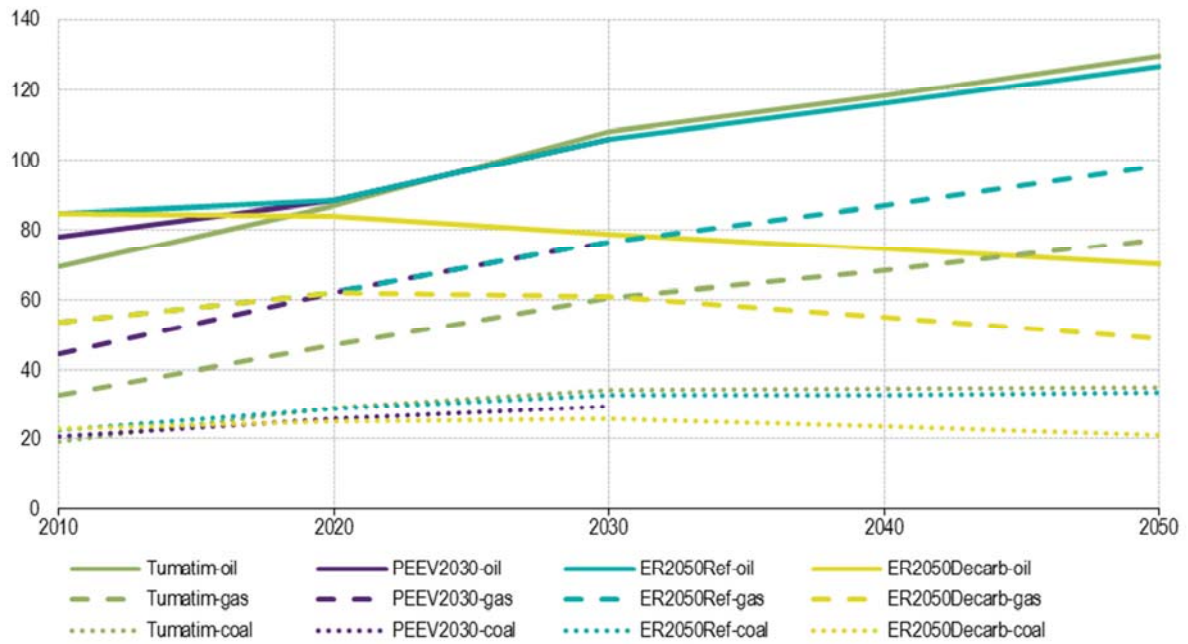
Source: European Commission (2011).

²¹ Reference and Current Policy Initiative.

²² All the other scenarios described in the Energy roadmap 2050 - impact assessment, part 2.

²³ Assuming an inflation of 2% (ECB target) this corresponds to some 300\$ in nominal terms in 2050.

Figure 6 : Comparison of the evolution of international energy prices between different sources (\$'08/boe)

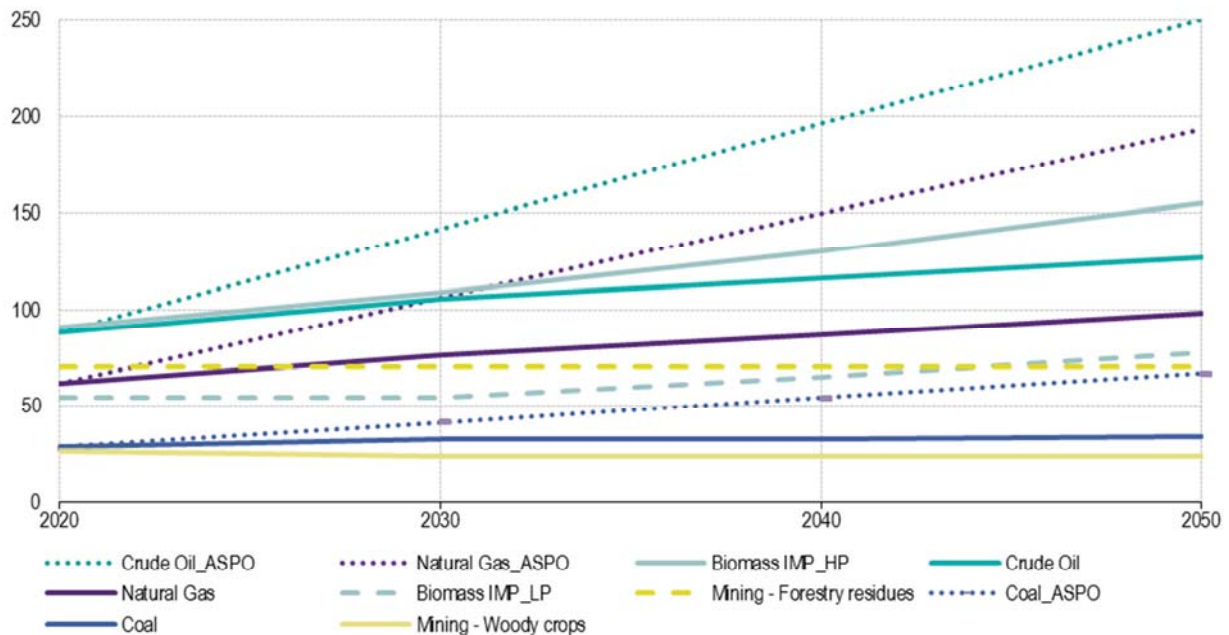


Source: FPB, own calculations.

Note: All monetary values are expressed in constant terms (without inflation). The dollar exchange rate for current money changes over time; it starts at the value of 1.45\$/€ in 2010 and is assumed to decrease to 1.25\$/€ by 2020 and to remain at that level for the rest of the period.

Figure 7 elaborates Figure 6 by also depicting the evolution of imported (suffix IMP_HP) and domestically available (Mining) biomass prices next to the withheld and alternative fossil fuel (suffix _ASPO) and biomass' (suffix IMP_LP) prices. The alternative fossil fuels prices were found in the forecasts of the Association for the Study of Peak Oil (ASPO) (Brocorens, 2012). These alternative fossil fuel and biomass' prices are meant to assess the impact of uncertainties in fuels prices (see paragraph 8.5.2).

Figure 7 : Comparison of the evolution of international fossil fuel and biomass' prices (\$'08/boe)



Source: Brocorens (2012), FPB, own calculations.

Figure 7 shows the alternative fossil fuel prices marked with dotted lines. Also depicted are the different types of biomass, each showing different prices. Domestically available biomass is cheaper within a range going from 24 to 71 \$'08/barrel in 2050. The cost range for importing biomass going from 78 to 155 \$'08/barrel in 2050 is sufficiently large to cover uncertainty. The study *Reshaping* (Ecofys, Fraunhofer ISI, EEG and Lithuanian Energy Institute, 2011) focuses on EU domestic biomass with a cost in 2020 and 2030 of about 50 to 60 €/MWh. This boils down to about 106 and 128 \$'08/barrel in 2030. The oil price in 2030 is 106 \$'08/barrel, our biomass' prices are between 54 and 109 \$'08/barrel.

5.3. Policies and measures

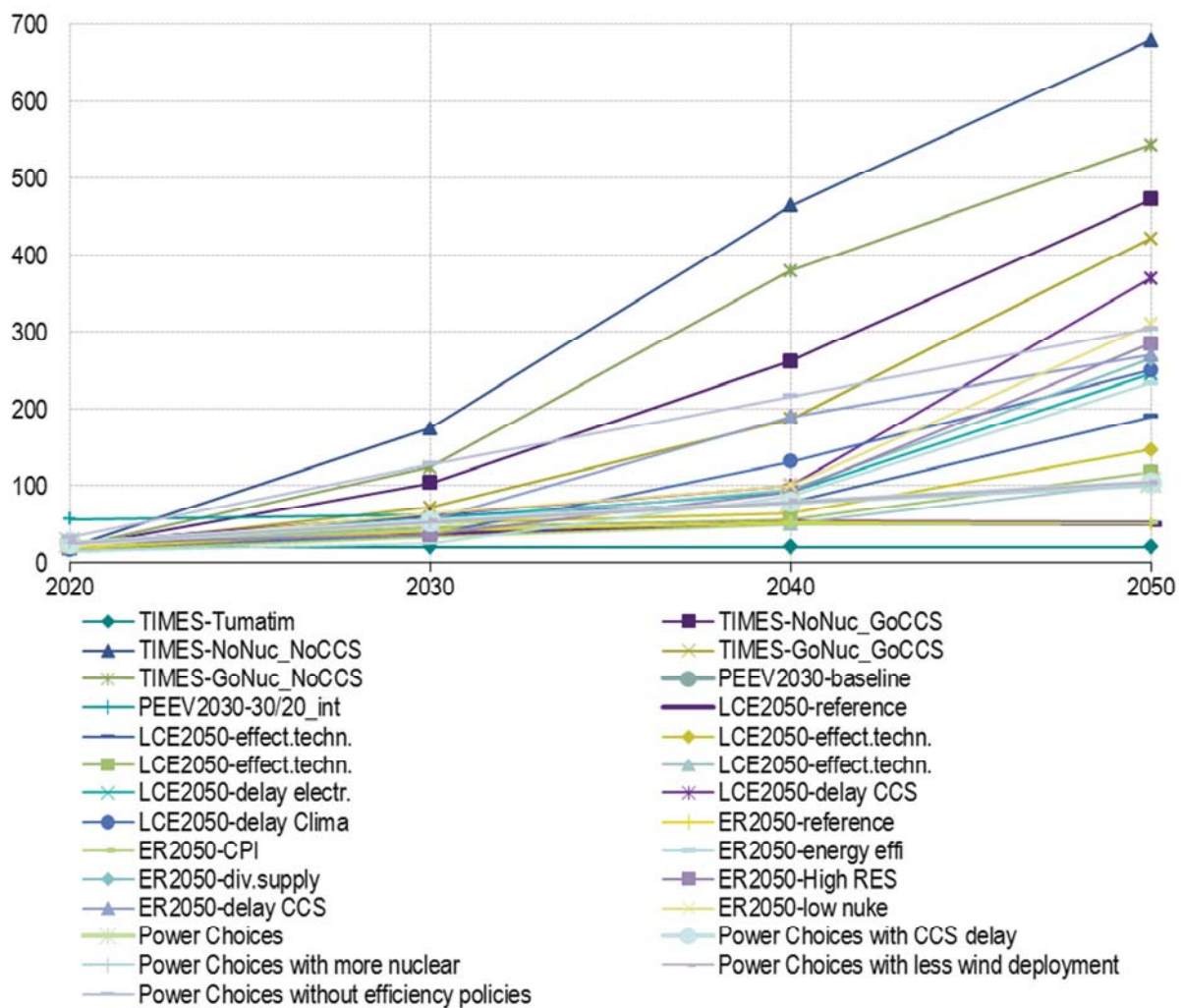
Further, the baseline assumes policies and measures implemented up to 2011. All policies and measures that have been implemented up to that date and also those for which the legislative provisions are defined in such a way that there is little uncertainty on how they should be implemented in the future are included in the reference scenario.

As for the carbon prices which, looking at Figure 8, can diverge by as much as a factor 34 in 2050, they are influenced by the choice made in 5.2, meaning that, because of the existence of a clear inverse correlation between energy prices and carbon prices, the choice of higher energy prices in 5.2 requires lower carbon prices in the following. Pricing in general, be it through carbon price or through energy prices, is an important driver to reduce emissions due to its impact on energy demand and energy efficiency. The combined effect of carbon prices and energy costs has a major impact on the type of investments that will be undertak-

en in the coming decades. So, the choice of carbon prices goes hand in hand with the selection made for the international energy prices. Since we opted in 5.2 for the energy prices of the Energy Roadmap's reference scenarios, we should, in an attempt to be coherent and consistent, take the corresponding carbon prices.

Other arguments for the rather modest carbon prices are that, first, they are determined at a European (not Belgian) level, second, our study does not fix any objective in terms of greenhouse gas emission reductions (only renewable targets in the alternative scenarios are imposed). Even if this study is integrated in the framework of a 20% GHG emission reduction on the European level through the implementation of the Climate/Energy Package, it does not go beyond that. Increasing the climate effort through higher carbon pricing would entail the problem of not being able to discern, on the one hand, the "climate" effect, on the other, the 100% RES effect since results coming from the model would be "mixed". On top of that, it is important to remember that in the end, GHG emissions of the renewable scenarios decrease dramatically since renewable energy sources are an instrument to decarbonise.

Figure 8 : Comparison of the evolution of carbon prices between different sources (€'08/tCO₂)



Source: FPB, own calculations.

This implies carbon prices going from 15 €/tCO₂ in 2020 to 51 €/tCO₂ in 2050. The trajectory is given in Table 14.

Table 14 : Evolution of the carbon prices according to the Energy Roadmap 2050, CPI scenario (€/tCO₂)

	2020	2030	2040	2050
ER2050-CPI	15	32	49	51

Source: European Commission (2011).

As regards nuclear energy, the Act of 2003²⁴ is still into force today. However, on the 6th of December 2011 when the new federal government was appointed, this government agreed to take a (new) formal decision on nuclear energy after a national electricity equipment plan was drawn up and this within 6 months after its appointment. The publication of this plan in June, 2012 led the government to decide that Doel 1 and 2 would be closed according to the law of 2003, but that Tihange 1 would be granted an operational life time extension of an additional 10 years. Meanwhile, in the summer of 2012, anomalies discovered in the reactor vessels of Doel 3 and Tihange 2 caused the premature shutdown of these two nuclear power plants without specification as to a potential production restart (if ever). Because a lot has been going on (and still is going on) in this field, because a lot of uncertainty still lingers around nuclear energy in Belgium and because for the moment, the only legal certainty lies embedded in the law of 2003, we decided to subscribe to the current legal context of the law of 2003. It implies a gradual closure of the existing nuclear power plants as foreseen in the Act of 2003 and an embargo to construct new nuclear plants during the projection period covered by this study.

As to coal power plants, we made the assumption that no new coal fired power plants could be constructed during the entire time horizon of the study. This hypothesis was inspired by the recent decline of the environmental permit's application for the construction of a new coal fired power plant in a geographically interesting²⁵ area for this type of investment (Port of Antwerp) for reasons that had to do with the quality of air.

Turning to renewable energy, the reference scenario includes the Belgian target for the share of energy from renewable sources in the gross final energy demand by 2020 as specified in the Directive 2009/28/EC (April 23, 2009) on the promotion of the use of energy from renewable sources, namely a 13% share of renewable energy in gross final energy demand and a 10% share in transport. The Belgian renewable target of 13% in 2020 is incorporated in the reference scenario.

No carbon capture and storage (or usage) technologies are taken into account in this exercise.

²⁴ January 31, 2003, published in the Belgian Official Journal of February 28, 2003, pp. 9879-9880. The phase-out law calls for each of Belgium's 7 reactors to close down after 40 years of operation with no new reactors built subsequently.

²⁵ Interesting means from the point of view of both balancing electricity demand and supply and ease of coal provision through the harbour, coal being shipped in from other countries and continents.

5.4. Electricity and biomass imports

Three additional variables are exogenously determined in the baseline setting, namely the level of import of electrical energy to answer to Belgian electricity needs, the level of imports of (different forms of) biomass to cope with Belgian energy²⁶ needs and the future level of energy service demand. This paragraph then deals with the import assumptions, energy service demand will be commented in 5.5.

For the evolution of the net electricity imports in the baseline, we assumed to take the historical average of net electricity imports in Belgium between 2003 and 2010, being 5.8 TWh. This figure is kept constant over the entire projection period. Although this figure might seem rather low given announced and planned grid expansion investments including considerable future transborder connections, we opted to work with a rather low base level of electricity imports to avoid depending too much on electricity imports of which the origin cannot be tracked²⁷, meaning that we cannot for sure presume that the imported electricity is generated through the use of renewable energy sources²⁸.

Concerning the evolution of biomass use in the baseline, we decided to fix a ceiling based on the global biomass potential according to Haberl et al. (2010). The cited range in this publication is 160 à 270 EJ which is estimated with sustainability considerations as major criteria²⁹. This range then was divided on an equal per capita basis taking the world population in 2050 as a given (United Nations, Department of Economic and Social Affairs projections), which leads us to a Belgian potential biomass use in 2050 of approximately 300 PJ. This limit of biomass use is kept constant over the entire projection period.

5.5. The energy service demand

The macroeconomic background for Belgium sketches the general growth assumptions used for deriving the demand for energy services of the different consumption sectors in the reference scenario. In TIMES, it is this demand for energy services that is driving the model. There is a clear distinction between energy services and energy and between energy service demand and energy demand, the latter being expressed in litres of gasoline or diesel used to fuel a car or litres of domestic fuel oil to heat a home, the former is expressed in tons of steel produced or kilometres driven by car or a certain inside room temperature of a residential dwelling. These energy services can be seen as a reflection of society's welfare or its comfort level.

Determining this energy services' demand (ESD) is not a trivial exercise since data is limited and a lot of variables enter into play. Defining for example the residential ESD for an inside

²⁶ Biomass can be applied for all energy uses as defined in Directive 2009/28/EC (23 April 2009), being transport, heating and cooling and electricity.

²⁷ We work with a national version of the TIMES model, not with an interconnected type.

²⁸ Only exception being made by the importation of very far offshore wind, see renewables' scenario description.

²⁹ Other criteria can be used to estimate the global potential of biomass, such as a more energetic vision of the available biomass (see e.g. Panoutsou and Castillo, 2011).

room temperature of 21°C necessitates knowledge, not only of the (future) number of households and the number of dwellings, but also of the type of dwellings, the surface of the dwellings as well as the disposable household income. To gather all these data and combine them into a meaningful ESD, we proceeded in 2 steps: a thorough literature review was performed and expert judgment was called upon. For the expert judgment, we contacted several sector federations (e.g. cement, iron and steel) to check if our hypotheses on ESD were valid for their respective sectors and also discussed with (academic) experts in the field in order to validate the figures given in Table 15.

In short, the main determinants for the evolution of the demand for the different energy services are the GDP, the sectoral activity levels, private income, the growth in population and in households and the housing stock. The demands are exogenously determined in the reference scenario but can change in the RES trajectories in function of price changes.

Table 15 : Energy service demand, period 2020-2050 (annual average growth rate per decade, %)

	20//10	30//20	40//30	50//40
Agriculture (PJ)	0,2%	0,1%	0,4%	0,4%
Commercial (PJ)	0,4%	0,4%	0,7%	0,7%
Residential (PJ)	0,3%	0,0%	0,2%	0,2%
Freight transport (tkm)	2,0%	1,4%	1,2%	1,0%
Passenger transport (pkm)	1,1%	0,7%	0,4%	0,4%
Industry Ammonia demand (ton)	0,3%	0,9%	0,8%	0,4%
Industry Cement demand (ton)	1,5%	1,7%	1,8%	1,5%
Industry Copper demand (ton)	-0,4%	0,3%	0,4%	0,0%
Industry Glass demand (ton)	1,7%	1,9%	2,0%	1,7%
Industry Iron and steel demand (ton)	0,0%	0,0%	0,0%	0,0%

Source: Federal Planning Bureau, VITO.

5.6. Other assumptions

The tax rates are kept constant in real terms.

In all scenarios, the discount rate is fixed at 4%. This corresponds to a so-called social discount rate reflecting the public sector approach in the policy evaluation with TIMES. This 4% represents a real discount rate. On an informative note, developed countries all seem to hover around this 4% real social discount rate. In Europe, Germany uses 3%, based on values of real long-term government bond rates, Norway has been using a 3.5% discount rate after 1998, which is also based on the real government borrowing rate, while France's Commissariat General du Plan in 2005 lowered its project discount rate to 4%. Italy uses a 5% discount rate, while Spain adopts a 4 to 6% according to different sectors (see Zhuang et al., 2007).

All monetary values are expressed in constant 2005 terms (without inflation). Taking a 2% inflation rate (ECB target), 1 €'05 corresponds to some 1.1478 € in nominal terms in 2012 and to 2.4379 € in nominal terms in 2050.

Degree days, which capture the effects of possible variations in weather conditions having a noticeable impact on energy consumption, have been kept constant at the 2005 level. This ensures direct comparability of projections with Eurostat data for 2005 and implies furthermore that the baseline does not consider the effects of future climate change, when the speed and geographical distribution of e.g. warming or precipitation patterns is still uncertain (and not directly subject of energy analysis).

6. The scenarios

Due to the uncertainty surrounding such a long period, different RES scenarios have been elaborated in order to test a large range of possible ways to achieve the 100% renewable energy target by 2050. These scenarios are compared to a reference scenario which does not include any renewable energy targets except for those listed in the Climate-Energy Package.

6.1. The reference scenario

The starting point of the scenario analysis is the construction of a baseline or reference scenario. It is important to stress the role of this scenario for policy analysis with the TIMES model. The reference scenario is not aimed at forecasting the development of the energy system. It gives a consistent development path for the energy system, using a cost optimisation approach and a simplified representation of the energy users' and suppliers' behaviour in TIMES. The reference scenario serves as a basis to evaluate the cost of policies and their impact on the technological choices in the energy system. The reference scenario can therefore deviate from the evolution of the energy system in recent years which reflects the behaviour of the economic agents in real life, their expectations and the dynamic adjustment of the energy system. It allows however a consistent treatment of the technologies in the policy evaluation. This reference scenario (REF) includes the basic assumptions outlined in chapter 5.

The REF scenario does not imply any renewable energy target by 2050 but it takes into account the objectives of the 2020 EU Climate-Energy Package. For Belgium this means that according to Directive 2009/28, the share of renewable energy in gross final consumption of energy in 2020 equals 13% but that there are no other binding targets beyond 2020 .

It is important to notice that although the REF scenario is bounded by some renewable technology parameters (biomass, PV, wind) these limits are never reached. Since there is not yet clear evidence that this technology will be able to be deployed on a large scale under the current circumstances, no geothermal capacity is included in the REF scenario.

Finally, the evolution of fossil fuels is largely discussed by experts, some of them arguing that the peak oil will soon occur (or even has already happened) and therefore taking fuel prices to a very high level. In order to estimate the impact of this possibility, an alternative reference scenario has been defined, the REF – ASPO scenario in which fuel prices are supposed to soar to 250 \$₂₀₀₈barrel in 2050.

6.2. The 100% RES scenarios

The following two tables summarize the main characteristics of the different scenarios that have been studied. The first table gives information related to the energy service demand and the different renewable energy potentials while the second table explains the main assumptions used in every scenario.

Table 16 : Definition of the scenarios (general and technology parameters)

Scenario name	Main characteristics	Variants	General parameters			Technology parameters				
			Energy services demand	Import of ELE	Bio-mass use	PV	Wind onshore	Wind offshore	GEO	
REF	Reference scenario 2020 EU climate-energy package	NO	Exogenous			DEM constraints				0 GWé
DOM	100% Renewable Energy by 2050; DOMestic check	NO	Exogenous	Average of 2003-2010 (5.8 TWh)	300 PJ	250 km ²	9 GWé	8 GWé	4 GWé	
DEM	Low energy services demand	NO								
GRID	Flexible electricity imports	NO		Free (but max 10 GWé)						
BIO	More biomass imports	Low price High price	Endogenous: price elastic	Average of 2003-2010 (5.8 TWh)	Free (+check < GDP based)					
PV	More solar PV	Low price High price			300 PJ	Free (but < 10% of BE)				
WIND	More Wind (onshore and offshore)	NO				250 km ²	Free (but max 20 GWé)	Free		

One of the common assumptions of the RES scenarios is the share of renewable energy in intermediate periods (2030 and 2040). These are implemented exogenously. We first only had the 2050 goal of 100% renewable energy, but the investments in the last periods were too big. An important element explaining this is the discount rate that actually makes future investments less costly. This is an interesting paradox: on the one hand, the model tells us to wait as we only want to reach 100% renewables in 2050, on the other hand, we see that the outcome becomes unrealistic: the total additional investments would be (1) too high and (2) increase too fast. Nevertheless, there is a limitation on the growth of installed PV capacities as otherwise the growth would be too rapid in the last periods in the PV scenario.

In this study, the following renewable targets are fixed: 35% in 2030, 65% in 2040 and 100% in 2050. These targets are taken as a fraction of the primary energy consumption (while the European renewable targets for 2020 are defined as a fraction of the gross final energy demand). Both methodologies have their pros and cons. Typically, energy mixes of countries

are compared at the level of primary energy. When using final energy as comparison basis, energies that feed directly into the final energy demand (such as solar, wind and biomass) are valued higher than energies bearing losses in the conversion from primary to final energy (such as fossil fuels for thermal power plants).

Table 17 : Definition of the scenarios (general and technology assumptions)

Scenario name	Main characteristics	Variants	General assumptions		Technology assumptions		
			CO ₂ price	Energy price	Nuclear	CCS	Renewable target
REF	Reference scenario 2020 EU climate-energy package	NO	15€/ton in 2020 and 51€/ton in 2050	EU Roadmap Ref.	Phase out	No CCS	13% in 2020 and beyond
DOM	100% Renewable Energy by 2050; DOMestic check	NO					100% in 2050 (intermediate targets 13% in 2020, 35% in 2030 and 65% in 2040)
DEM	Low energy services demand	NO					
GRID	Flexible electricity imports	NO					
BIO	More biomass imports	Low price					
		High price					
PV	More solar PV	Low price					
		High price					
WIND	More Wind (onshore and offshore)	NO					

6.2.1. The DOM scenario

In this first 100% renewable scenario, the domestic (DOM) scenario, the only renewable energy sources that can be used in Belgium must be local (except biomass and off-shore wind). Furthermore, the energy service demand is supposed to be inelastic in the DOM scenario. So ESD remains at the same level as in the REF scenario.

Model runs show that the DOM scenario is unfeasible. This means that it is not possible to power the Belgian energy system with 100% local supply of renewable energy if the ESD cannot be reduced below the REF levels.

Even if there is no mathematical solution, this scenario is useful to assess the gap between the whole Belgian renewable energy potential and the foreseen energy demand in 2050. The gap is about a third (502 PJ or 12 Mtoe) of the average energy use of the non-domestic scenarios (1441 PJ or 34 Mtoe), based on primary energy.

6.2.2. The DEM scenario

The demand (DEM) scenario has exactly the same characteristics as the DOM scenario except that the demand is presumed to be elastic. In this scenario, the insufficient availability of local renewable energy sources raises energy prices, simultaneously lowering the energy service demand to a level that is compatible with the Belgian renewable energy potential.

6.2.3. The GRID scenario

In the GRID scenario the lack of renewable energy is compensated by an increased possibility of importing electricity from abroad. In this scenario, the level of electricity imports is unconstrained but the interconnection capacity cannot exceed 10 GW.

Because our model is limited to the Belgian energy system, it cannot give any information about the energy mix of the electricity imported from Europe as a whole.

6.2.4. The BIO scenario

The world biomass supply is assumed to vary between 160 and 270 EJ³⁰/year according to sustainability criteria (see paragraph 4.1.1). In all renewable scenarios (except the BIO scenario), the Belgian use of biomass is assumed to be proportional to the share of the Belgian population in the world population in 2050. Since the Belgian population is presumed to equal 0.14% of the world population in 2050, the Belgian energy system can use from 224 PJ to 377 PJ. The average between these two values (300 PJ) has been used in the model. It is important to notice that this 300 PJ comprises both local potential as well as imports.

In the BIO scenario, the world potential is unchanged but the share of renewable consumption is no longer based on the share of the Belgian population but on the share of the Belgian GDP in the world GDP in 2050. In the BIO scenario, the Belgian use of biomass (local production + imports) cannot exceed this GDP based translation of the world potential which is equal to 1 097 PJ.

6.2.5. The PV scenario

In all renewable energy scenarios (except the PV scenario), solar panels (both thermal and photovoltaic) are widespread on all available well oriented buildings' roofs (residential, tertiary and industrial) representing a global surface of 250 km² in Belgium. In the PV

³⁰ 1 EJ (Exajoule) equals 10³ PJ

scenario, other additional surfaces can be mobilized (parking lots, gardens, greenfields, etc.) but the maximum surface used to install solar panels has to remain lower than 10% of the Belgian territory (i.e. not more than 3 000 km²).

6.2.6. The WIND scenario

The wind resources are composed of two energy sources: onshore and offshore. In all scenarios (except the WIND scenario), the onshore potential is limited to the 9 GW that have been estimated in different regional studies, while the offshore potential equals 8 GW. The latter represents only a limited part of the Belgian offshore potential as calculated in the study of Mathys et al. (2010). In all scenarios (except the WIND scenario), a complementary 13 GW offshore capacity is supposed to be installed in maritime areas of neighbouring countries. In the WIND scenario, these limits can be exceeded by lowering the constraints related to the construction of windmills (co-visibility, etc.) or by importing more offshore electricity from the EEZ of the North Sea countries. Thus, in the WIND scenario, the onshore potential increases to 20 GW and the offshore potential is considered to be unlimited³¹.

³¹ Nevertheless, it is worth noting that the offshore capacity equals 47 GW in the WIND scenario.

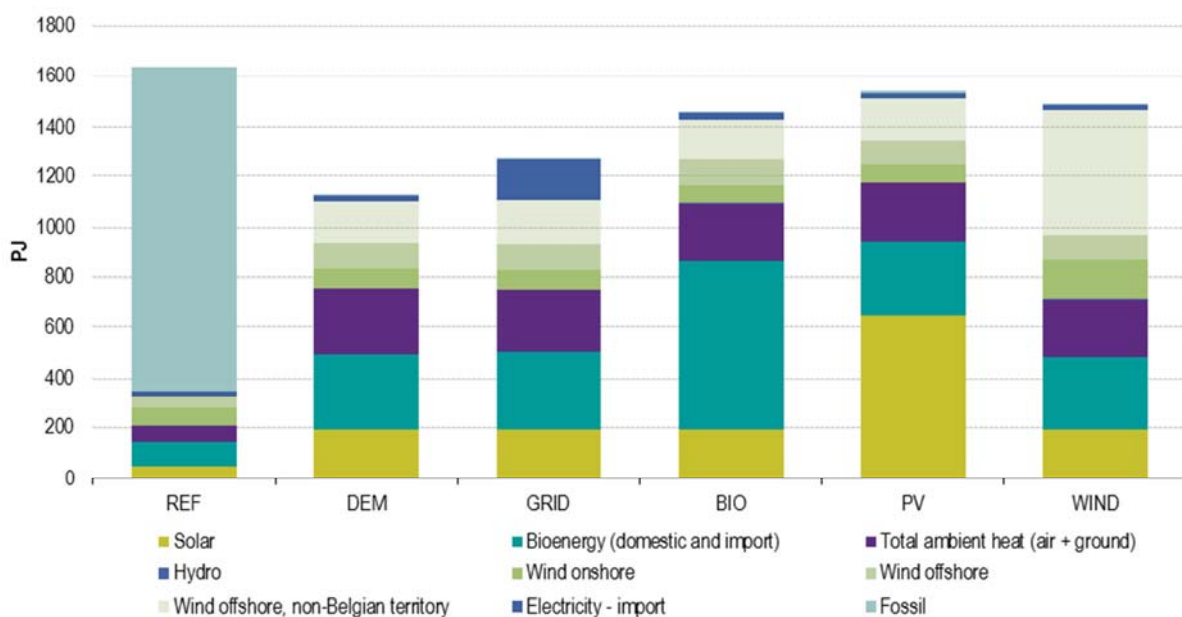
7. Impact on the Belgian energy system

This chapter describes the results in terms of energy sources and energy uses in the Belgian energy system. For this purpose, we use the five standard renewable scenarios and the reference scenario as a comparison basis.

7.1. Primary energy

In order to reach the proposed targets of renewable energy in 2030, 2040 and 2050, we see, in all renewable scenarios, a decrease over time in primary energy demand, pointing to the fact that transforming the system towards renewable energy necessitates, on the one hand, high energy efficiencies and savings, on the other, lower total amounts of primary energy since the majority of renewable energy sources have higher efficiencies (reaching 100%) than fossil fuels and nuclear energy.

Figure 9 : Primary energy demand in 2050 (PJ)



Note: Gross inland consumption as reported by Eurostat minus fuel consumption by aviation.

Source : TIMES model results

Total ambient heat (air and ground) is the combined effect of geothermal systems and heat pumps. In Figure 9 geothermal electricity is accounted in a similar way as wind and solar, i.e. at the production side (not accounting for the low efficiency levels in the conversion of these renewable technologies).

DEM and GRID are the most restricted scenarios in terms of availability of renewable energy supplies (see section 4.1). Relaxing these limitations increases the primary energy consumption as can be seen in the BIO, PV and WIND scenarios. All these results can be explained by different mechanisms that simultaneously influence the use of primary energy:

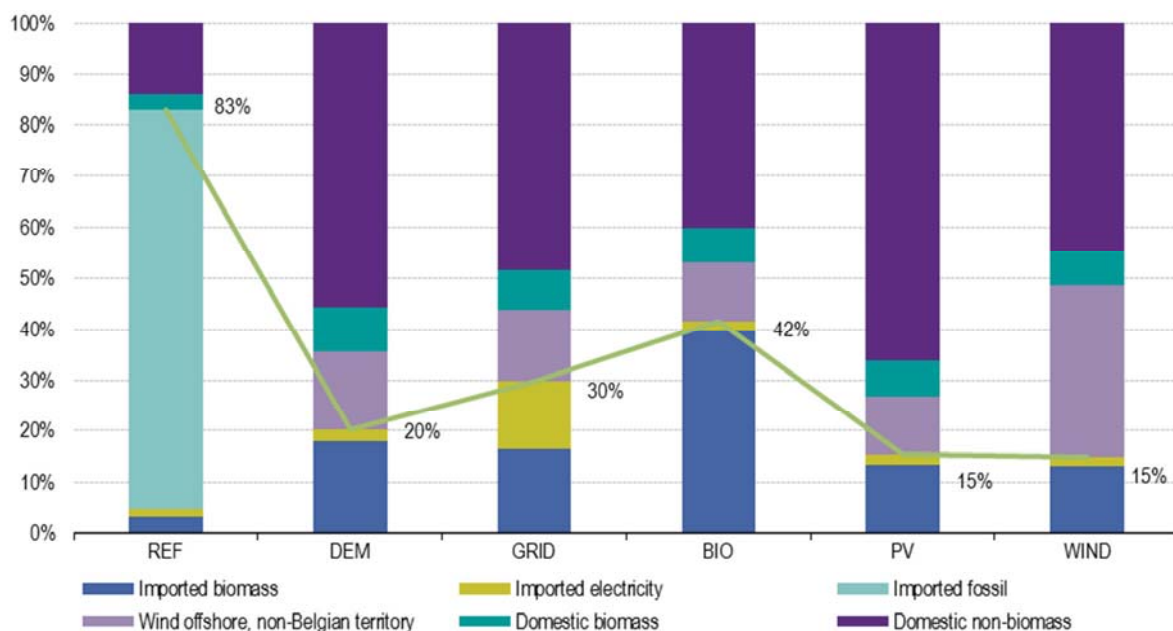
first, a decrease in energy services demand due to higher prices, with the effect in the PV scenario being somewhat higher because of the more significant price increase in energy services; second, less final energy per unit of energy service demand because of (forced) savings and energy efficiency measures; third, an increased use of primary energy per unit of final energy because of an increased use of biomass (in the BIO scenario with an efficiency lower than 100%) in electricity production, excess production of electricity in PV (in the PV scenario), losses in the conversion of energy via for example hydrogen and storage losses.

Only with a few exceptions, renewable technologies are always installed up to their full potential unless they were unconstrained. Hence, part of the model outcome is basically determined by assumptions (input) on RES potential. Exceptions are scenarios using very low prices for the unlimited sources (unlimited biomass at low price and very low price for solar in the PV scenario). This would mean that if the potentials could be increased, these technologies would also be used more intensively. Consequently, none of the scenarios is optimal in terms of providing the optimal energy mix, although it is worthwhile mentioning that the WIND scenario almost achieves an optimal mix between wind and solar.

7.2. Import dependence

Energy imports continue to take up a notable share in primary energy as biomass and electricity imports are still needed. However, this share decreases strongly from 83% in the REF scenario to between 15% and 42% in the renewable scenarios.

Figure 10 : Import indicator (share of imports in primary energy consumption), 2050



Source: TIMES model results

Note: 100PJ is assumed for the domestic biomass in 2050, except in REF (50 PJ).

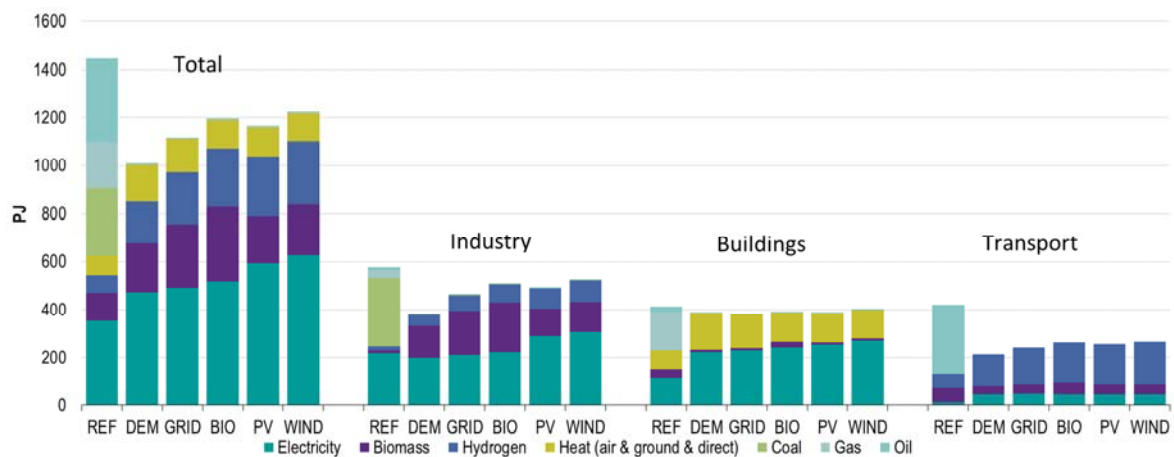
Note: The import indicator gives the share of imports in primary energy consumption.

Note that in all the scenarios, an amount of offshore wind is not accounted for as imports because although these wind mills are supposed to be installed outside the Belgian territorial waters, their costs are taken into account as if they were in Belgian waters. If this would be considered as imports, then the import indicator would be between 28% and 53% depending on the scenario.

7.3. Final energy

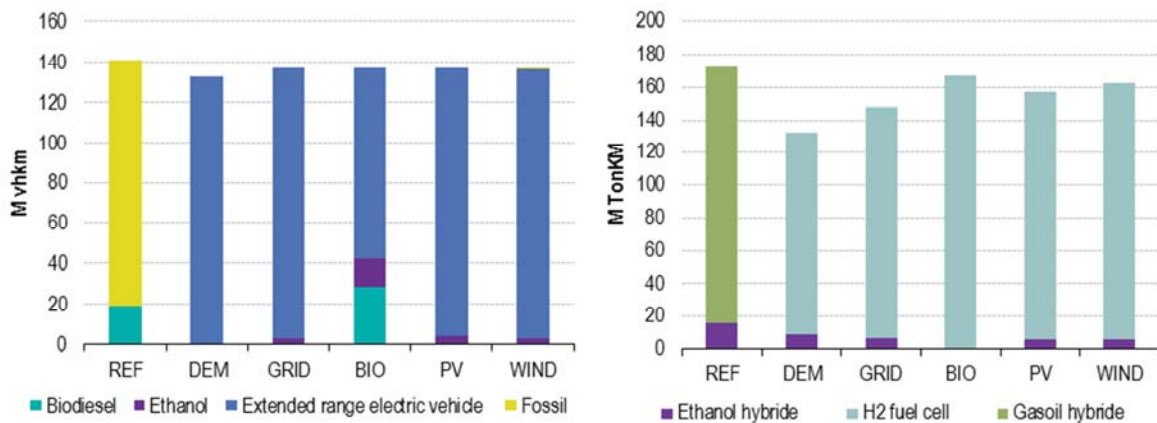
Final energy consumption is 15% to 30% lower in the renewable scenarios compared to the reference scenario. This is explained by higher energy efficiencies and the reduction in the energy services (most outspoken in the DEM scenario). The highest reductions can be seen in the transport sector (a 36% to 49% decrease depending on the scenario). This is mainly explained by the higher energy efficiency of the transport technologies in the renewable scenarios (Figure 12, left for passenger transport and right for freight transport). For instance extended range electric vehicles consume 75% electricity and 25% ethanol and achieve an energy efficiency which is almost three times higher than a traditional combustion engine. The energy service levels for freight transport have only a marginal impact. The lowest reductions are in the building sector (residential and tertiary). This is due to stringent legislation and energy efficiency measures implemented compulsorily in the reference scenario.

Figure 11 : Final energy demand (PJ)



Source: TIMES model results

Figure 12: Technology choices in road transport, passenger transport (left – MvhKm) and freight transport (right – MtonKm)



Source: TIMES model results

7.4. Electricity generation

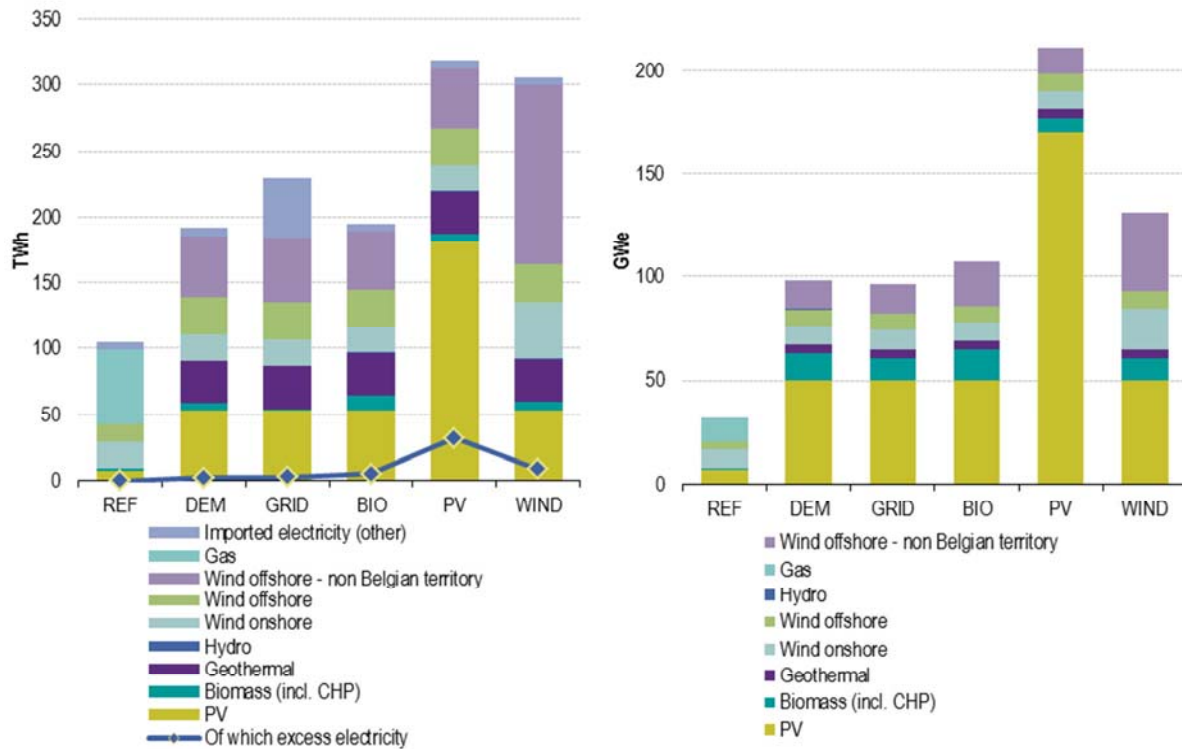
Turning to the electricity sector, an important result is that all renewable scenarios, given the 35% renewable share in primary energy demand in 2030, show an important RES penetration in power production as from an early stage of the projection period. Different studies (European Commission, 2011a and b) confirm that the power sector is, of all sectors, particularly fit for a quick and swift decarbonisation. This decarbonisation is triggered by the combination of different low carbon technologies, but given that Belgium faces a nuclear phase-out and that investments in CCS equipped fossil fuel power plants are not allowed, only renewables can do the trick. We also observe that in this welfare optimizing setting with perfect foresight, a 96% renewable share in electricity generation is reached in 2030 already, to evolve afterwards into a fully renewable electric power park by the year 2050 (Figure 14). In the figure, the model results are compared with the official targets in both Belgium and Germany.

It is important to notice that the operation of the power units is not fixed in advance: capacity activity relation is a model result. Excess electricity is “low” compared to total production. It would be much higher if there would be less flexibility at the level of electricity consuming processes like iron production.

On top of that, electricity production increases significantly in all scenarios. This increase is particularly outspoken when supply of biomass is limited (as in PV and WIND). Restricted access to this renewable option urges society to rapidly transform into a fully electrified civilization. Some similarities between the renewable scenarios are that they use up to the full potential of geothermal and hydro while the use of biomass is limited, even in the BIO scenario. The production is lower in the DEM and in the BIO scenario. In the DEM scenario, this is explained by the reduction in the energy services. In the BIO scenario, hydrogen

production for the industry and the electricity demand for the transport sector are lower. With the exception of the PV scenario, excess electricity production (curtailment) is limited.

Figure 13 : Electricity generation (left - TWh) and power capacities (right - GWe) in 2050

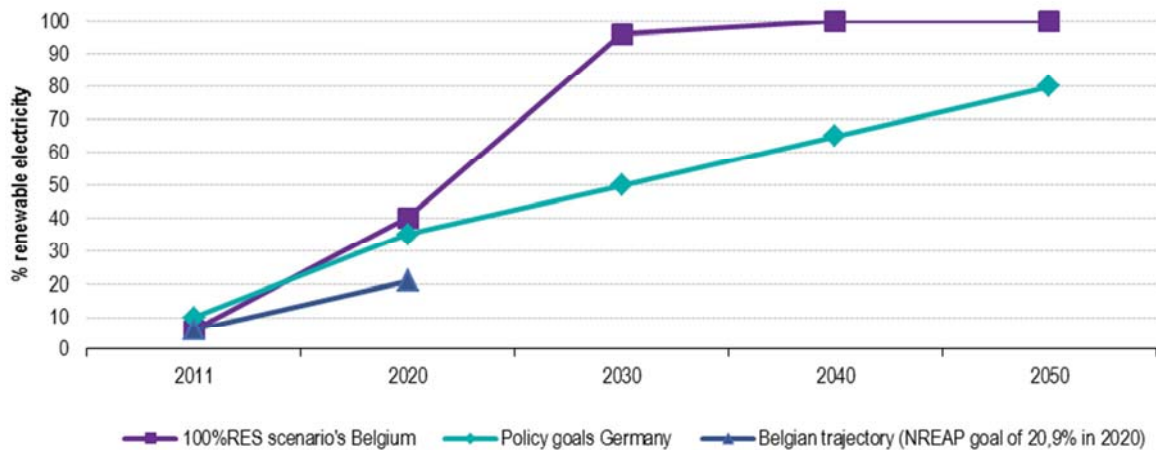


Source: TIMES model results

Figure 13 also depicts the power generation capacities. The particularly high corresponding capacities for solar can be explained by the low availability levels for this type of energy. It also shows that, from a cost-optimal point of view, it pays off to invest in PV overcapacity (the total power capacity in 2050 in the PV scenario is more than five times higher than in REF). This overcapacity replaces investments in highly expensive and relatively little efficient seasonal storage. On the other hand, short-term storage in the form of pumped storage or batteries is indispensable in this kind of setting.

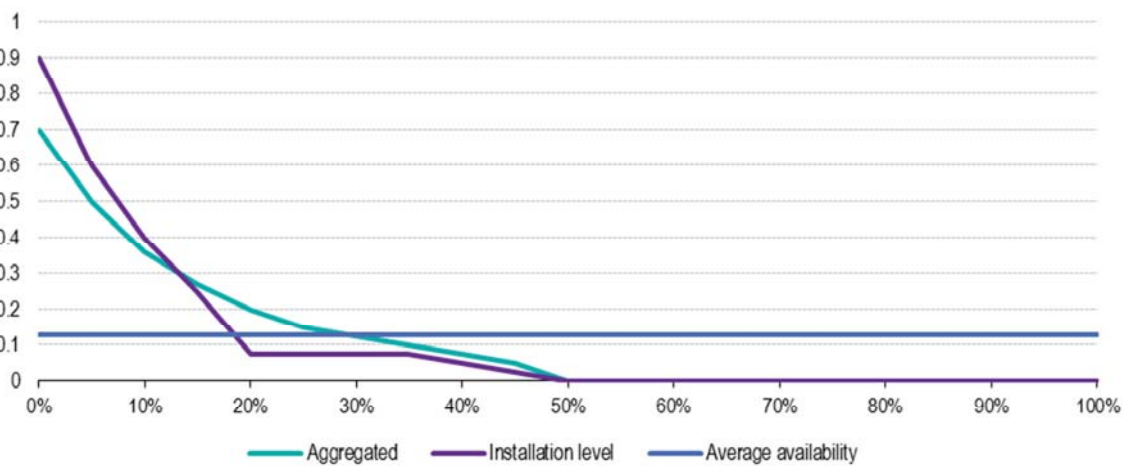
High capacities of PV panels are installed, mainly in the PV scenario, raising the question of how this energy can be absorbed by the energy system. First, we include an aggregated profile for the available PV panels in the model. At installation level, high efficiencies can be attained under optimal conditions like clear sky, good temperature, good orientation etc.

Figure 14 : Share of renewables in electricity production, evolution 2011-2050



We assumed a maximum aggregated efficiency of 67% and a distribution as presented in Figure 15. This efficiency is lower than the efficiency of a single PV system because Belgium can be partly covered by clouds and some advantages are connected to having the PV panels oriented in different directions. The average availability is always met and amounts to approximately 12%, similar to a level of 1050 full load hours. As a result, the distribution of electricity production of the Belgian average is less peaked.

Figure 15 : Electricity production distribution from PV (percentage of maximum capacity)



Note: The horizontal axis represents time (8760 hours) and the vertical axis load (percentage of maximum capacity)

Because of these assumptions, the 181 GWe becomes an actual maximum of 121 GWe (67%). There is massive curtailment beginning from around 70 GWe. The electricity curtailed adds up to roughly 11% of total possible production by PV panels.

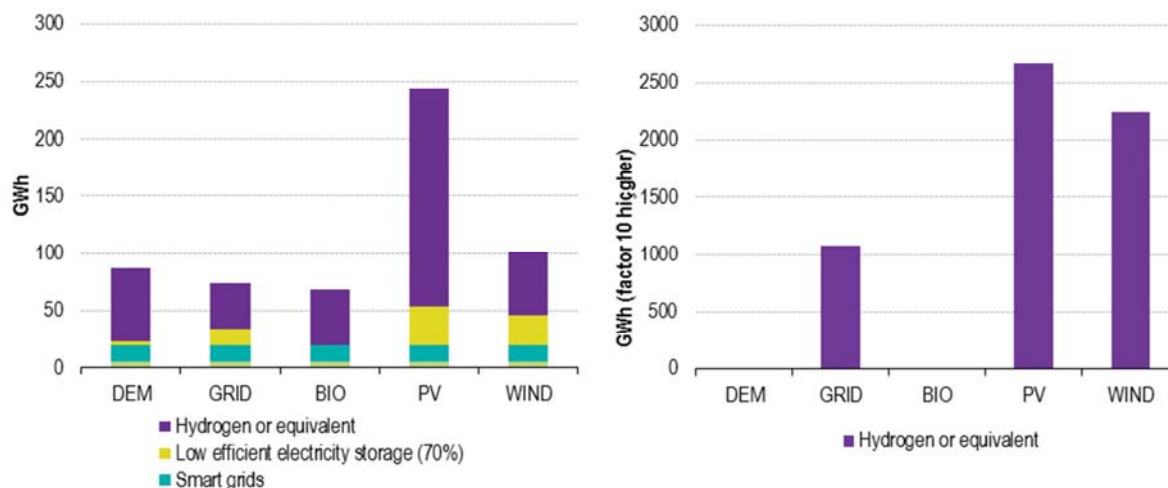
Looking to one time slice (a sunny day), the model chooses to convert electricity in hydrogen at a rate of some 35 GWe. During the day, there is an intake of produced hydrogen of some 15 GW into a day/night storage process as well as a consumption of hydrogen (some 5 GW). Both during day and night, there is intake of hydrogen at a rate of some 4 GW into a seasonal

hydrogen storage process. During the night, the hydrogen from the day/night storage process is feeding the steel production, the transportation sector as well as the seasonal hydrogen storage process.

7.5. Storage requirements

Basically, technologies to store both electricity and hydrogen for averaging out day/night fluctuations and technologies to store hydrogen for seasonal fluctuations are chosen. For electricity, a combination of pump storage, smart grids and low efficiency batteries (70%) is cost-optimal. When hydrogen is included, the total amount of day/night storage capacity fluctuates between 70 (in the BIO scenario) and 250 GWh (in the PV scenario). The assumptions for these technologies are described in section 4.4.2.

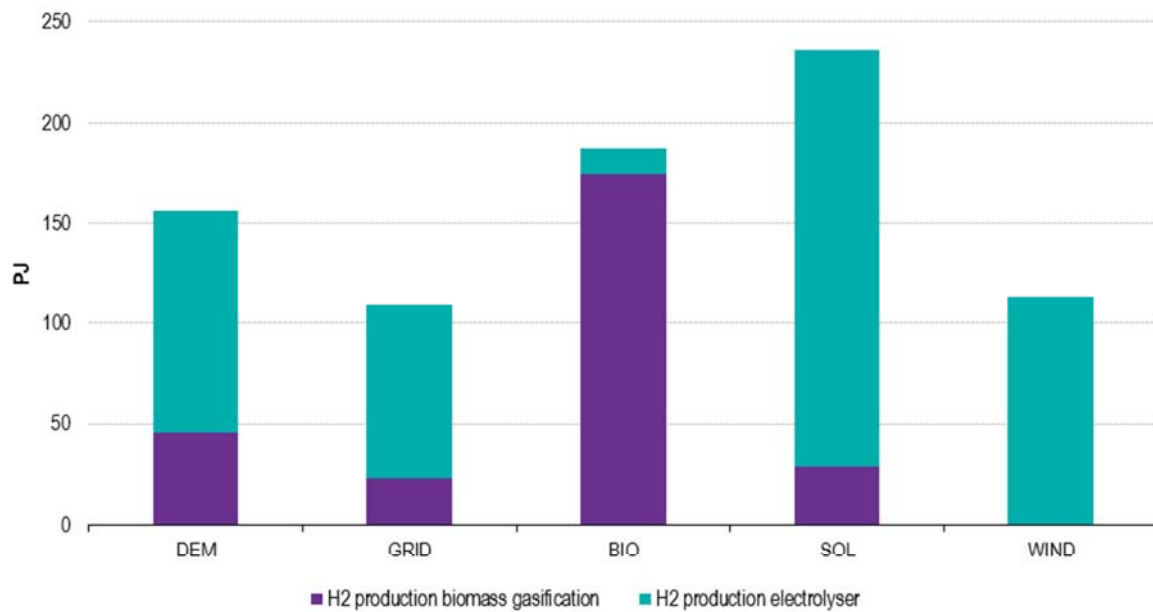
Figure 16 : Electricity and hydrogen storage for day-night (left – GWh) and seasonal (right – GWh) fluctuations



Source: TIMES model results

For the longer term, a significant amount of hydrogen is used as a storage medium. The seasonal hydrogen storage (or equivalent) has a storage capacity of more than 2500 GWh hydrogen (9 PJ) in the PV_LO scenario. Assuming a 2.2 GJ/m³ hydrogen density (200 bar), 4 × 10⁶ m³ would be needed. Taking an arbitrary height of 4 meter, we would need 1 km². The storage amount is dependent on the assumption of solar and wind availabilities.

We prefer to speak about hydrogen or equivalent. Some long term storage is needed for some scenarios in the model to bridge the remaining long term cycle of PV (summer/winter). Whether this can be done with hydrogen or electricity-to-gas or new battery types does not really matter. Hydrogen is never converted back to electricity in the model. Hydrogen is produced from biomass gasification or from electricity. Depending on the scenario, a different mix of both technologies is used (see Figure 17).

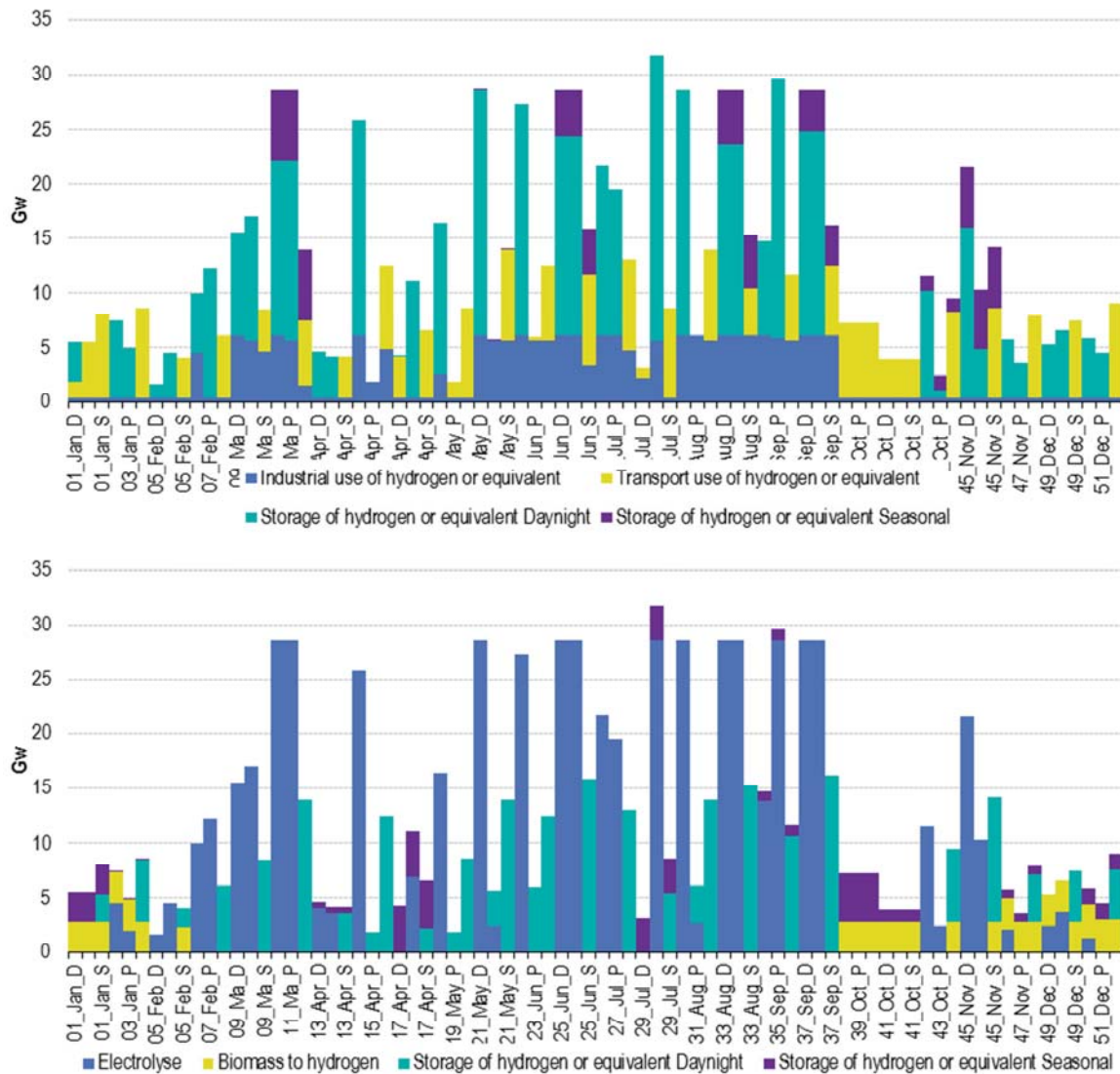
Figure 17 : Hydrogen production technologies (annual production), all scenarios, year 2050 (PJ)

Source: TIMES model results

The model results can only be understood by looking at results with more time details. Figure 18 below shows the flows of hydrogen in the PV scenario in 2050 for the 78 time slices in the model.

The upper part represents hydrogen consumption (or equivalent) and the lower part hydrogen production/origin. The pattern of industrial hydrogen use is evident from February until October, as well as the importance of a high-power day/night storage device. This figure shows the strength of the model to optimise over the 78 periods in one year.

Figure 18 : Example of hydrogen routes for 2050 in the PV scenario. The upper part represents hydrogen consumption, the lower part the origin of hydrogen (Gw)

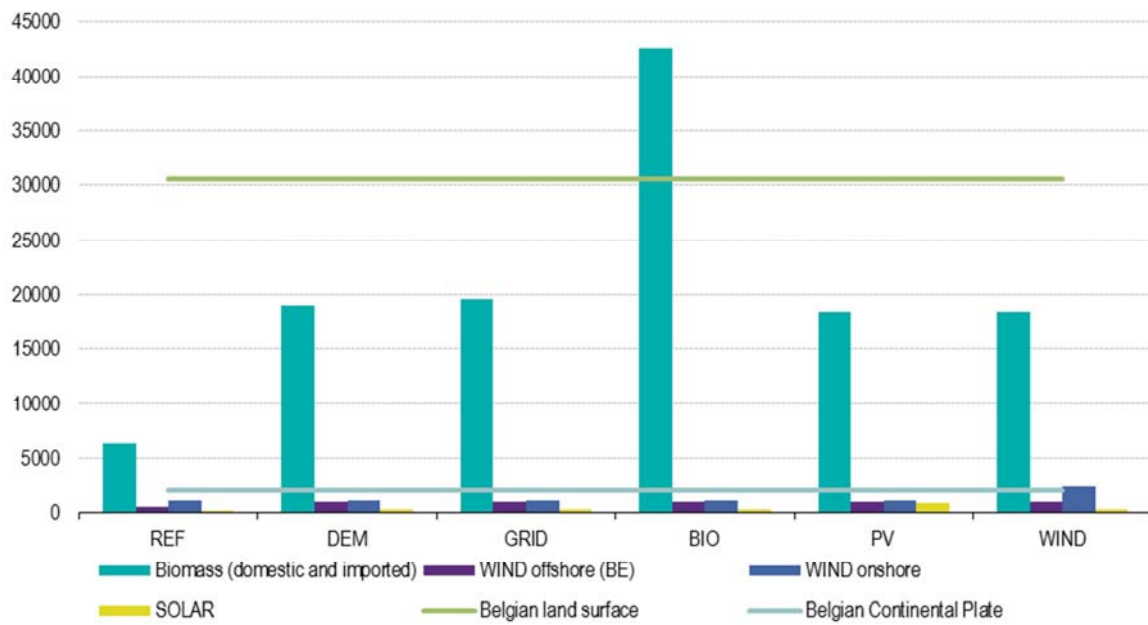


Source: TIMES model results

7.6. Space requirements

The installed solar PV capacity necessary to power the entire energy system in the PV scenario shows a steep increase with average annual growth rates of 11% over the period 2020-2050. Although these growth rates presume an aspiring, proactive and consistent renewable solar policy, the figures are not completely unrealistic. Translated into physical terms, they can be interpreted as necessitating approximately 600 km² to be covered by PV panels. Given that the Belgian surface amounts to 30 528 km², this means that even this highly ambitious result may be feasible given proper initiative and will ‘only’ occupy around 2% of the total surface.

Figure 19 : Space requirements for renewables (km²)



Source: TIMES model results

8. Socio-economic impact analysis

A transformation towards a fully renewable system does not solely impact the energy system in terms of levels of energy consumed or the structure of energy provided; it also has an undeniable influence on the society as a whole through diverse socio-economic impacts like prices, costs, investments and employment. In the analysis that follows, several of those impacts are scrutinised using a dual methodology, on the one side the analysis of results coming directly from the quantitative study described in part 7, on the other an extensive literature review of both national and international studies. Three variables are described based on TIMES' results, being the electricity prices, the external fuel bill and investments, whilst the employment effects are dissected by means of an ex post analytical instrument.

8.1. Introduction

It is often assumed that transforming the current system towards a less carbon obese configuration comes at a significant monetary cost. However, an increasing number of studies are finding precisely the opposite is true in the case of renewable energy: greater use of renewable energy generates (economic) benefits through investments in research and innovation and job creation but also through avoided greenhouse gas emissions, reduced local pollution and numerous beneficial health effects. At the same time protecting the economy against political and economic risks and costs associated with overdependence on a too limited choice of energy sources and fuels and a sizeable money drain towards geopolitically unstable regions. In the following paragraphs, the analysis of these different impacts is described in more detail.

8.2. Impact on electricity prices

This paragraph describes the changes that the electricity price³² is likely to encounter when shifting to an all renewable system. These changes are calculated using the TIMES model and are given with respect to the expected price evolution of the reference scenario.

Looking at Table 18, we notice that the electricity price already in the reference scenario mounts up to 139 €/MWh in 2050. The biggest jump seems to take place between 2020 and 2030 (rise of 29%), followed by a 14% increase between 2030 and 2050. The big jump between 2020 and 2030 is primarily due to the fact that extra capacity has to be installed (owing to an ever increasing electricity demand³³ and the introduction of the RES target in 2020) whilst at

³² It is important to keep in mind that electricity prices in TIMES are in fact the shadow prices of the electricity balance constraint and do not necessarily coincide with the marginal cost of producing electricity. Shadow prices then capture the choice between two system options: either the system chooses to produce one more unit of electricity (at a certain price), or the system consumes one unit less of electricity (by choosing e.g. more efficient end-use devices or by reducing an electricity-intensive energy service). This also comes at a price, which can be interpreted as a price for one unit of demand lost, or the price that is necessary to reach a similar reduction in demand.

³³ The average annual growth rate of electricity demand amounts to 0.8% between 2020 and 2030.

the same time, 'cheap' nuclear energy³⁴ is being phased out. The installed capacity then increases by 26%, of which a large part is being taken up by the bringing into service of numerous gas fired power plants (an extra 7 GW over the considered period) covering several needs: replace nuclear, back up renewables and answer to a growing demand of electricity.

The renewable scenarios, then, deviate from this reference, not only in the price level achieved in 2050, but also and foremost in the evolution of the electricity price. While all renewable scenarios seem to be able to restrain electricity prices beneath the level recorded in the reference scenario until 2040, we see that after 2040, the price of electricity in the renewable scenarios starts to surpass (largely) the reference scenario price. One exception is made in the WIND scenario: its 2050 electricity price is 19% lower than the reference price. (Part of) the explanation has to be sought in the fact that offshore wind becomes a relatively cheap source of electricity production with a rather low system cost of power generation. The WIND scenario in fact presents a combination of different capital intensive technologies, but due to the fact that the discount rate is fixed at 4% (see part 5.6), these technologies soon become competitive³⁵. On top of that, the electricity production in the year 2050 in WIND equals three times the 2050 level of the reference scenario (300 TWh compared to 99 TWh respectively). So when prices are expressed in relative terms, WIND prices are disseminated over more MWh, hence creating a volume effect that depresses relative prices.

The BIO scenario can be seen as keeping its 2050 price rather close to the one listed in the reference scenario (difference of +9%) but the other scenarios show steep increases in the power price during the last (two) decade(s) (e.g. a doubling in GRID³⁶, a tripling in DEM³⁷), leading to moderate to very high price differences with respect to the reference in 2050. These price differences with respect to the reference scenario are caused by the fact that costs for the high generation capacity needs³⁸ (including those necessary for back-up) and for far more significant grid and storage capacities³⁹ have to be recovered through pricing.

³⁴ The production cost of electricity generated by nuclear power plants to cover the base load is lower than that produced by any other type of power plant. This is due to the fact that nuclear power plants in Belgium are completely written off, hence forego annuity payments.

³⁵ The concept of "price" then is extremely sensitive to this discount rate parameter. Assuming a higher discount rate more in line with actual economic agents' preferences (amounting to an actual cost of capital of around 7 to 8%) would alter prices significantly.

³⁶ The price in GRID is exogenously determined in such a way that the 2050 price equals half the price in DEM.

³⁷ The DEM scenario in fact reflects the second model option demand (see footnote 32), namely the option that the system consumes one unit less of electricity (by choosing e.g. more efficient end-use devices or by reducing an electricity-intensive energy service). This also has a price, which can be interpreted as a price for one unit of demand lost, or the price that is necessary to reach a similar reduction in demand.

³⁸ Installed capacity increases by 55% in the reference scenario in the period 2020-2050, whereas the renewable scenarios note growth rates between 233 and 541% for the same period. The biggest capacity rise is registered in the PV scenario.

³⁹ Grid expansion and storage investments are between 43 and 70 billion € higher than in the reference scenario. The additional 43 billion € corresponds to the DEM and BIO scenarios, the 70 billion € to the PV scenario.

Table 18 : Electricity prices, all scenarios, evolution 2020-2050 (€/05/MWh)

	2020	2030	2050	30/20	50/30	30//20	50//30
REF	94.3	121.7	139.0	29%	14%	2.6	0.7
DEM	93.2	103.2	358.3	11%	247%	1.0	6.4
GRID	93.6	93.8	181.0	0%	93%	0.0	3.3
BIO	92.8	101.4	150.9	9%	49%	0.9	2.0
PV	88.5	99.0	160.2	12%	62%	1.1	2.4
WIND	87.7	98.1	112.6	12%	15%	1.1	0.7

Source: TIMES model results.

Note: y/x stands for increase between x and y, $y//x$ stands for average annual increase between x and y.

This finding is confirmed in both the Energy Roadmap 2050 (European Commission, 2011) and the Roadmap 2050 (European Climate Foundation, 2010). The former shows that, amongst the entire set of decarbonisation trajectories, the High RES scenario in 2050 records the highest average electricity prices, to be situated around 30% above the 2050 reference level. The latter examines several decarbonisation scenarios for the power sector, one of those trajectories being a 100% RES pathway for the EU. The levelised cost of electricity in this scenario appears to be between 15 and 50% above the 2050 reference case.

8.3. Impact on external fuel bill

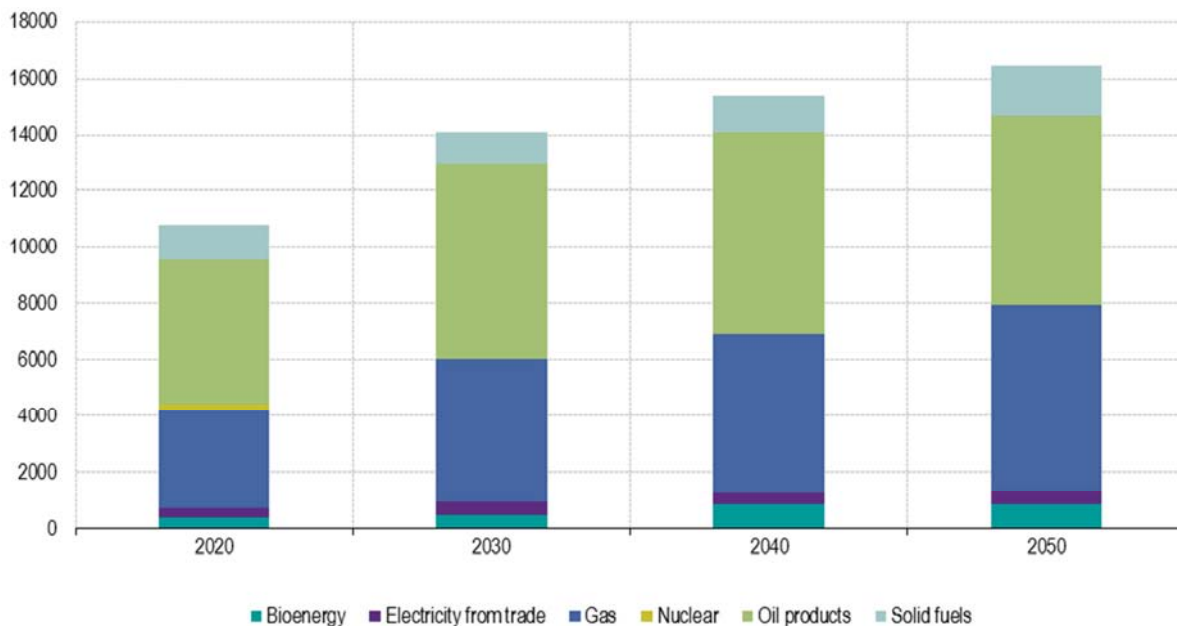
Next to electricity price differences, another likely influence may be seen on the nation's energy bill. Since Belgium is a country poorly endowed with natural resources i.e. fossil fuels, it is bound to import all what is consumed in terms of fossil fuels, e.g. the petrol used to drive our cars, the natural gas used to heat our homes and the coal used to fuel the iron and steel sector. Since all of this has to be imported, mostly from countries with a rather unstable geopolitical background, we are exposed to a lot of risks in terms of economic vulnerability and resource dependence. On top of that, a lot of money is draining out of our society. Hence, if we are able to curtail and ultimately completely eliminate the current massive fossil fuel import volumes, this may prove beneficial to the nation's financial and economic situation.

This phasing out of all fossil (and nuclear) fuels used on Belgian territory goes hand in hand with a growing deployment of renewable energy sources. Nonetheless, all the renewable trajectories (and some to a great extent) are still based upon imports, not of fossils or fissiles anymore, but of biomass and electricity. This exercise then adds up the pluses and minuses and presents the total gain (or loss) on the nation's energy bill. This gain results from the progressive decrease of fossil fuel imports up to 2050 (year in which they have to equal zero), corrected, if necessary, by an increase in electricity and biomass' imports. This estimation is made based on the TIMES results.

As shown in Figure 20, the reference scenario depicts an ever increasing amount of imports in monetary terms. In 2050, energy import costs are 53% higher than noted in 2020. Next to the increase in costs, also a change in structure of the costs can be observed. Whereas in 2020,

a bit less than half of the import costs are represented by the purchase of petroleum products, in 2050 we see a more balanced division between oil and natural gas (both around 40%) with oil being principally used in the transport sector and natural gas in both power generation and buildings' heating. Biomass share in import costs in the reference scenario is (and remains) rather marginal: 4% in 2020, 5% in 2050. In the same period, solid fuels which sole use is in the iron and steel sector, tend to stabilise: their market share is kept constant at 11%.

Figure 20 : Total energy import costs, Reference scenario, evolution 2020-2050 (M€2005)



Source: TIMES model results.

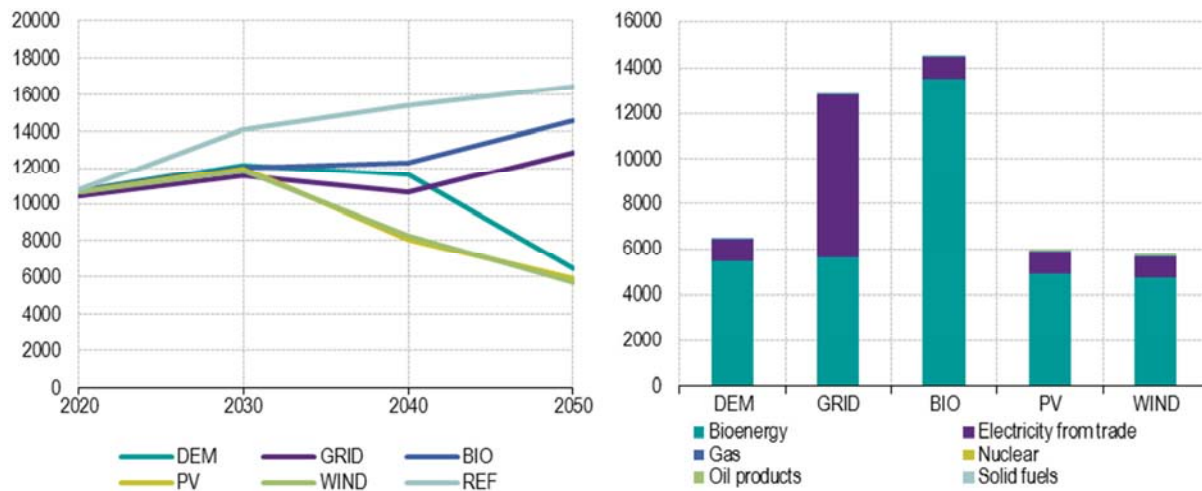
What we then observe in the renewable scenarios (see Figure 21), is that:

1. throughout the entire projection period, all renewable scenarios have lower energy import costs than the reference scenario. In 2050, energy import costs are between 12% (BIO) and 65% (WIND) lower than in the reference scenario;
2. energy import costs in the renewable scenarios in 2050 are lower than in 2020. Only exceptions are the GRID and BIO scenarios: in the GRID scenario, import costs reach a level that is 23% higher than noted in 2020, in BIO, this percentage amounts to 36%. All other scenarios see their import costs dwindle (considerably) compared to 2020;
3. the shares of biomass and electricity in the total import costs rise considerably: whereas they stand at around 9% in 2020, they increase gradually to ultimately strand at (close to) 100% in 2050.

All in all, we can safely state that a turnaround of the traditional fossil fuel based energy system into a 100% renewable energy configuration will present a gain on the nation's trade balance in terms of energy imports, and this even in the BIO and GRID scenarios in which

the purchase of large amounts of imported biomass and electricity is more than compensated by the significant decrease in fossil fuel import costs. This gain observed in all renewable trajectories can be situated between 2 and 11 billion euro in the year 2050 (or between 0.3% and 1.6% of Belgian GDP in 2050), but in fact represents a yearly amount of money that may be saved/spent/recycled in the national economy.

Figure 21 : Total energy import costs, all scenarios, evolution 2020-2050 (left) and year 2050 (right) (M€2005)



Source: TIMES model results.

Next to external fuel bill effects, there may also be trade balance consequences in terms of product investments. For a renewable scenario pathway, it is clear that a lot of investment goods essential to the transformation towards a 100% renewable configuration have to be imported. Belgium has a wind turbine (component) manufacturing sector (e.g. Turbowinds, Xant, Hansen Transmissions, Cockerill Forges and Ringmill) and a solar cell producer (e.g. Photovoltech⁴⁰), but the major players nowadays are located abroad (China, India, Germany, ...), leading to the fact that a significant share of these goods will have to be imported, e.g. wind turbines mainly from Denmark, the United States, Spain, Germany, China and India, photovoltaic cells principally from China, Germany, Japan, Taiwan and the United States⁴¹. Inevitably, this will result in multiple effects in terms of foreign investments, employment, logistics, etc. Due to the fact that these effects cannot be taken up in a (partial equilibrium) energy model⁴², the estimation of this kind of general impacts falls out of the scope of this analysis.

⁴⁰ On September 14, 2012, Photovoltech announced to have halted its production activities.

⁴¹ Source: SERV, *Rapport Hernieuwbare Energie*, Full report, 6 april 2011.

⁴² Partly explained by the fact that these effects are not constrained to the sole energy or renewable sector, also the raw materials' and intermediate supply sectors like e.g. steel are affected. As such, there might be an upward pressure on steel prices due to a massive demand of wind turbines in the WIND scenario, which could in turn cause various and diverse effects on multiple other sectors.

8.4. Impact on investments

This section represents the estimation of the investment costs necessary to reach the 100% RES target in 2050. It both concerns investments in energy production and consumption technologies as well as investments in infrastructure. This estimation is made based on the TIMES results.

Looking at Table 19, depicting the total costs in the year 2050 for the entire energy system subdivided in its different components and expressed as additional costs relative to the reference scenario, we see that the investment costs constitute the major part of the total energy system cost. Investment costs represent in fact the amount of money necessary to finance a project. This investment can be financed on equity (own funds) or through loans from national or international financing agencies. The difference between the former and the latter is that when financing upfront through equity, a “lump sum” is paid one time equalling the monetary amount of the investment as mentioned on the price tag. When borrowing, you not only pay your lump sum (in monthly instalments), you also have to pay the price for the borrowed money i.e. interest payments. The sum of the monthly part of the investment and the interest payment is called the annuity. Summing up all annuities does not amount to the lump sum as capital has a price.

Investment costs comprise a.o. necessary investments in the electricity grid and demand side investments but do not include e.g. battery costs for electric vehicles⁴³. The scenario demonstrating the highest investment costs is undeniably the PV scenario, although the WIND and DEM scenarios also display high upfront investment costs. Lowest investment costs are registered in the BIO scenario. This can be explained by the fact that the BIO scenario may be seen as maintaining more or less the current energy system paradigm but replacing fossil fuels by other, renewable energy sources amongst which non-intermittent biomass plays the first fiddle (in terms of primary energy, that is). By contrast, the PV and WIND scenarios completely abolish the actual energy configuration and substitute it by a totally new way of thinking on energy and energy equilibria.

Table 19 : Total additional (wrt REF) energy system costs, year 2050 (Annual M€2005)

	<i>DEM</i>	<i>GRID</i>	<i>BIO</i>	<i>PV</i>	<i>WIND</i>
Variable O&M	-75	-452	257	-160	-415
Import costs, transmission and distribution costs	-12204	-5876	-3961	-12675	-12878
Fixed O&M	6020	5953	6231	6442	7801
Investment costs	17660	14269	13523	19617	18634
Total additional energy system cost	11401	13893	16050	13225	13142

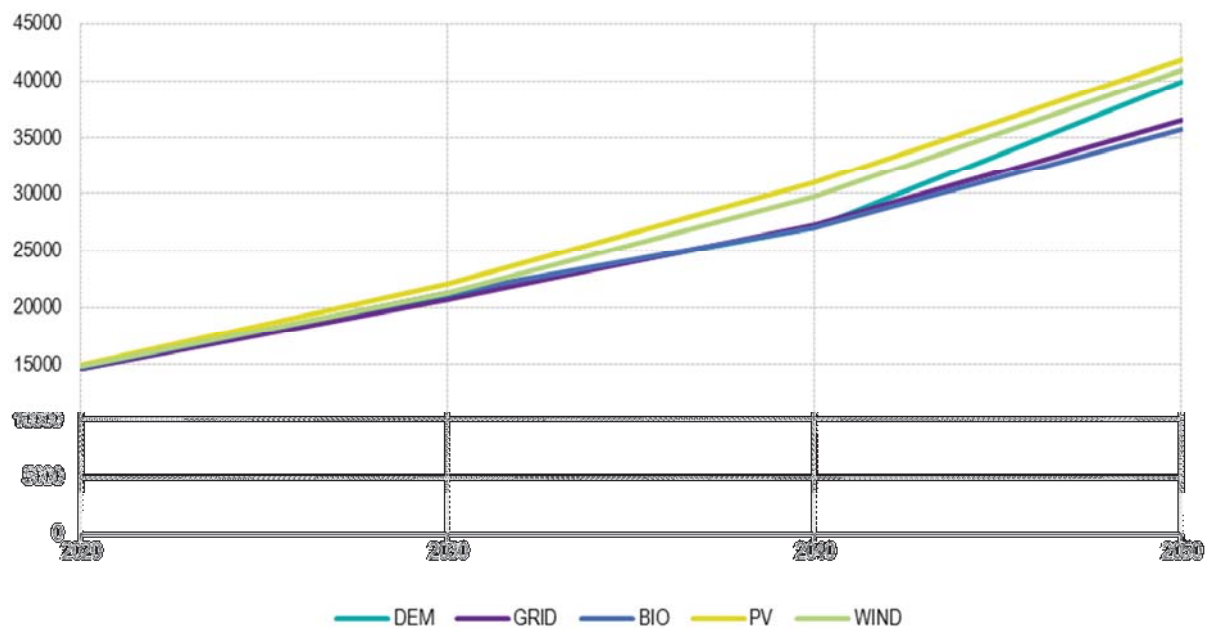
Source: TIMES model results.

Note: O&M stands for Operation and Maintenance.

⁴³ These are reflected in the Fixed O&M category.

Next to year 2050 investment costs, it is also instructive to look at the evolution in required investments during the horizon of time. In Figure 22, yearly investment costs are shown for the period 2020-2050. One distinct result is that the lion's share of yearly investments seems to take place at the end of the period, during the last decade (2040-2050). This may seem counterintuitive at first since a uniform social discount rate of 4% is used (see 5.6), leading to relatively more evenly spread investments over time (due to less risk averseness of the different economic agents). However, one has to bear in mind that technical lifetimes of a number of capital investments within the energy system only last for around 20 to 30 years on average, leading to necessary replacements of a number of investments undertaken in the first decennium causing and adding to the high upfront costs in the period 2040-2050.

Figure 22 : Annual investment costs, all scenarios, evolution 2020-2050 (M€2005)



Source: TIMES model results.

Note: The representation of the years between the decades is a linear interpolation and does not necessarily coincide with the exact form of the investment cost curve.

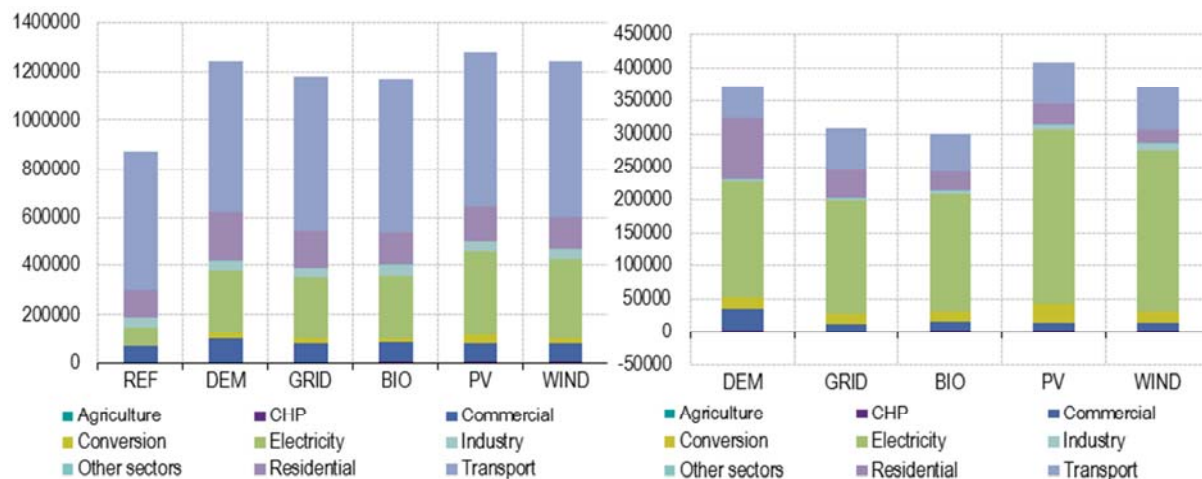
Now that the aggregated investment cost curves are known, it is also possible to further dissect into needed sectoral investments. For this purpose, nine 'sectors' are identified, being transport, residential, industry, electricity, conversion⁴⁴, commercial, CHP, agriculture and other sectors.

The biggest investments, both in the reference scenario as in the renewable scenarios, have to be made in the transport system. Investments needed include mainly material assets amongst which the alternatively propelled (including hydrogen) transport means. Next to investments in the transport sector, power generation investments are the largest and eat up around a quarter of all investments to be made in the energy system for the 100% renewable energy future. Above that, power generation investments are what differs the most from investments to be made in the reference case, leading to the fact that this sector takes up the

⁴⁴ In Eurostat terminology, the sector 'conversion' corresponds to 'other transformation sectors'.

giant chunk of the additional investments (with respect to the reference scenario, see right hand side of Figure 23). These power sector investments can be further subdivided into different cost components like storage, grid expansion, solar investments, etc. The composition of these elements can be found in Figure 24.

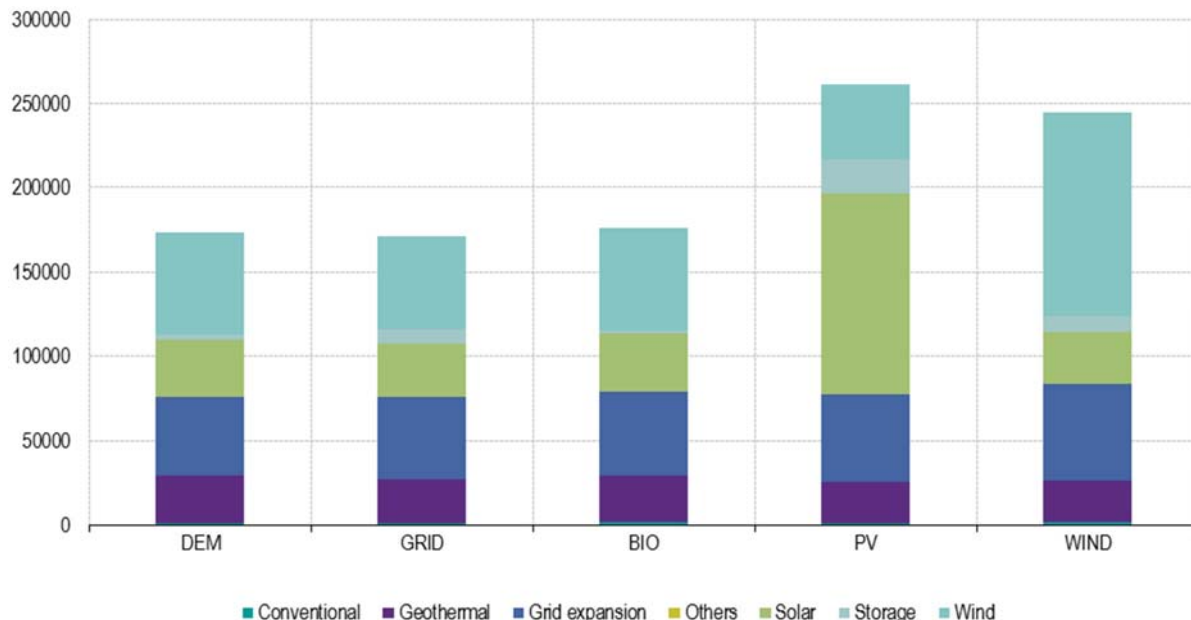
Figure 23 : Total cumulative (left) and cumulative additional (wrt REF) (right) investment expenditures, all scenarios, period 2013-2050 (M€2005)



Source: TIMES model results.

Note: Conversion stands for other transformation sectors.

Figure 24 : Cumulative additional (wrt REF) investment expenditures in the electricity sector, all scenarios, period 2013-2050 (M€2005)



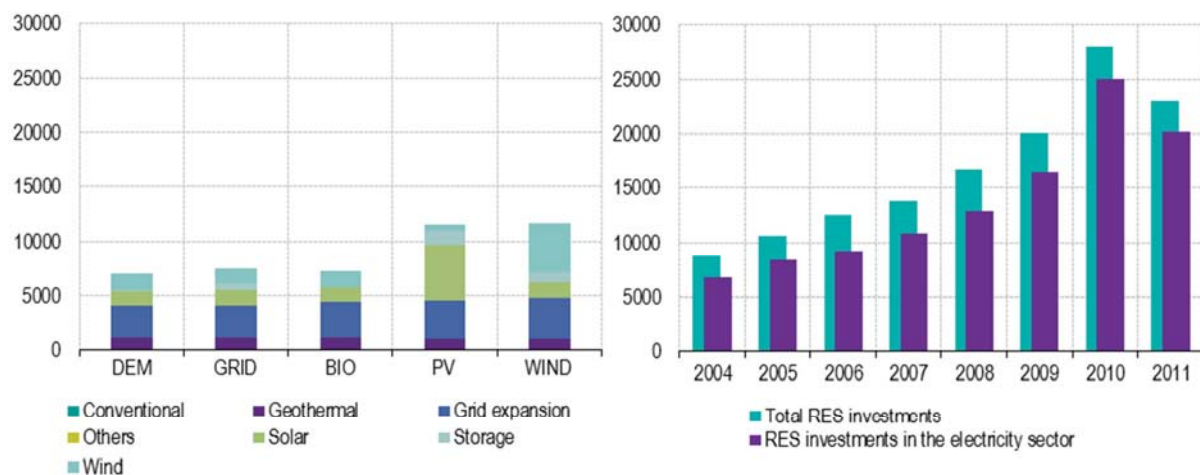
Source: TIMES model results.

Note: The cost for the grid connection of wind turbines falls under 'Wind'.

Figure 24 illustrates that in the period 2013-2050 the PV and WIND scenarios necessitate the largest future investments in the power generation sector.

A similar graph can be constructed for one single year, more specifically, the year 2050. This is what is illustrated on the left hand side of Figure 25, it depicts for all scenarios the height of necessary power sector investments as well as the composition of the investments. For comparison sake and especially to have a benchmark in mind concerning the order of magnitude of the proposed investments, we include the right hand side of the graph. This figure depicts recent statistics (2004-2011) of investments in renewable energy sources in Germany, as well as the part of these investments that is uptaken by the German electricity sector. Expressed in terms of (future) GDP, this boils down to around 1% of German GDP in 2010 and 2011 and between 1.0% (DEM scenario) and 1.7% (PV and WIND) of Belgian GDP in 2050.

Figure 25 :Additional investments in the electricity sector, all scenarios, year 2050 (left), investments in renewable energy sources in Germany, period 2004-2011 (right) (M€2005)



Source: TIMES model results (left), BMU-KI III1 (right).

Note: The cost for the grid connection of wind turbines falls under 'Wind'.

8.5. Energy system cost

The energy system cost is the total of all energy expenses in an energy system. It can be decomposed by its different components. Table 20 shows the additional energy system costs relative to the reference scenario costs in the year 2050 subdivided in variable, fixed and investment costs. We calculated that the increase of the energy system cost can be compared to 2% of the Belgian GDP in 2050 (GDP_{2050}). The 2% additional energy system cost can be decomposed for most of the scenarios into additional investment and fixed costs of around 4% of GDP_{2050} and reduced variable costs of around 2% of GDP_{2050} . The highest reductions of variable energy costs are observed in the DEM, WIND and PV scenarios with a saving of more than 10 B€ a year. Again relative to the reference scenario, investments have to double to be able to reduce the variable costs with 60%. In a biomass based scenario, investments need to increase with at least 50% to have savings of at least 20%. The necessary power sector

investments boil down to between 1.0% (DEM scenario) and 1.7% (PV and WIND) of GDP₂₀₅₀. In conclusion, we can say that 300 to 400 B€ of investments are needed in Belgium from today up to 2050 to transform our current energy system into a 100% renewable energy system.

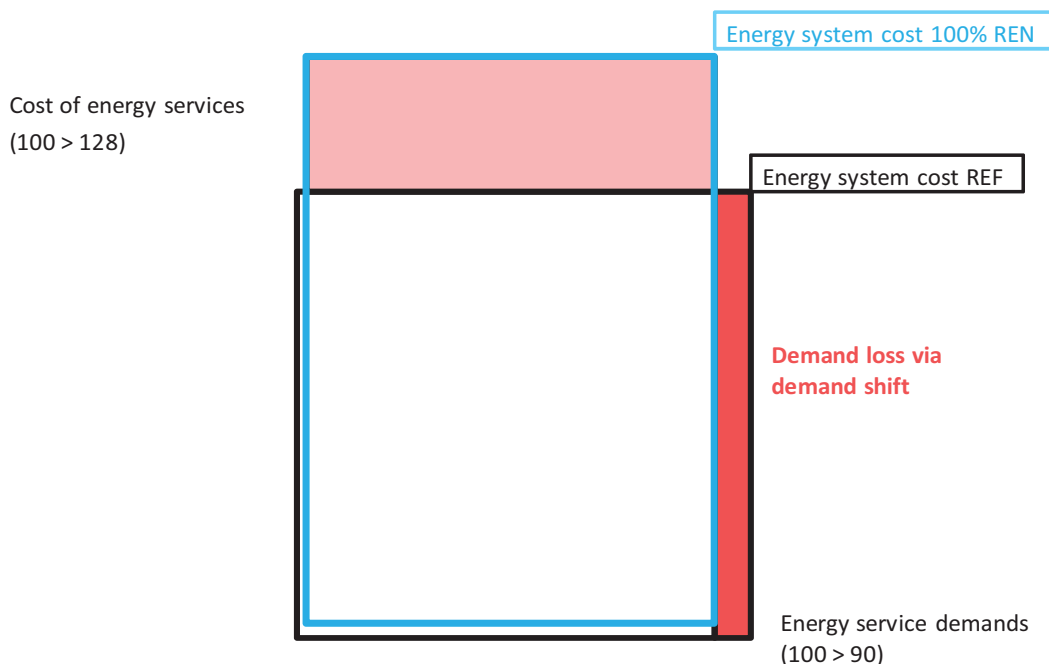
The energy system cost can also be calculated from the average cost of energy services and the amount of services used (Table 20). In general, the average cost of energy services increases with around 20% to 30% in 2050 in comparison to the reference scenario. The demand for energy services decreases on average from zero up to 10% in the DEM scenario. The combined effect of both changes, a cost increase per unit of energy service and a reduced use of energy services, is an increase of the energy expenses -energy system cost- by around 20% in 2050. These additional costs are rather stable over the different scenarios as demand reduction is higher when energy services become more costly. In the DEM scenario, the additional energy system cost is somewhat lower, namely 15%.

8.5.1. Total cost, excluding avoided damage from greenhouse gases

The additional total cost or welfare loss is higher than the additional energy system cost. Figure 26 helps to understand the difference between energy system cost and total cost. The additional total cost is the sum of the additional energy system cost and the demand loss. The demand loss is a difficult concept (see also the annex) but the easiest way of looking at it is that a loss in demand is a loss of consumption that generates a utility. When the decrease in consumption is small compared to the total consumption, the demand loss is adequately approximated by the market value of the decreased consumption; i.e., market price times the decrease in consumption.

This part of the demand loss can be easily represented graphically and is equal to the lost red area in Figure 26. The graph shows a simplification of the energy model outputs for the REF and the DEM scenario. In the REF scenario, both cost concepts, energy system cost and total cost, are equal. It is the sum over all investment, fixed and variable costs to fulfil the energy service demands. The black square shows these costs by a simplified and normalised representation of the demand (100) and the cost of energy services (100). Transforming to the 100% renewable situation, the square becomes a blue rectangle as the cost of energy services goes up and the demand goes down.

Figure 26 : Additional total cost and additional energy system cost of DEM, compared to REF (normalised to 100 in REF)



Source: TIMES model results

Note: For the DEM scenario (BLUE), the average demand loss is some 10% whereas the average cost increase is 28%. The energy system cost of DEM is the area of the blue rectangle and is equal to the multiplication of 0.9 and 1.28 being 1.15. The additional energy system cost, the difference between the pink and the red rectangle, is 15%, compared to the original square.

For most of the scenarios, the increase of the average cost can be taken as an approximation of the additional total cost, see Table 20. In the GRID, BIO, PV and WIND scenarios, the average cost increase amounts to 19% to 25% and the welfare loss amounts to 19% to 27%. In the DEM scenario, the welfare loss is higher than the approximation used in the graphical representation.

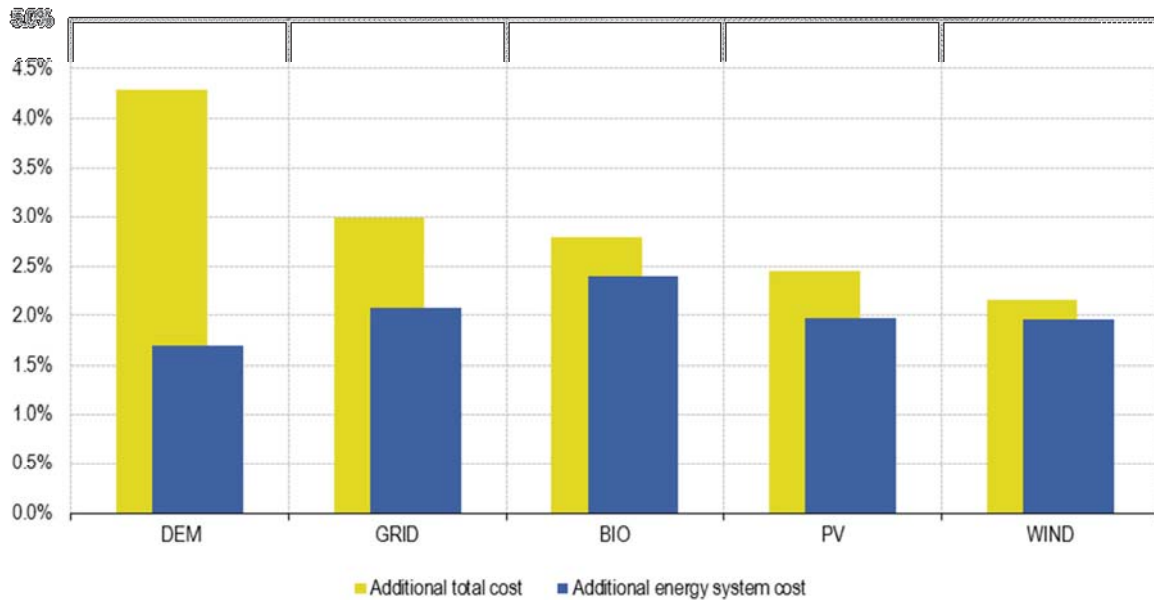
Table 20 : Additional (wrt REF) energy system costs, additional total cost and increase of average cost of energy services, year 2050 (% and Annual B€2005)

	<i>DEM</i>	<i>GRID</i>	<i>BIO</i>	<i>PV</i>	<i>WIND</i>
Demand loss via surplus loss	13%	3%	1%	2%	0%
Demand loss via demand shift	10%	5%	3%	3%	1%
Total additional energy system cost	15%	19%	22%	18%	18%
(B€2005)	11	14	16	13	13
Total additional cost = welfare loss	38%	27%	25%	22%	19%
(B€2005)	29	20	19	16	15
Average cost of energy service	28%	25%	25%	21%	19%

Source: TIMES model results

Again, we can express this total cost relative to the GDP in 2050. As can be seen in Figure 27, the differences between the two cost concepts are most important for the DEM and GRID scenario. The WIND scenario has the lowest increase in average cost of energy services.

Figure 27 : Additional total cost and additional energy system cost (% of GDP in 2050)



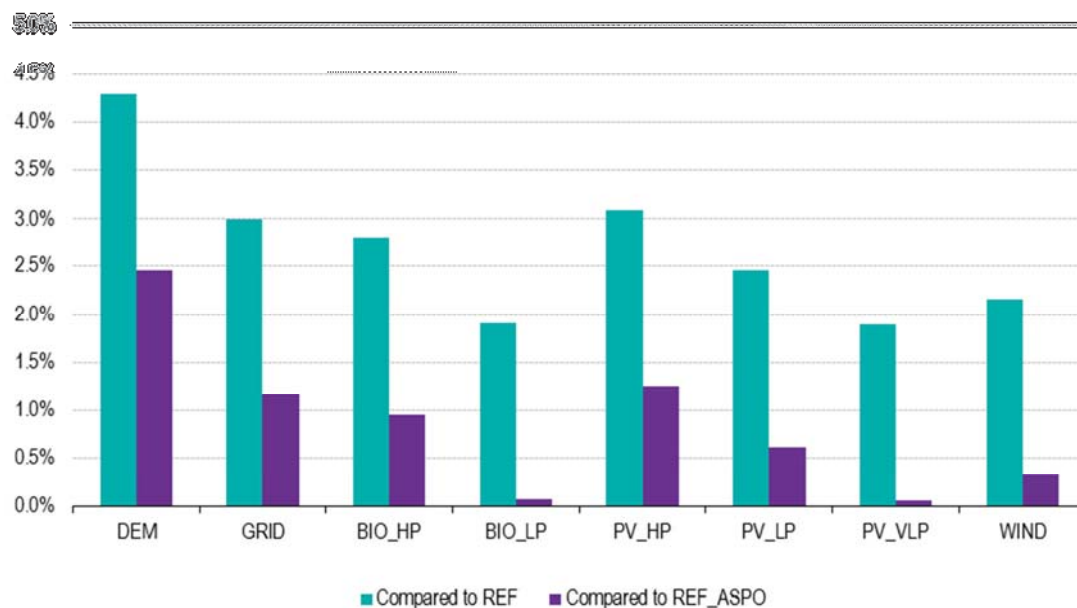
Source: TIMES model results

8.5.2. Impact of variants on the additional total cost

The impact of the most important uncertainties has been quantified by running the TIMES model for variants of the standard scenarios. These variants include an alternative reference scenario in which fuel prices are supposed to soar to 250 \$'08/boe in 2050 (the REF_ASPO scenario based on Brocorens, 2012); an alternative biomass price scenario in which the price for imported biomass decreases from 155 \$'08/boe in 2050 to 78 \$'08/boe (the BIO_LOWPRICE or BIO_LP scenario); two alternative PV panel costs scenarios (see section 4.1.6): 1000 and 371 €'05/kW_{peak} rather than 500 (the PV_HIGHPRICE or PV_HP and PV_VERYLOWPRICE or PV_VLP scenarios).

When comparing the cost of the 100% renewable scenarios with REF_ASPO, it is clear that they are drastically lower in the former scenarios. The impact of the alternative reference brings down total additional costs with some 2% of Belgian GDP in 2050. Decreasing the cost assumption for biomass importation decreases total additional costs with 1% of GDP₂₀₅₀. Increasing or decreasing the cost assumption for PV panels makes the total additional costs go up or down by 0.5% of GDP₂₀₅₀. In comparison with REF_ASPO, the scenario's BIO_LP and PV_VLP have the same total costs (see Figure 28).

Figure 28 : Additional total cost (excl. avoided CO2 damage) in the different scenarios and variants (% of GDP₂₀₅₀).



Source: TIMES model results

In addition to these scenario variants, a cost optimal “MIX” scenario was run with more freedom (fewer constraints) than the other renewable scenarios. In the MIX scenario, no restriction was implemented for the biomass import, PV potential and WIND potential. We learn from this MIX scenario that much wind offshore is installed, but somewhat less than in the WIND scenario, as more biomass is imported. The costs of both scenarios (MIX and WIND) are very comparable.

8.5.3. Total cost, including avoided damage from greenhouse gases

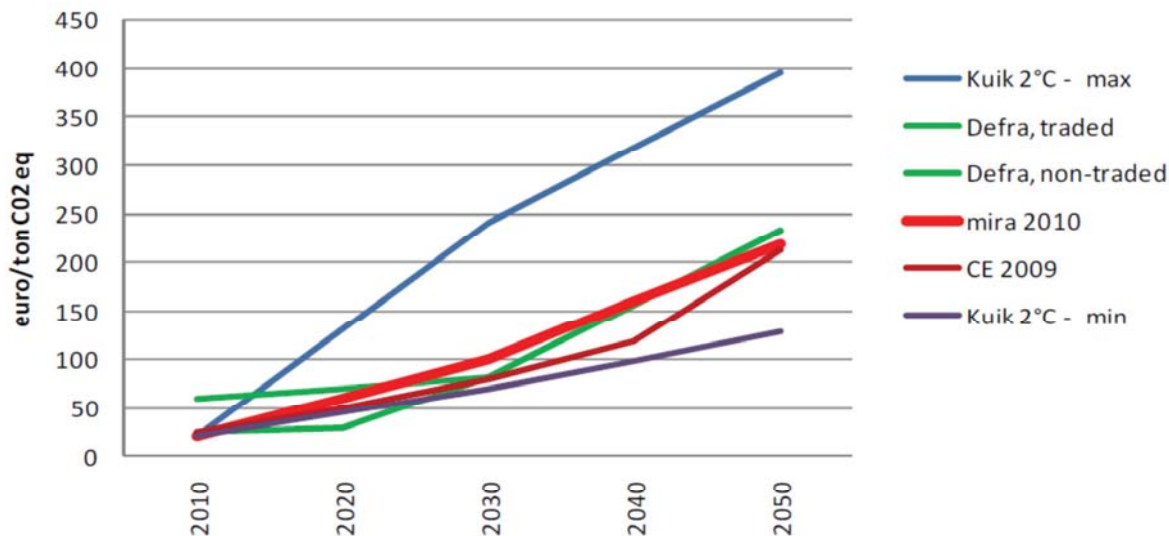
The negative impact of greenhouse gas emissions is slowly becoming a factor that influences investment decisions (“internalised in the market”) via trading or tax mechanisms. However, damage from climate change is still the most important externality of fossil energy use today. The CO₂ price used in the scenario runs (up to 51 €/ton) reflects the climate policy. After the TIMES model runs, we did a post calculation with the CO₂ price reflecting the damage of CO₂-emissions. Damage calculations can be based on real estimated damage (to environment and man) or on prevention cost methodologies. Avoided greenhouse gas damage was analysed by De Nocker et al. (2010).

Table 21 : CO₂ prices for post calculation of avoided CO₂ damages (€/t)

	2020	2030	2050
Lower range	18	23	130
Upper range	73	105	300

Source: De Nocker et al. (2010) and Mayeres et al. (2009)

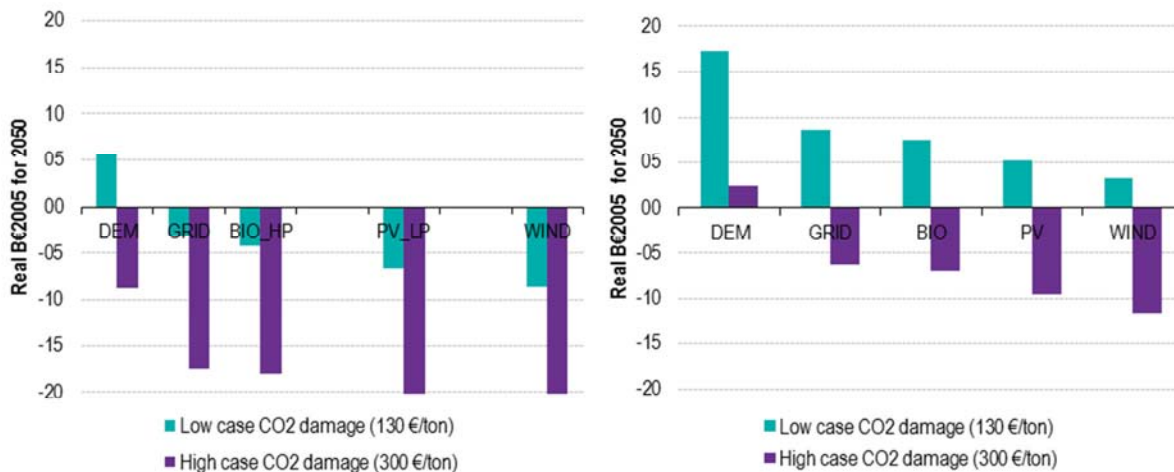
Figure 29 : Overview of different damage costs of CO₂ emissions from different studies (€/t CO₂ eq.)



Source: De Nocker et al. (2010)

Based on De Nocker et al. (2010) and Mayeres et al. (2009), we assume the ranges of avoided CO₂ damages for the post calculation as described in the table 21.

Figure 30 : GHG damage costs, all scenarios, year 2050, upper part compared to REF scenario, lower part compared to REF_ASPO scenario, variation of fuel prices (for example biomass) not included (real B€2005)



Source: TIMES model results

When including both disutility costs (see paragraph 8.5.1) and avoided damage costs of greenhouse gas emissions, some scenarios have a positive net effect of 10 billion € per year, a number that strongly depends on the GHG damage cost assumptions (see Figure 30).

8.6. Impact on employment

Next to impacts on electricity prices, the external fuel bill and investments, another major influence of an energy system transformation may be seen in the (number of) people employed. Changes will unavoidably happen during the system transition as fossil and nuclear value chains will be abandoned in favour of energy efficiency, renewable energy sources and accompanying innovative technologies and processes. Employment will be created, new jobs will become mainstream, but others will be revised/reformed and some will completely vanish, not only in the non-renewable energy sectors, but also in other parts of the economy due to a.o. energy costs' increases.

8.6.1. Some definitions

To discern the effects of a transition towards a 100% renewable energy system on employment, we first of all changed the methodological approach. Instead of relying solely on the results generated by the partial equilibrium model TIMES, we conducted a thorough literature review.

In order to properly examine the employment effect, it is indispensable to first give a brief overview of some of the concepts, definitions and methodologies used.

For starters, it is important to define employment terms as there is often confusion about types of jobs and job-years. One job-year (or equivalently person-year or "full time equivalent" FTE) is full time employment for one person for a duration of one year. Often, "jobs" and "job-years" are used interchangeably; however referring to "jobs" created without stipulating a time concept can be misleading⁴⁵.

Another nontrivial difference resides between net and gross employment effects and between employment (as a stock variable) and job creation (as a flow variable). A net increase in employment (hence, job creation) can come from either opening units or expanding units. A net decrease in employment can come from either closing units or contracting firms. Gross job gains include the sum of all jobs added at either opening or expanding units. Gross job losses include the sum of all jobs lost in either closing or contracting units. The net change in employment is the difference between gross job gains and gross job losses. In this framework, the distinction between net and gross is important to bear in mind since speaking of gross employment can be misleading, including jobs that would be created anyway and not accounting for jobs that may be lost in the coal and natural gas chains. Mentioning the amount of net jobs that can be created over and above what is projected from existing policies and accounting for any job losses that may occur from reductions in the supply chains of coal and natural gas then gives a better idea of the societal benefit of a transformation towards an all renewable energy system.

⁴⁵ Macro-models may function in terms of number of hours worked. Converted into an annual average duration per employee, it allows determining the quantity of jobs created.

Next, definitions of direct, indirect, and induced jobs vary widely across studies. In this study, we choose to follow the definitions and usage of these categories as described in Wei et al. (2010):

- *“Direct employment* includes those jobs created in the design, manufacturing, delivery, construction/installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration. This data can be collected directly from existing facilities and manufacturers in the respective phases of operation.
- *Indirect employment* refers to the “supplier effect” of upstream and downstream suppliers. For example, the task of installing wind turbines is a direct job, whereas manufacturing the steel that is used to build the wind turbine is an indirect job.
- *Induced employment* accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees, e.g. non-industry jobs created such as teachers, grocery store clerks, and postal workers. When discussing energy efficiency, a large portion of the induced jobs are the jobs created by the household savings due to the energy efficiency measures.”

Not only job definition and types of jobs are important in this part of the study, also the way in which they are estimated is crucial. Glancing through the employment literature focused on the renewable industry, two types of methodologies can be distinguished: (1) those that use input-output (I/O) models of the economy (“top-down”); and (2) those that use simpler, largely spreadsheet-based analytical models (“bottom-up”). Both types of models have advantages and disadvantages (Kammen et al., 2004) and are briefly reviewed.

I/O-based models are intended to model the entire economy as an interaction of goods and services between various industrial sectors and consumers. I/O-based models provide the most complete picture of the economy as a whole. They capture employment multiplier effects, as well as the macroeconomic impacts of shifts between sectors; that is to say, they account for losses in one sector (e.g. coal mining) created by the growth of another sector (e.g. the wind energy industry). I/O models are thus designed to encompass both the direct and indirect employment effects of shifts in energy demand as brought upon by various policies as well as the induced economic effects due to economic impacts of spending by workers. In practice, I/O models are very complex and may be opaque to understand. Within a larger I/O model, there are also disaggregation problems in modelling the employment generated by specific technology types such as solar PV or wind and in isolating the impact of specific policies versus a suite of policies. Collecting data to build an I/O model is highly data- and labor intensive, and I/O models also can suffer from time delays between when industry data has been collected and when the I/O model has been run.

Then again, most analytical models calculate direct employment impacts only, but an increasing number include indirect jobs as well. Although analytical models typically do not account for job losses in the fossil fuel sector, they are much easier to understand and model.

Sensitivity analysis of specific policies or changing key assumptions can be readily modelled, and data can be collected more frequently than with I/O models which are based on supply-use tables and typically have a time lag of around 3 to 4 years.

Various normalization approaches for comparing the job creation potential of different technologies can be utilized. They include jobs produced for a given level of spending (Pollin, 2008) or jobs produced for a given level of output, such as jobs produced per unit of energy production. Jobs produced per unit energy provide an indication of job creation potential for aggressive conversion of the existing energy supply to renewable sources, a case in which we are particularly interested in this study.

8.6.2. Some literature

After this short introduction on employment, a thorough literature review was undertaken in order to distillate some interesting reflections. From a long list of reports (all cited in the section References), two major inferences can be drawn.

First, all the quantitative studies that were digested in the framework of this analysis have one thing in common: although the horizon of the study may be (very) long (up to 2050), quantitative employment effects are only given up until 2030 (see e.g. European Commission, 2011, European Climate Foundation, 2010, European Commission, 2009, Wei et al., 2010). It seems that the horizon 2030 might still be comprehended in GDP and employment terms, whilst the horizon 2050 is subject to so much uncertainty that predicting job effects does not make sense. It seems especially challenging to take into account the job impact of all kinds of new, explorative technologies and processes like e.g. massive storage, the hydrogen chain and smart grids. Although they can and certainly will create extra jobs, one also has to be aware of the innovation effect: industry innovation at first may create a lot of jobs (Lachenmaier and Rottmann, 2011), but might over time lead to a reduced job dividend (see also Zagamé, Fougeyrollas and le Mouél, 2012).

Second, most to all studies scrutinised have as object range a rather vast territory like the European Union (European Climate Foundation, 2010, European Commission, 2011) or the United States (Wei et al., 2010). Member State level employment estimates of decarbonisation or renewable policies are rather scarce.

In what follows, we zoom in on four studies with the intention of gathering some interesting figures that may feed a future discussion. The four studies being discussed⁴⁶ are:

- **ECF, 2030:** European Climate Foundation, 2010, *Roadmap 2050, a practical guide to a prosperous low-carbon Europe*.
- **EmployRES, 2030:** Fraunhofer ISI, Ecofys, EEG, Rütter + Partner Socioeconomic Research + Consulting, Lithuanian Energy Institute, SEURECO, 2009, *EmployRES, The impact of re-*

⁴⁶ The studies are being abbreviated by their acronym or major author and the time horizon considered for the estimation of the job impacts.

newable energy policy on economic growth and employment in the European Union, Final report, Contract n° TREN/D1/474/2006.

- **WP9/11, 2020:** Bossier, Devogelaer, Gusbin and Thiéry, 2011, *Impact of the EU Climate-Energy Package on the Belgian energy system and economy-Update 2010*, Federal Planning Bureau, Working Paper 9-11.
- **Kammen, 2030:** Wei, Patadia and Kammen, 2010, *Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?*, Energy Policy 38, p. 919-931.

The order of discussion is chosen in such a way that gradually, we find out more about future job prospects for Belgium, zooming in from an overall European approach and general climate and renewable policies towards Belgian oriented figures calculating the impact of the energy system transition on national employment.

a. ECF, 2030

The first study scrutinised is the Roadmap 2050. The Roadmap 2050 project is funded by the European Climate Foundation and constitutes an analysis that illustrates why a zero carbon power sector is required and how that can become a reality, in line with Europe's long-term climate and energy security commitments up to 2050. The project is based on extensive technical, economic and policy analyses conducted by several organizations (a.o. McKinsey & Company, KEMA, Oxford Economics). The roadmap examines several decarbonisation scenarios for the power sector, of which one contains a 100% RES pathway.

Containing a lot of interesting results described in the technical and economic analysis, the report also has a policy part. In the technical analysis, the macro-economic implications of decarbonisation are described. Amongst the different impacts, the impact on jobs is estimated for the horizon up to 2030 for the entire European Union. What we learn from this estimation is that, for the EU, the reduction of employment in the fossil fuel supply chain is more than compensated by employment in RES and energy efficiency. The net effect amounts to around 300 000 jobs in 2020 (approximately +0.17% of EU employment in 2010) and 160 000 jobs in 2030 (approximately +0.09% of EU employment in 2010). No figures per Member State are provided.

b. EmployRES, 2030

This study is based on an input-output based model (MULTIREG) on historical data that was used to assess the effect of developments in the RES sector on other economic sectors. To assess future economic effects, two independent macro-economic models (NEMESIS and ASTRA) were used in parallel and their results were compared for maximum reliability.

The study reveals that increased use of RES has various effects on the economy, some of which are positive in terms of employment and economic growth, while others are negative. Both gross and net effects are presented. What the results then show is a clear increase in

gross employment and value added under RES-promoting policies. Future employment growth, especially in the years beyond 2020, is mainly triggered by investments stemming from the use of technology and knowledge intensive RES generation technologies under strong RES promotion policies. In the case of an optimistic export projection, an additional increase in jobs can be expected in 2030. Increased exports in particular in knowledge intensive RES technologies are the main driver for this development. About two thirds of the jobs created in the RES sector are based on small and medium-sized enterprises (SME). A strong increase in RES technologies such as wind power, photovoltaics and solar thermal electricity is responsible for roughly 50% of the gross employment increase in 2030 compared to a No Policy situation.

As for net employment, the basic conclusion is that it would also be slightly stimulated by RES policies, but the effects would be rather moderate (compared to the GDP effects). The main results at the EU27 level can be summarised as follows:

- Business as usual RES policies in EU Member States combined with moderate export expectations result in a roughly constant positive employment effect of 115 000 – 201 000 employees in 2020 (between 0.06 and 0.09% with respect to a No Policy scenario) and 188 000 – 300 000 employees in 2030 (between 0.08 and 0.14% with respect to No Policy)⁴⁷.
- The Accelerated RES Deployment Policy scenario combined with moderate export expectations leads to a slightly higher increase of average employment by 396 000 – 417 000 employees by 2020 and by 59 000 – 545 000 employees compared to No Policy in the last years before 2030.
- The effect on employment strongly depends on the energy cost increase. If there are significant cost rises, these may dampen the employment increase.
- At the sectoral level, the areas in which employment increases most due to RES policy would be the agriculture and the energy sector, the former due to increased demand for biomass, the latter due to the higher labour intensity of RES and increased expenditures on electricity. Sectors losing jobs would suffer from higher household energy expenditures, higher sectoral elasticities in response to higher goods prices driven by energy cost increases and the prevailing budget constraint of households. Examples would be the trade and retail sector as well as the hotels and restaurantbranch.

The study also gives figures per Member State: the figure for Belgium seems to be in the neighbourhood of 5 000 jobs in 2020 due to an accelerated RES deployment policy scenario with moderate exports and this compared to a baseline⁴⁸.

⁴⁷ See Figure 97 and Figure 123 of the cited publication.

⁴⁸ This approximate figure is in fact the result of the combination of two figures, i.e. Figure 103 and 111. This was done in order to have as reference the BAU-ME scenario instead of the No Policy scenario, the latter representing the virtual case in which no further RES support is implemented until 2030, whilst the former simulates the case in which RES policies are applied as currently implemented, a situation that is closer to our REF scenario.

c. WP9/11, 2020

This study is in fact an update of the study performed in 2008 by the Federal Planning Bureau. That Working Paper described and analysed the impact of the EU Energy-Climate Package on the Belgian energy system and economy. The starting point of the analysis was the Impact Assessment and its annexes released by the European Commission in January 2008. The WP9/11 then updates that Working Paper and analyses target scenarios for greenhouse gas emissions (GHG) and renewable energy sources (RES) for Belgium in a European context. The design of the target scenarios is inspired by the analysis of options to move beyond 20% GHG emission reductions issued by the European Commission in June 2010 (COM(2010) 265/3) whilst integrating the new economic and energy policy context. Two 20% GHG reduction scenarios are investigated, differing in the amount of flexibility used to achieve the national target. They are both inspired by the Reference scenario as defined and analysed in EU energy trends to 2030-update 2009. Two 30% GHG reduction scenarios are also scrutinised destined to assess the impact of moving from the 20% GHG reduction target specified in the Climate-Energy Package to a 30% GHG reduction target at EU level in 2020 compared to the 1990 level. Also for the -30% case, more than one scenario was designed differing in the amount of flexibility in both ETS and non-ETS sectors.

This study also mentions some employment effects calculated using the FPB's HERMES model⁴⁹. For the year 2020, employment impacts are calculated for the 30/20 target scenarios with respect to the 20/20 target scenario and arrive in a range between 7 000 and 25 000 jobs. The 30/20 target scenarios can be seen as integrating more severe greenhouse gas emission reduction targets on European level, hence implementing more energy efficiency and a slightly higher share of renewables in Gross Inland Consumption than the 20/20 target scenario.

d. Kammen, 2030

The article from Wei, Patadia and Kammen (2010) contains an analytical job creation model for the US power sector from 2009 to 2030. The model synthesizes data from 15 job studies covering renewable energy (RE), energy efficiency (EE), carbon capture and storage (CCS) and nuclear power. The paper employs a consistent methodology of normalizing job data to average employment per unit energy produced over plant lifetime. Job losses in the coal and natural gas industry are modelled to project net employment impacts. Benefits and drawbacks of the methodology are assessed and the resulting model is used for job projections under various renewable portfolio standards (RPS), energy efficiency and low carbon energy scenarios.

Findings are that all non-fossil fuel technologies (renewable energy, energy efficiency, low carbon) create more jobs per unit energy than coal and natural gas. Aggressive energy efficiency measures combined with a 30% RPS target in 2030 can generate over 4 million full-

⁴⁹ For the sake of completeness, we have to mention that this study primarily zoomed in on the employment effect triggered by a taxation shift from one factor to the other. The impact of new investments in renewable energy sources was much less the centre of attention.

time-equivalent job-years by 2030, while increasing nuclear power to 25% and CCS to 10% of overall generation in 2030 can yield an additional 500 000 job-years.

Next to this article, it appears that an older version focusing exclusively on renewables was published in 2004 (Kammen, Kapadia & Fripp, 2004) and revised in 2006. Main conclusions boil down to

- The renewable energy sector generates more jobs per megawatt of power installed, per unit of energy produced and per dollar of investment than the fossil fuel-based energy sector.
- Embedding support for renewables in a larger policy context of support for energy efficiency, green building standards and sustainable transportation will greatly enhance the net positive impact on the economy, employment and the environment.

Although both articles focus on the US power sector, it is explicitly stated that the model can be adopted and applied to other (developed) countries.

8.6.3. Some estimations

So what we basically did was try out the model and insert results coming from TIMES in the job model⁵⁰ created by Kammen et al. Results are produced for 2020 and 2030 with a total for the two distinct years. We then tried to estimate the job-years created for the intermediate years between 2020 and 2030. This estimation is based on the employment impact figures as expressed in WP9/11 (Bossier et al., 2011) that demonstrate that although the job impact increases over time, the growth rate flattens out⁵¹. Depending on the assumed growth rate, the cumulative amount of job-years can vary.

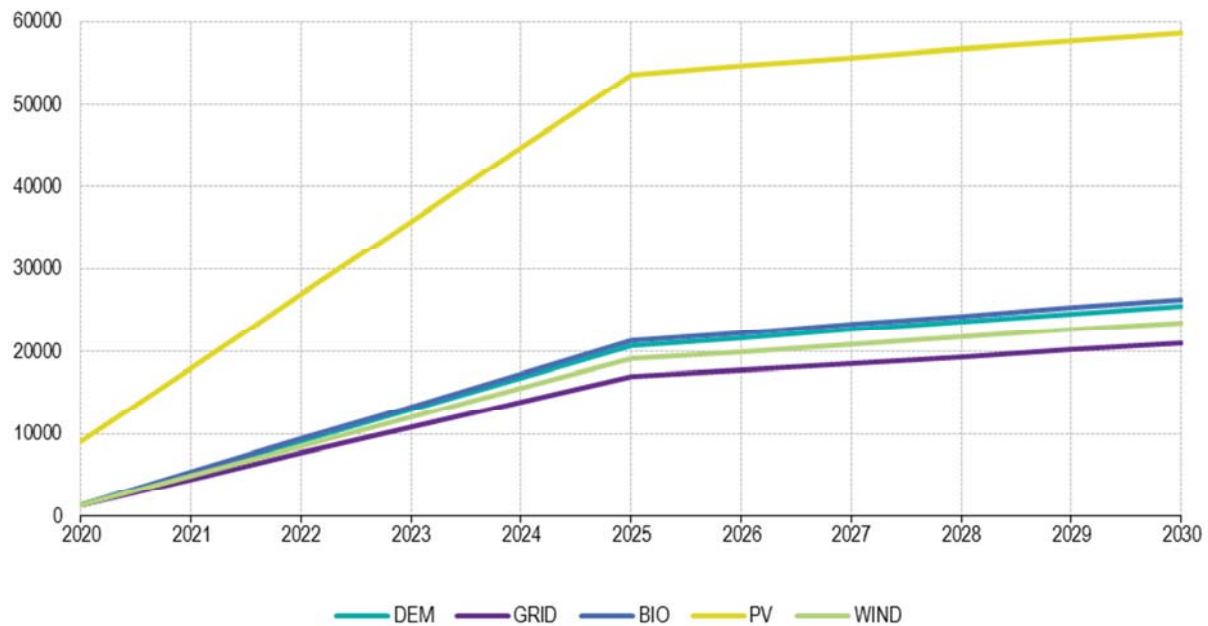
What we then learn is that:

- the renewable trajectories all create more job-years or FTE's than the reference scenario;
- the PV scenario creates the most FTE's in any year, but also over the horizon. As many discrete panel installations are necessary to foster a significant solar PV development (as compared to e.g. a single location for a wind farm) and solar has a large installation component in employment, a lot of FTE's are being formed.
- BIO and DEM are the second highest job generating scenarios, the BIO scenario mainly through the increased demand for inland farming, the DEM scenario through the major boost that is given to the national building sector and with it, its entire value chain.
- GRID employment seems to be at the lower end of the spectrum. This might be due to the fact that grid investments specifically destined to transborder interconnections are not specifically accounted for in the model, hence total employment for this scenario might be underestimated.

⁵⁰ This model synthesizes data from 15 existing job studies.

⁵¹ A possible explanation can be sought in the innovation effect (cfr. infra) or the learning curve effect through improvements in industry productivity and cost reduction.

Figure 31 : Annual job-years over REF due to the RES trajectories, period 2020-2030 (total FTE's)



Source: Wei et al. (2010), FPB's own calculations.

Three side remarks concerning this estimation can be made, all pointing to the fact that results might be higher than shown in Figure 31. First, it is important to bear in mind that the reference scenario already has a relatively large share of renewables in its power generation (37% in 2020, 42% in 2030). This has to be attributed to the specific outset of the reference scenario with the nuclear phase-out and the implicit ban on coal for power generation within the existing TIMES modelling framework. This also means that renewable job creation as shown in Figure 31 might be underestimated compared to a reference scenario characterised by a more moderate share of renewable energy sources in total power generation. Second, although Wei et al. (2010) specifically mentions the fact that the model and the job multiplier data can easily be adopted by other (developed) countries, it contains some country specific features that differ from the Belgian ones. As a matter of fact, the capacity factors for solar PV and wind used in the article amount to 20 and 35% respectively, whilst in Belgium these factors are more in the neighbourhood of 10 and 25% respectively, hence when performing the calculation with job multipliers expressed in total job-years per GWh, even more FTE's may be created. Third, this job model relates to the power sector. Although it allows for indirect and induced jobs in other sectors of the economy, it does not include jobs created in the bio-fuels' (transport sector) or renewable heating and cooling sector. Even though these chains are, for the years considered, much smaller than the power sector, adding these extra jobs onto the jobs created in or through the electricity chain will further increase total employment.

Next to this more general outlook, two specifications can be added to the above analysis. First, to construct Figure 31, average ratios of total job-years per GWh were used. The article, however, contains a job model that is the result of the combination of 15 job studies with dif-

fering estimations of the job impact. It was then possible to go back to the original data and estimate the minimum and maximum, hence the range, of the job creation potential initiated by the different renewable trajectories. On top of that, the article also contains information on a subdivision between types of jobs. A distinction can be made between jobs in (1) construction, installation and manufacturing (CIM) and (2) operations, maintenance and fuel processing. So the tools were there to provide a more detailed analysis for the years 2020 and 2030. What we then learn is that:

- In 2020, there seems to be more jobs in O&M and fuel processing than in CIM except in the PV scenario. The range of additional CIM jobs lies between 500 (BIO) and 10500 (PV) compared to the REF scenario. The range of additional O&M and fuel processing jobs lies between -800 (WIND) and 5000 (PV) compared to the REF.
- In 2030, the situation is more mixed: PV, WIND and GRID have more CIM jobs, BIO and DEM create more O&M and fuel processing jobs. The range of CIM jobs lies between 7100 (WIND) and 54700 (PV) compared to the REF scenario. The range of O&M and fuel processing jobs lies between 6000 (GRID) and 36900 (PV) compared to the REF.

8.6.4. Some reflections

The findings expressed in the different studies have to be complemented by some other reflections on the type of jobs and the context creation of the jobs. Even if job impacts can be positive overall, significant shifts in employment among or within sectors are to be expected. The implementation of guiding and appropriate policies and measures will be of major importance to ensure an orderly transition of job switching between sectors. This is of particular importance in the energy sector with some sectors experiencing growth whilst others undergo decline as a result of major moves in investments and changes in production and consumption patterns. The key challenge will be to revise and upgrade the 'green' skills of workers in all sectors. This is the case in any sector, those that will be majorly affected such as workers in the building (renovation) sector to improve energy efficiency in technologies as well as in materials, but also in sectors that are only indirectly involved such as insurance companies that are faced with new assets and instruments for some new technologies such as geothermal or very far offshore wind investments.

On top of that, our quantitative assessment made using TIMES has another complement to bring to this analysis: jobs will not only shift between or within sectors, jobs can even shift in time. The explorative analysis discussed in the previous sections indicates that it might be interesting (from a cost optimal point of view) to, for certain periods of the year, alter the current industrial organisation of some specific sector(s) (in casu the iron and steel sector) towards a more seasonal production-oriented system, using the necessary energy commodities like electricity only during the cheapest periods of the year when e.g. sunlight is abundantly available and closing down during the darker winter months. This flexibility within industry can be perceived as having the same effect as a giant battery in which electricity may be stored in the aggregation state of e.g. steel. From an energy, materials', financial or logistics' point of view, this is one thing, from the workers' point of view, this is another.

This would drastically change the way in which work will be organized in the sector, currently employing around 100 000 people⁵² (INR, 2011). This calls for a major change not only in mind set, but also in training, in follow-up, in job flexibility and in social security. To put it differently, from a strict price/cost rational point of view, this could mean that we are heading to a society in which, during the winter months, less energy or electricity intensive activities should be scheduled in whilst the most energy consuming activities should be reserved for summer time.

Not only for the seasonal labour type of organisation, but in general, there is a need to reinforce and educate human capital because of these changes in production methods, but also in consumption patterns and in the materialization of new value chains and business models in an entirely renewable economy. On top of that, interest in science and engineering, two major pillars in the transition towards an all renewable society, is often lacking and will make an energy transformation all the more challenging.

⁵² It is important to specify that not all jobs in this sector will be impacted. According to side calculations based on model results, only a few thousands will be affected.

9. Policies and measures

9.1. Introduction

In order to reach the 100% renewable target, the TIMES model assumes that the Belgian energy system will have abandoned fossil fuels energy by 2050. However, in a world where energy is produced by enterprises operating in competitive markets, no obligation would be sufficient to reach the objective, since the development of renewable energy production depends mainly on market conditions: price of fossil fuels, costs of renewable technologies, perceived risks (and then interest rates) for investments in renewable production, etc.

Although the cost of energy produced by renewable energy technologies has fallen over the past 30 years and further cost reductions are projected (see for example IPCC, 2011), most renewable energies are still more expensive than conventional energy production⁵³. However, energy markets do not fully account for the social and environmental costs and benefits connected to energy production. For example, fossil fuels exploitation often results in real costs to society in terms of climate change, human health, nuclear waste, etc.

This means that unless governments actively intervene to correct market inefficiency with respect to, for example, environmental protection, the share of renewable energy sources in the energy mix will be less than optimal (from a social point of view) and not in line with the 100% objective. Furthermore, even under favourable market conditions, the development of renewable energy production could be hampered and delayed by other obstacles, such as social barriers. For example, even though the public is generally in favour of renewable energy promotion, resistance towards renewable energy technologies might occur at local level.

Thus, it is not surprising that the market growth of renewable energy has been supported by a wide range of policies designed to overcome barriers to renewable energy adoption and create a level playing field with fossil energies. This policy landscape has been highly dynamic. From 2005 to early 2011, the number of countries with national renewable energy policies nearly doubled from 55 to 119 (REN21, 2011). During the same period, existing policies were frequently amended, strengthened and/or expanded.

The complexity of policies has also increased. This can be expressed by the number of different measures to support renewables. In the OECD countries, for instance, governments have actively intervened in energy markets with a variety of instruments in order to achieve environmental objectives. Research and development support for renewable energy technology was implemented in some OECD countries as early as in the 1970s, followed by investment incentives (capital grants, loan guarantees and low-interest rate loans), taxes (accelerated depreciation, tax credits, tax exemptions and rebates), price-based policies (feed-in tariffs) and quantity obligations, often followed by certificates with tradable obligations. The number

⁵³ Indeed, some estimates show that when the externalities associated with different energy sources are fully reflected in policy incentives (and when subsidies to fossil fuels are ruled out), some renewable energy sources, particularly wind power, are already as cost efficient as conventional energy sources (REN21, 2011).

and the budget associated to these measures have surged since the Kyoto Protocol was signed in 1997 (Kalamova et al. 2011).

This part of the report presents the different axes on which policies for promoting renewable should insist, based on a review of existing policies and measures and on international recommendations. This is done by pointing out the critical areas where government intervention will be needed according to the results of the pathways to 2050 described in chapter 7. Subsequently this chapter describes a broad portfolio of measures that can be used to promote renewable energy production in practice and proposes an evaluation scheme to assess how they can be used successfully in bringing the energy system to rely fully on renewable energy. Finally, although the choice between all those instruments lies with policymakers as in function of their different political perspectives, the chapter draws some recommendations, putting some measures on the front and highlighting their level of priority, the sectors that will be mostly affected and the critical issues each measure will raise.

9.2. Exploration of policies and measures to be implemented to meet the 100% RES target

So far, this study has shown that the transformation of the current Belgian energy system into a 100% renewable energy system is not only technically feasible but could also follow different pathways (i.e. the scenarios described in chapter 5). The impacts of each pathway in terms of investments and infrastructure for the energy sector over the entire time horizon are important and diverse.

As this study is the first to explore the different impacts of the 100% renewable target in Belgium, we point out some research areas that need more attention, i.e. capital constraints, determining long-term demand effects, industrial demand-side management, quantification of smart grids, macro-economic evaluation, new energy market concepts. Further research is necessary to get a better view on the relation between impacts and the policies and measures at the origin of these impacts.

New power plants, grid lines, interconnections and transport systems will have to be financed. Also the impacts on the non-energy sector of the economy will be non-negligible, as well as the effects on private and public finances. Consumers will have to switch to electricity. Production activities will have to be re-organised and adapted to the new energy paradigms. Governments will face major challenges: (undergone) fiscal revenues from fossil energy will need to be replaced, support to renewable energy as well as support to keep Belgian production competitive will need to be implemented, just to cite a few.

The pathways illustrated in the study show that going for 100% renewables will strongly affect the energy system and be characterized by:

1. a reduction in energy services demand;

2. a surge in the production of renewable energy, which will impact the energy system in particular because of:
 - a. its intermittency;
 - b. the need of reinforcing the energy infrastructure (grids, interconnections, meters, etc.) due to the increasing importance of electricity trade as a result of decentralised production.
3. a major shift to electricity;
4. the need to further improve existing renewable technologies and explore new technologies;
5. the need for a reinforced international cooperation to ensure the reliability of renewable energy imports.

Moreover, going for a 100% renewable energy system will inevitably affect consumption and production patterns. Producers and consumers will be asked for a major change in behaviour to adapt to the new characteristics of the energy system.

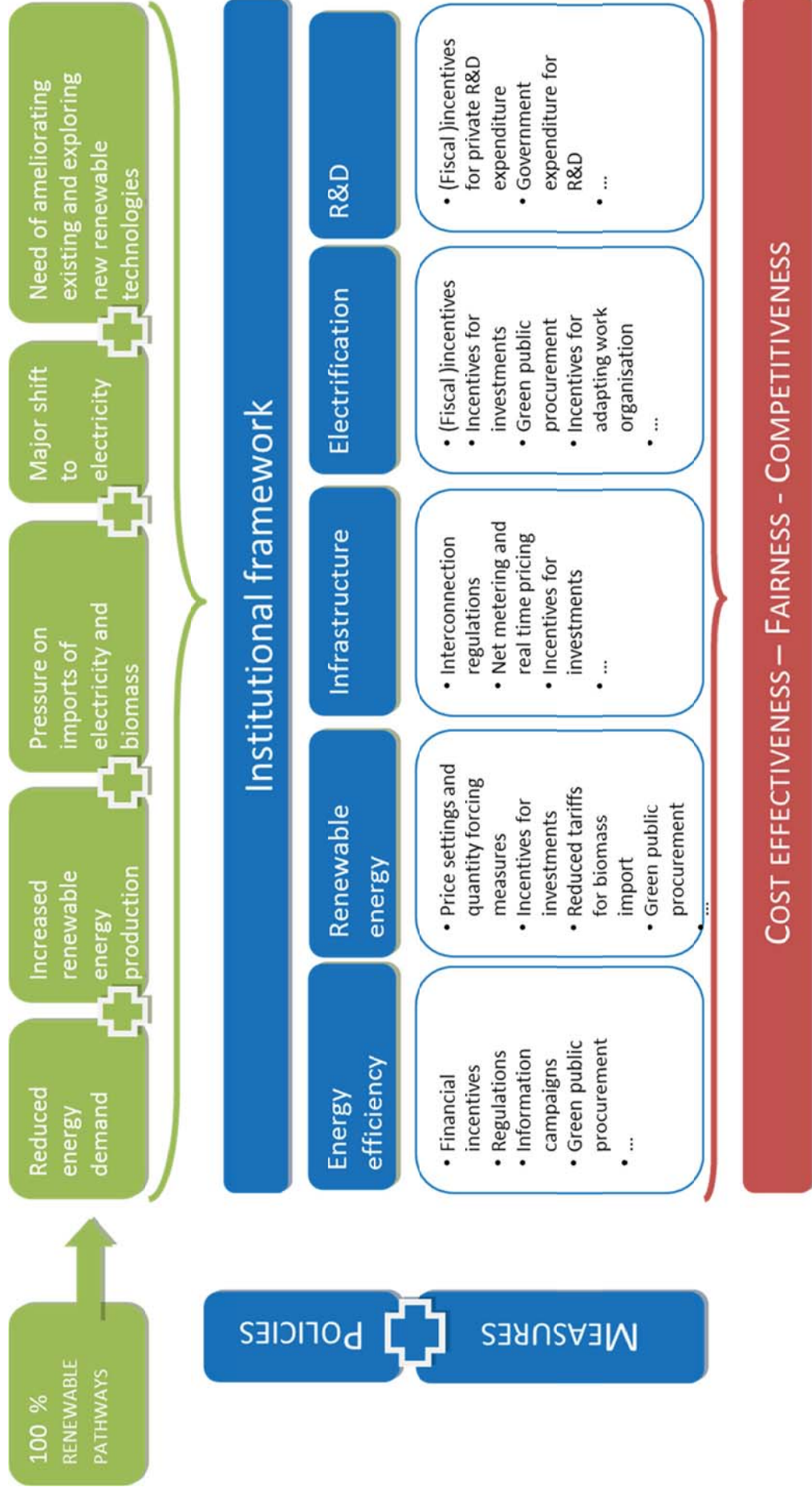
Governments will be asked to intervene in creating a favourable environment to reach the 100% renewable target. Furthermore, government intervention will likely to go beyond the energy system. Governments will be called to help producers and consumers to adapt to the new energy system and, if necessary, correct any undesirable effect the transition to a 100% renewable energy system could have on society.

Different policies target different objectives, but a single policy cannot solve all renewable energy market challenges. Based on the characteristics of the 100% renewable energy system and on international best practices and recommendations, six critical areas of government action/intervention can be pointed out (see also Figure 32):

1. institutional framework;
2. energy conservation;
3. renewable energy production;
4. energy infrastructure;
5. research and development (R&D);
6. electrification.

The next paragraphs highlight the main tools governments could use to support the transition to a 100% renewable energy system and the challenges this objective entails. How can governments help to step up the development of a 100% renewable energy system?

Figure 32 : 100% renewable energy policies and measures



9.2.1. Implementing a favourable institutional framework

Setting up an institutional framework is clearly important for not only making the transition to a 100% renewable energy system possible but also smoothing out the impact of such ambition at all levels of the Belgian society.

In order to make government support to renewable energy fully effective, a favourable and stable institutional framework is of utmost importance. This is a prerequisite to any other policy and measure. What could a favourable institutional framework look like?

An institutional framework is a set of rules (and institutions) defining the general context in which all specific policies and measures for reaching the 100% renewable target should be included.

It aims at reducing:

- the administrative burden and transaction costs. This would in turn help reducing renewable energy production costs;
- the risk associated to investing in renewable energy production, lowering the risk premium asked for financing the transition to a 100% renewable energy system;
- negative interferences with other policies which would increase the renewable energy costs.

Such an institutional framework should first of all ensure effective administrative procedures through the removal of administrative barriers, such as excessively long lead times for new renewable energy projects⁵⁴ and complicated application procedures with a high number of authorities involved⁵⁵.

A proper regulatory framework should rely on official and stable long-term and intermediate quantitative targets for renewable production (and energy efficiency)⁵⁶. The main role of the targets would be to quantify a long-lasting context in which all the other measures needed to spur renewable energy development are to be inscribed.

The institutional framework should ensure that related policies should be well planned (e.g. avoiding “start and stop” effects), regularly strengthened and properly enforced. For example, all policies implemented to reach the 100% objective and the related future measures being planned should be given ample notice and be taken while involving all relevant parties.

⁵⁴ Long lead times could be avoided by establishing a maximum time limit for the entire permitting process or single steps in the permitting process, thus exercising pressure on each institution involved to handle applications in a timely manner.

⁵⁵ A large number of authorities involved often prolongs the process and makes it unnecessarily expensive for project developers. The number of authorities involved normally increases because of competences at different political levels, e.g. national, regional and local. The European Commission (European Commission, 2008) even suggested to establish a “one-stop-shop” organisation that could coordinate and simplify the entire administrative process. Developers would then only have to get in contact with this organisation that would in turn deal with all other authorities.

⁵⁶ Targets could be designed and/or integrated with emission reduction objectives.

This would allow stakeholders impacted by the measures to adapt in advance and reduce any potential social resistance to the deployment of renewables⁵⁷.

A favourable institutional framework would not be limited to the energy system. Energy aspects should be integrated in other policies, such as emissions reduction policies, in order to maximize their effects. All administrative levels should take into account energy issues when designing public policies with regard to the environment, land use planning, transport, housing, industrial policies... An integration of energy efficiency and other public policies will make the mix of instruments in support of renewables more efficient and avoid incoherence in the outcome of the policy making process⁵⁸. The early inclusion of renewable energy projects in spatial planning is equally important for quick administrative procedures. Spatial planning provisions are generally implemented to organise land use in a given region. Therefore, spatial planning provisions have to anticipate the increased deployment of renewable energy projects.

A favourable institutional framework would reinforce the evaluation of implemented measures and their monitoring by using indicators. Monitoring the impact of measures through ex-post evaluation, as well assessment of energy efficiency trends through indicators should be strengthened so as to reveal possible policy shortfalls.

To be fully effective the institutional framework should also address international cooperation issues. International cooperation will be mostly important for (1) exploiting all the advantages of being part of an international energy market as for example ensuring stable imports of renewable energy from Belgian neighbours (security of supply) but also for (2) avoiding or reducing carbon leakage towards countries not implementing strict energy and climate policies.

All the measures and policies which could be implemented to reach the 100% renewable target would not be effective if they are not inscribed in such a general framework.

9.2.2. Energy efficiency and energy conservation: only investing in what we need

In order to reach the 100% renewable target by 2050, our results showed in all renewable scenarios a decrease over time in primary energy demand, pointing to the fact that moving to a renewable energy system necessitates high energy efficiencies and savings. This is particularly true when reduced energy imports are combined with a rather limited national renew-

⁵⁷ Renewable energy power plants are often small-scale and decentralised. Therefore, social acceptance is even more important than in the case of large-scale, centralised conventional power plants. Social barriers are often related to the NIMBY effect (Not In My BackYard) and the lack of inclusion with the local population in planning and ownership. Opposition from the local public has frequently been observed when deploying renewables. Even though the public is generally in favour of renewable energy promotion, resistance towards renewable energy technologies, especially wind energy, might occur at local level. The NIMBY effect can be overcome by including the local public in the decision making process (e.g. spatial planning) at an early stage. The local acceptance of renewable energy projects can also be increased by ownership participation of the local people. The design of the national tax system can also contribute to local revenues and thus local acceptance. (WEC, 2008)

⁵⁸ This could be done, for example, by defining a common carbon value which would be taken into account in public decisions to direct choices toward energy efficiency (WEC, 2008).

ables' potential: the DEM scenario. In this scenario, the growth of the energy services demand has to be drastically reduced, leading to a reduced energy demand.

How could governments contribute to the energy consumption reduction foreseen by the pathways to 2050?

The greatest impact will come from the joint implementation of several complementary measures, which mainly include information programs, financial incentives and regulations (Gillingham et al., 2009).

Information programs typically aim to induce energy efficiency investments by providing information about potential energy savings or examples of energy savings. Information programs are motivated by the informational problems and behavioural failures economic agents incur when they face the choice of investing in new less energy-consuming products (appliances, cars, buildings, etc.). The intention is to phase out issues of uncertain future returns and asymmetric information by providing more reliable information. Additional information may also lower the cognitive cost⁵⁹ of energy-related decision making and help guiding consumers toward better decisions.

Incentive programs provide financial motivation for energy efficiency investments through direct subsidies, tax credits, tax deductions, rebates, or loan subsidies (they will be discussed in section 9.2.3 below).

Regulations such as product standards set a minimum level of energy efficiency for all covered products on the market (in some cases, standards are differentiated by product size and type)⁶⁰. There is a strong need to develop energy efficiency norms for energy-consuming appliances and equipment but also for buildings: norms allow a differentiation between low- and high-efficiency products and could be used as labels to inform consumers and to implement incentive policies (tax credit, eligibility to funding schemes etc.).

Equipment complying with energy efficiency norms could benefit from public procurement, allowing new efficient technologies to penetrate the market. This would provide an important factor for the cost reduction of new less energy consuming technologies.

To be effective, standards must be updated regularly. Indeed, there is no incentive for manufacturers/constructors to go beyond what is required if no stricter standards are planned for the future. It is therefore essential to review and reinforce standards at regular time intervals as a way to stimulate technical progress and ensure a steady improvement in energy efficiency.

⁵⁹ Cognitive costs are related to the coordination of economic agents when they must exchange information, coordinate their actions, and make joint decisions. Such activities require talking, writing, reading, and thinking – tasks that all require time and energy.

⁶⁰ This is the case for the ecodesign regulation at the EU level (Directive 2009/125/EC of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products). This is axed on labelling to raise consumer awareness and the energy efficiency requirements imposed on products in the design phase.

The experience shows that technologies and buildings complying with future standards (i.e. more efficient than current standards) are in general a few per cent more costly than the market average. However, this extra cost drops rapidly with the implementation of upgraded standards, due to learning effect (WEC, 2008). Therefore, complementary policies aiming to increase the market share of the most efficient appliances and buildings are highly effective to reduce costs and facilitate the implementation of the new regulations.

9.2.3. Supporting renewable energy production

As the results of the renewable pathways show, the 100% renewable energy target implies a societal shift from a fuel-intensive to a capital-intensive energy system. This means that an important amount of investments will need to target new production plants, grid extensions, new interconnections, etc. In order to make the mobilisation of such a large amount of resources possible, the government will have to play an important role.

Since renewable energy production is a mix of multiple technologies at different stages of maturity, it can be supported in multiple ways: by modifying the rules of the energy markets and trade, by promoting equity or debt investment through direct financial transfers, by tax rules or by the government directly providing energy-related services, just to mention a few.

Broadly speaking, renewable energy policy measures can be divided in two groups⁶¹: incentives and regulations. Incentives directly address economic and financial barriers to renewable energy. They include direct cash payments, tax incentives and financing programs. Participation in an incentive-based policy is, by definition, voluntary. Regulations target non-economic barriers to renewable energy policy and include streamlined permitting, interconnection standards for renewable electricity and alternative fuels blending mandates. Although regulations are not voluntary, they may apply to society as a whole or to specific economic actors only.

When these measures are into practice, the distinction between incentives and regulations blurs. It occurs, for example, that some of the most popular policy types, such as feed-in tariffs, incorporate both regulations and incentives.

A full catalogue of policies would be challenging to assemble because of the rapid pace at which policy has evolved⁶². Table 22 sums up different renewable energy policy instruments.

Table 22 : Overview of different renewable energy measures.

Type	Description
Feed-in tariffs	Feed-in tariffs typically have three key elements: guaranteed purchase of clean energy by utilities; long-term purchase contracts for the electricity (or heat) produced; and performance-based incentives for generators. Most feed-in tariffs are set based on the incentive levels producers need to make profit (i.e., so-called "generation cost-based rates"). In addition to incentive payments and purchase and contracting regulations, feed-in tariff policies may also include regulations requiring producers to be interconnected to the energy grid, and all

⁶¹ Other taxonomies of renewable energy policies exists: price-based vs. quantity-based mechanisms; direct and indirect mechanisms, fixed price measures vs. endogenous price measures, etc. see Glemarec, 2011.

⁶² A recent publication by the United Nations Environment Programme (Glemarec, 2011) identified 150 different climate and energy policies.

Type	Description
	clean energy to be given priority in the transmission and distribution systems. Feed-in tariffs (FITs) are currently the most widespread renewable energy policy in the world. In early 2011, over fifty countries had a feed-in tariff policy (REN21, 2011).
Capital grants and rebates	Grants and rebates are normally one-time payments from a government to a project developer or owner to cover part of the capital costs of a project. The amount of the payment is typically based on the installed capacity of the system (e.g., €/kW), although some upfront payments are based on total expenditure (e.g., 50% of project costs). Grants are usually awarded before a project begins, whereas rebates are paid after a project has been successfully installed. Unlike loans, grants and rebates are not expected to be repaid.
Performance-based payments	Performance-based payments are cash incentives awarded for every unit of energy generated (or saved). Performance-based payments create incentives for efficient system design and ongoing system maintenance.
Low-interest loans and loan guarantees	Publicly-backed loan programs provide access to the funds necessary to build projects. They includes projects that otherwise might not be eligible for financing or , for various reasons, be attractive to lenders or inspire their confidence. Such loan programs attempt to fill the “gaps” left by private sector lenders. Loan programs involve creating a pool of subsidized or low-interest loans (also known as “soft” loans) and then facilitating access to these loans and guaranteeing access to loan funds to projects that otherwise might be ineligible. Governments often partner with the private sector to create these types of loan programs. Under a loan buydown scheme, for example, a public body provides money to banks in order to subsidize the lowering of interest rates to renewable energy projects.
Government-funded venture capital funds	Venture capital is a type of equity financing that addresses the funding needs of entrepreneurial companies that, for reasons of size, assets, and stage of development, cannot obtain capital from more traditional sources, such as public markets and banks. Venture capital investments are generally made in cash in exchange for shares and an active role in the invested company.
Accelerated depreciation	Tax codes in many countries require businesses to spend eligible equipment investment costs through depreciation deductions over the lifetime of the system. Accelerated depreciation allows eligible equipment costs (for example, capital equipment for a new renewable power plant) to be depreciated quicker than usual. This allows project developers to obtain the full tax advantage of the depreciation in a shorter period of time.
Tax credits	Tax credits allow project owners to reduce their income tax liability. Tax credits can be structured like cash payments: they can be one-time credits, similar to rebates, and based on capacity or expenditure (e.g. investment tax credits) or be paid out over time and based on performance (e.g., production tax credits). Tax credit-based policy incentives are most attractive to project investors with sufficient “tax appetite” (i.e. tax liability resulting from taxable earnings).
Tax reductions and exemptions	Tax exemptions/reductions allow clean energy projects to avoid paying/ to pay certain types of tax, including, but not limited to, sales tax on capital equipment, property tax on renewable power plants, and import duties.
Renewable portfolio standards (quotas)	Utility quota obligations are regulatory policies that require utilities to supply a specified percentage of their sales with energy produced from clean energy sources. Utility quota obligations include renewable portfolio standards, clean energy standards, alternative energy standards and similar policies. There are also energy efficiency portfolio standards that mandate energy providers to meet a part of their energy demand through greater energy efficiency and that are entirely separate from clean energy generation. Some quota obligations combine energy efficiency and clean energy under the same mandatory target.
Tradable renewable energy certificates	Environmental attributes are one of the two commodities produced by a clean energy project (the other being energy production or savings) and consist of the environmental advantages or emissions benefits associated with the project. Environmental attributes trading agreements are a mechanism to enable the selling and purchasing of environmental attributes. Environmental attributes have assumed the status of a tradable commodity and are often codified in the form of Renewable Energy Certificates (RECs). The upshot is that the environmental attributes of a clean energy project are assigned a cash value which can be used as a source of project revenue. A purchaser of the RECs may be different from the purchaser of the clean energy.

Sources: OECD (1998), Glemarec (2011), RETScreen (2012)

Emission trading schemes could also have beneficial effects on renewable energy production. Although they aim to reduce greenhouse gases or other pollutants (including NO_x and SO_x) through the sale of a credit or permit to emit a defined amount of the pollutant, they impact renewable energy technologies development, since renewable energy producers can also benefit by generating their own emission credits which they can sell on the market, thus generating an additional project revenue stream.

Government support to renewable energy can also be represented by services provided by government at less than full cost. In the case of renewable energy development, two examples emerge in this area: public intervention in infrastructure development and government research and development expenditure.

Given the large number of available options, which one is more suitable for reaching the 100% renewable target? Should policy makers move budget to feed-in tariffs or to investment grants for renewable power? Should governments set mandatory efficiency standard for new and refurbished construction or encourage utilities to support voluntary energy efficiency incentives?

Of course the answer to these questions depends on a number of considerations beyond the scope of this study. Although the choice of mechanism depends on local political and economic conditions, the economic literature in the field (Glemarec, 2011) and recommendations of international organizations (IEA, 2008) recognise that for a successful renewable energy policy intervention, any chosen instrument should meet a number of conditions. It should be stable, long-term and legally protected and transparent, with well-defined eligibility criteria. It should have adequate compliance penalties and enforcement mechanisms. It should be designed to ensure that incentives (if any) do not exist in perpetuity or create industries that are economically dependent on them. It should be tailored to the particularities and realities of the economic/financial, political and social conditions. The measures should undergo periodical evaluation to provide practical feedback for rearrangement and if needed any modifications. All measures should be effectively integrated into the broader institutional framework for the transition to renewable energy.

Different measures (incentives and regulations) should ideally be combined in an optimal mix in order to most efficiently accomplish the 100% renewable target.

Special attention should be given to financing the investments the country will need in renewable energy plants, grid extensions, etc. Given the large amount of investments needed to reach the 100% renewable target, investment policies should be carefully designed to attract sufficient financing for renewable projects.

Capital grants are used to support early-stage technologies and to stimulate commercialization of new technologies. They can help reduce risks and capital costs for building a new energy plant as they are paid in advance, based on installed capacity. Grants have been used successfully, for instance, in developing renewable energy production in many countries (REN, 2011). Moreover, in response to the recent financial crisis, most governments have agreed on green stimuli packages, the largest share of which will be distributed to the energy sector as capital grants and loans.

Low interest rates and loan guarantees have a major impact on the overall cost of renewable energy projects. The developers of renewable energy projects often do not have a proven track record, as well as some of the new technologies they are investing in have not yet reached a mature state. As a result, these investors are struggling for capital and access to

commercial loans at reasonable conditions. By offering low-interest loans with long repayment periods or loan guarantees, governments can increase the commercialization of such projects. On the other hand, loan guarantees by the government warrant debt repayment to the lending bank in case the project fails. This policy measure reduces risk and hence the interest rate, debt term and debt service conditions of the loan (IEA 2008, among others).

Accelerated depreciation schemes grant the right to depreciate certain types of clean energy equipment over an accelerated time frame, thereby lowering effective tax rates in the early years of an investment. This way, the tax benefit of depreciation can be maximized by the equity provider, on the condition that they have a net income which is large enough to completely absorb the tax deduction. In general, an accelerated depreciation scheme produces a higher overall net present value of the project (REN 2011).

Investment tax credits (ITC) allow renewable energy developers to deduct a specified percentage of their project investment from their tax liability in addition to the normal allowances for depreciation. They are linked to installed production capacity. ITC are similar to accelerated depreciation because they allow faster amortization of investment in the early years of a project. However, it differs by offering a percentage deduction at the time a plant is built/purchased.

National and state-run venture capital funds and publicly-funded venture capital have also been used around the world as a solution to perceived equity gaps (REN 2011).

All policy measures targeting investment entail risks for the government, particularly in the case of direct financial transfers. For that reason the measures to be taken for the renewable energy sector should be inscribed in a stable framework, as explained above.

Since governments do not have preferential access information relative to private agents, they are concerned with two main issues: (1) how can it reliably distinguish between firms in order to maximize the return on public investments? and (2) how can it be sure that a firm will use the financing granted to behave in a manner that it otherwise would not have ?

In the case of direct loans on preferential terms, government support may encourage cash-poor firms with good projects to carry out their projects. On the other hand, they create an incentive for subsidized entrepreneurs to overinvest beyond the desired investment level. Furthermore, they can create a disincentive for all agents to save ('crowd out' private investment) and a disincentive for unsubsidized firms to enter the market.

A significant shortcoming of fiscal incentives can be their perceived instability. Many studies argue that uncertainty is the major barrier for the breakthrough of renewable energy technologies. These policies are often unpredictable and subject to manipulation over time as government leadership changes. Thus, changes to renewable energy subsidies tend to be abrupt and are therefore disruptive for investors. They usually rely on government budgets and are thus subject to frequent political negotiations and annual budget constraints. Moreover, in the case of measures for which the benefits at the project level are accrued over a

number of years, the effects are likely to be even more important. For those reasons, fiscal incentives should be announced and guaranteed for a fixed period of time in advance. Theoretically, they could be financed through a surcharge on energy consumption, which is automatically adjusted to the amount of support paid. These measures are likely to increase stability and reduce regulatory risk.

9.2.4. Upgrading infrastructure: improving the grid and facing the challenge of distributed electricity generation and more electricity trade

All pathways to the 100% renewable target share some common features with regard to energy infrastructure. In particular, the electricity grid will have to be improved in many aspects in order to meet the challenge of distributed electricity generation and more electricity trade (both import and export).

What has been mentioned above about investments for renewable energy production also applies to the vast amount of investments needed to upgrade the grid.

Distributed generation avoids some of the costs of transmission and distribution infrastructure and power losses, which together can total up to half of delivered power costs. Policies to promote distributed generation—including net metering, real-time pricing, and interconnection regulations—do not only apply to renewable energy, but can nevertheless strongly influence renewable energy investments.

Non-discriminatory interconnection laws and regulations are needed to address a number of crucial barriers to interconnection of renewable energy with the grid. Interconnection regulations often apply to both distributed generation and “remote” generation with renewable energy that requires transmission access, such as wind power.

Historically, transmission policies have often imposed severe penalties on unscheduled deviations from projected (advance-scheduled) power generation. These penalty structures render intermittent generation, such as wind power or PV, uneconomic.

Real-time accounting of power transfer deviations that charges or credits producers based on the value of energy at the time of the deviation, as well as elimination of discriminatory deviation penalties allow intermittent renewable energy to compete more equitably with traditional generation.

Policies that allow near-time or real-time scheduling of the output levels of intermittent resources can further reduce deviation costs. For example, wind farms are able to predict their output much more accurately, up to an hour in before generation, and can thus be better scheduled hour-by-hour rather than day-ahead.

Because distributed renewables, such as wind power, are often remotely located, they could incur high transmission fees as power crosses multiple jurisdictions to reach the customer⁶³. Such cumulative addition of transmission fees is known as "rate pancaking." (Beck and Martinot, 2004). Elimination of access rate pancaking, either by consolidation of long-distance tariffs under a regional transmission organization and/or by creating access waiver agreements between multiple owner/operators can reduce discrimination against wind power and other remote distributed renewables.

Transmission congestion occurs when the demand for a transmission path exceeds its reliable capacity. In such circumstances, system operators must allocate available capacity among competing users. Traditional utility policies often favour early market entrants, "grandfathering" them into capacity allocation rules. Wind power is particularly susceptible to transmission constraints, as sites are generally located far from load centres. Elimination of grandfathering would allow transmission users to bid for congested capacity on an equal footing. Allowing wind power to bid for congested capacity closer to the operating hour and reducing congestion through transmission line upgrades would also reduce barriers to wind energy development.

Furthermore, trying to match renewable electricity production and electricity demand at local level can reduce the need for new transmission capacities. This can be achieved by encouraging consumers to postpone some of their consumption or by granting conditional grid access to renewable producers in order to avoid the injection of excess power into the grid when it is overloaded.

Utilities may require the same interconnection procedures for small systems that are required for large independent power production facilities. The process of negotiating a power purchase/sale contract with the utility can be very expensive and utilities can charge miscellaneous fees that greatly reduce the financial feasibility of small grid-connected renewable installations. Standardized interconnection agreements can expedite this process.

Net metering allows a two-way electricity flow between the electricity distribution grid and customers with their own generation. When a customer consumes more power than he/she generates, energy flows from the grid and the meter runs forward. When a customer's installation generates more energy than it consumes, energy flows into the grid and the meter runs backward. The customer pays only for the net amount of electricity used in each billing period and is sometimes allowed to carry over net electricity generated from month to month. Net metering allows customers to receive retail prices for the excess electricity they generate at any given time. This encourages customers to invest in renewable energy because the retail price received for energy is usually much higher than if net metering were not allowed and customers had to sell excess energy to the utility at wholesale rates or avoided costs.

⁶³ In Belgium, this would be the case for offshore wind parks as well as any other electricity transmission across the three regions.

Electricity providers may also benefit from net metering programs, particularly with customer-sited PV which produces electricity during peak periods. Such peak power can offset the need for new central generation and improve system load factors.

Real-time pricing, also known as dynamic pricing, is a utility rate structure in which the per kWh charge varies hourly based on the utility's real-time production costs. Because peaking plants are more expensive to run than baseload plants, retail electricity rates are higher during peak times than during shoulder and off-peak times under real-time pricing. When used in conjunction with net metering, customers receive higher peak rates when selling power into the grid at peak times. At off-peak times, the customer is likely to purchase power from the grid, but at the lower off-peak rate. Photovoltaic power is often a suitable candidate for real-time pricing, especially if maximum solar radiation occurs at peak-demand times of days when power purchase prices are higher. Real-time metering equipment is necessary; adding complexity and expense to metering hardware and administration.

9.2.5. Moving towards electrification

A major shift towards electrification will occur in the pathways to the 100% renewable target. Electricity production increases significantly in all scenarios. This increase is particularly outspoken when the supply of biomass energy is limited (as in the PV and WIND scenarios). Restricted access to biomass urges society to rapidly transform into a fully electrified society. In addition to all technical consequences of such a drastic energy transformation, this will also impact consumers and producers.

The importance of storage costs implies that it may be more cost-effective to adapt electricity consumption to the intermittent renewable energy flow instead of trying to store enough energy to maintain current consumption habits. This would encourage all economic players, residential or professional, to shift some parts of their consumption to low electricity price periods.

This would have important consequences for work organisation such as collective closure during winter period when solar radiations are insufficient to cover a major part of the energy demand. Doing so, excess electricity would partly be stored in consumer goods instead of in costly storage capacities.

Such a radical transformation would necessitate broad negotiations between governments, employer federations and trade unions. Changing the division of active and non-active periods throughout the year would be a challenge of the renewable transition from social and economic points of view. Although this can be seen as a major difficulty towards a 100% renewable energy system, it is important to note that companies have since long adapted their work organisation to benefit from the lowest electricity prices (e.g. electric arc furnaces that only run during night periods). However, this is just an adaptation to day-night variation of electricity prices, while in the case of the renewable transition described in this report, companies would have to consider seasonal variation, which is much more challenging.

9.2.6. Stimulating technical change

As some of the renewable and related technologies are still in early phases of their respective development chains (e.g. hydrogen technologies, storage technologies, etc.), further cost reduction is essential and research and development financing, alongside market development, is a crucial driver towards such reductions.

In the broadest sense, policies to support the adoption uptake of any technology can be divided into “technology push” policies (research and development) and « market pull » policies (deployment policies) (IEA, 2008).

In recent years, members of the research community have begun to refer to the existence of a “valley of death” between the demonstration of a technology and its uptake by the market, even with proven cost-benefit balance. If countries are to benefit fully from resulting innovations, and if those innovations are enabled to move from “novel” technology status to the mainstream, coherent policy frameworks should be designed to seamlessly join R&D policies in pushing technologies towards the market with “market pull” policies.

Government R&D investments are usually targeted at areas with high risk and long-term perspectives, whereas private sector involvement usually tends to be in pre-competitive, short-term demonstration and commercialisation of technologies.

The following elements and procedures contribute to good and effective policy making in technology research (IEA, 2008):

- Policy should be integral to a defined renewable energy strategy, which in turn is part of an overall energy strategy.
- Policy should be structurally linked to measures for commercialisation and deployment within a coherent framework.
- Priorities must be clearly defined but flexible enough to alter as breakthroughs occur or needs shift. The involvement of all stakeholders - private, academic and other - is paramount here.
- Evaluation and monitoring mechanisms should be in place from the start with clear guidance on what is expected.
- Clear definitions and boundaries with regard to the roles of government and all stakeholders.
- Adequate funding is essential to match the range and potential benefits of technologies.
- Funding must be stable. R&D can be lengthy; a degree of predictability with regard to funding availability is essential.

- Public-private partnerships should encourage both sides to provide significant funding.
- International collaboration can provide significant benefits (see above).

Research and innovation activities should also focus on instruments - training, public procurement, standardisation, insurance, etc. - to accelerate the transition from research to exploitation.

The emergence of new technologies will also require the improvement of labour qualifications as the availability of workers with the right skills will play a critical role in the transition to 100% renewables. In order to enable employers investing in new technologies to find workers with the right skills, future labour market demands must be anticipated. This will create the conditions for employment opportunities for both new workers and workers that will lose their jobs due to the transition to renewable energy.

9.3. Which measure for which aim?

In order to make the transition to renewable energy socially responsible, the following principles should be taken into account when mixing measures for designing policies for the 100% renewable target. Every instrument should be evaluated against 3 criteria: (1) cost-effectiveness, (2) fairness and (3) competitiveness.

9.3.1. Cost effectiveness

The transition to 100% renewables should be cost-effective⁶⁴, with initiatives providing the highest reduction in fossil fuels use for every euro spent.

Although the transition to 100% renewables will bring about many co-benefits, renewable energy policy initiatives can involve government's major expenditure. Thus, it remains a crucial consideration how to best balance the achievement of policy objectives with policy implementation costs. Policies must be designed to provide a sufficient incentive to achieve the goals set but to avoid unnecessary expenditure and thus undue burden on public funds or ratepayers. There is a delicate balance to be made between 'too much' and 'too little' support.

This means, among other things, that the focus is not on the large-scale use of technologies which require high subsidies. For these technologies focus is instead on research, development and demonstration, which in the long term can make them competitive at lower levels of subsidy.

⁶⁴ Efficiency is the extent to which the program has converted or is expected to convert its resources/inputs (funds, expertise, time, etc.) economically into results in order to achieve maximum possible outputs, outcomes, and impacts with the minimum possible inputs. Cost-effectiveness is the extent to which the program has achieved or is expected to achieve its results at a lower cost compared with alternatives. Value-for-money is a related concept which assesses the extent to which the program has obtained the maximum benefit from the outputs and outcomes it has produced within the resources available to it. (IEG-World Bank, 2007)

The transition to 100% renewables will inevitably pose a challenge to public finance, which will lose revenues from fossil fuels taxation on the one side and will need to increase spending for supporting renewable energy production on the other. The distribution of benefits and costs connected to the transition should not burden public finances. Therefore, the transition should be fully financed. Expenditure should be covered by energy consumers (companies as well as households), but also by moving taxation to non-sustainable consumption, through a wider use of environmental taxes.

A carbon tax, for instance, would push less carbon intensive activities. Taxing the burning of fossil fuels in proportion to their carbon content will immediately increase the competitiveness of renewable energy technologies. It will also help recovering some of the foregone government revenue from fossil energy taxes. Furthermore, it will allow for a "green tax reform", moving taxation, for example, from labour to non-sustainable consumption.

9.3.2. Fairness

Any policy/measure for the renewable transition should be evaluated taking into account the negative impact on low-income households, the risk of increasing energy poverty and the need not to increase the disparity in the access to energy saving measures and in the production of renewable energy.

The transition to 100% renewable energy should also not undermine nature or environmental assets. This implies, for instance, sustainable use of biomass resources and the fact that the new infrastructure will take nature into consideration.

9.3.3. Competitiveness (green growth)

The transition needs to take into account the competitiveness of Belgian businesses. This requires that companies know the long-term framework in which they must operate and that energy costs do not increase abruptly (due to the transition to 100% renewables).

On the one hand, moving to 100% RES will certainly create great opportunities for businesses to move towards a greener economy (new markets and investment opportunities). On the other, the 100% renewable target could put pressure on the most energy-intensive sectors of the economy which could be exposed to the risk of delocalization to the extent that the sum of direct and indirect additional costs induced by the 100% trajectories would lead to a substantial increase of production costs. So, any policy should be designed and evaluated while taking into account its impact on Belgian enterprises.

9.4. Recommendations

As shown in the precedent paragraphs, the transition to 100% renewable energy can be promoted by combining many different measures. Although the final choice between all those

instruments lies with policymakers in function of their different political perspectives, some recommendations can be given.

A favourable institutional framework would set up proper market mechanisms that can guarantee sufficient supply security and correctly value the electricity coming from different market players at different times. It is questioned whether or not today's market is able to guarantee a continuous energy supply. Capacity mechanisms have been introduced in other European countries ever since the electricity market deregulation. Different pricing mechanisms are possible in deregulated markets. In deregulated markets in general, but even more in deregulated markets with a high share of renewable electricity, investments in new capacity are risky. Part of the model results of this study can be used to further analyse the different market mechanisms that would be necessary in a 100% renewable energy system. One conclusion is certain: if demand flexibility is less than optimal or in absence of long-term energy storage, electricity prices will be much more extreme in some scenario's with periods with very high prices and periods with very low or zero prices. At the same time, price differences between periods will induce more research and hopefully cheaper electricity storage solutions. There are reasons to believe that the need for capacity mechanisms in the electricity sector will increase mainly because of uncertainty, market power and societal risk of supply security.

As for the institutional framework (see Table 23), priority should be given to fixing targets for renewable energy production and establishing clear administrative procedures for renewable energy related projects. Although it is not urgent, negotiation and cooperation with neighbouring countries on the development of far-offshore wind farms and of electricity interconnections will be a key for the successful transition to 100% renewables, in particular for the WIND and GRID scenarios respectively. In the BIO scenario, an important action for ensuring the sustainability of the transition to 100% renewable would be to insist on the sustainable criteria for biomass.

With regard to energy efficiency (see Table 24), policymakers should focus on measures to speed up the renovation of existing buildings and the increase of energy efficiency in the different economic sectors. Green public procurement, and in particular public expenditure related to highly energy-efficient products, should be used as a tool to accelerate the transition from research to exploitation of new, more efficient products.

As renewable energy production concerns, the measures to support renewable energy production in order to meet the targets should be carefully calibrated, taking into account market conditions for each renewable production technology. Geothermal electricity production, in particular, should be promoted as it represents an important renewable source that cannot be easily replaced.

With regard to the grid (including storage solutions), the future power system has to be more versatile and allow for a combined approach of both centralised and decentralised power generation. Hence, priority should be given to the measures connected to networks modernisation in order to be ready to electricity generation closer to electricity demand and improve

end-user participation and massive demand-side response to adapt to renewables availability. Storage, industry, residential and transport demand will need to be considered in an integrated way.

As for electrification, priority in all the scenarios (but to a lesser extent in the BIO scenario) should be given to the promotion of electric mobility. Policymakers should also prepare the way for a change in work organization.

With regard to R&D (see table 25), priority should be given to the deployment of technologies for geothermal electricity production and to storage solutions.

Tables 23, 24 and 25 further detail the recommended measures related to the institutional framework, energy efficiency and R&D. For each policy area, the measures are first described, their level of priority is highlighted, the sectors that will be mostly affected and the critical issues each measure will be confronted are given.

Table 23 : Recommended measures for the transition to 100% renewables by 2050 with regard to the institutional sector

Measure	Priority	Scenario (s) most impacted	Sector(s) most affected	Ren. Technology	Cost Effectiveness - Fairness - Competitiveness
Fixing targets for renewable energy production. As investment decisions in the energy sector are of a long-term nature, governments should quickly proceed with fixing binding intermediate renewable energy targets to reach 100% renewable energy by 2050. In particular, following the results of the renewable scenarios, a binding target for 100% RES electricity should be set by 2030.	1	ALL	Energy	ALL	A long-term framework for the development of renewable energy production would enhance the possibility to attract stable investments for the entire renewable energy sector, from technology production to energy production. This would ensure the technological and market leadership of the renewable energy industry, which will thus become the motor for sustainable economic development. A high degree of interaction is to be foreseen with other objectives in terms of energy efficiency and emission reduction in order to avoid possible conflicts.
Implementing cooperation mechanisms in the context of offshore wind parks in the north sea. Although there is ample space in the north sea, many attractive areas for developing offshore wind farms within reasonable cost ranges are already occupied by other sea users. Moving wind farms further from shores and into deeper waters not only drives costs up, but also raises the issue of the availability of deep-sea technology components and the need for an offshore grid.	2	WIND	Energy	WIND	International cooperation in this field would allow for setting a stable framework for investments. Offshore wind farms are strategic in order to achieve the 100% renewable energy target in some of the renewable energy scenarios. In addition, they are less subject to public resistance, which could be a problem for increasing onshore wind energy. Furthermore, the development of far-offshore wind farms would require specialized competences, which would offer interesting opportunities for enterprises.
Definition of sustainable criteria for biomass - incentives to sustainable biomass (imports). A standard dealing with sustainability principles, criteria and indicators including their verification and auditing schemes for biomass for energy applications should be developed. This includes greenhouse gas emission, biodiversity, environmental, economic and social aspects. This standard should be used for setting requirements and incentives for biomass energy use.	2	BIO	Government	BIO	Sustainable standards for energy used biomass would enhance the preservation of nature and would leave the possibility of using biomass for other non-energy uses.
Negotiating new interconnection capacities with neighboring countries. Interconnection of different electricity systems offers several advantages. In the first place, it provides reliability and increases the robustness of the system.	1	GRID	Government, Energy	STOGRI D	New interconnection capacity increases economic efficiency and reduces the possibility of abusing market power.

Measure	Priority	Scenario (s) most impacted	Sector(s) most affected	Ren. Technology	Cost Effectiveness - Fairness - Competitiveness
	Rules for speeding up administrative procedures for renewable energy projects (windmills, grids...). Including co-ordination between the different administrative levels to handle and speed up authorization requests; unique public attention desk ("one stop shop" approach); supporting the business sector involved with the public administration with the continuous improvement of the technical administrative procedure to the RES installations; fixing deadlines for decision making; etc.	1	ALL	Government, Energy	ALL

Priority : 1 act now and succeed soon ; 2 think now and prepare to act soon ; 3 wait for further developments (better knowledge)

Renewable technology/energy source : GEO : geothermal ; WIND : wind ; BIO : biomass ; STOGRID : storage and grid

Table 24 : Recommended measures for the transition to 100% renewables by 2050 with regards to energy efficiency

Measure	Priority	Scenario (s) most impacted	Sector(s) most affected	Ren. Technology	Cost Effectiveness - Fairness - Competitiveness
	Keeping up with the existing targets for new buildings (passive house before 2020)	1	DEM	Residential	EFF
Measures for speeding up the renovation of existing buildings (also demolition and rebuilding rules). This could be done through financial incentives, certification, targets (for example consumption by m2), pilot projects, training activities, supporting low-energy buildings through regulation, communication and information activities	1	DEM	Residential	EFF	Promoting a « low-energy » construction sector will be a driving force in job creation of jobs and for sustained growth for the economy
Further advancement of the Ecodesign legislation. Ecodesign provides rules for improving the environmental performance of energy-related products.	2	DEM	All	EFF	This should benefit both businesses and consumers by enhancing product quality and environmental protection.
Green public procurement for energy using products (including buildings). By using environmental criteria, public authorities can buy electricity, transport services, office IT equipment and many other goods and services that contribute to the reduction of environmental impacts (reduced energy consumption) and to the development of renewable energy production.	1	ALL	Government	EFF	GPP would be a great opportunity for market development, for example for new more efficient energy using products.

Measure	Priority	Scenario (s) most impacted	Sector(s) most affected	Ren. Technology	Cost Effectiveness - Fairness - Competitiveness	
Agreements for increasing energy efficiency and for increasing the renewable energy share in the industry and services sectors	1	ALL	Industry and Services	EFF		

Priority : 1 act now and succeed soon ; 2 think now and prepare to act soon ; 3 wait for further developments (better knowledge)

Renewable technology/energy source : GEO : geothermal ; WIND : wind ; BIO : biomass ; STOGRID : storage and grid

Table 25: Recommended measures for the transition to 100% renewables by 2050 with regards to R&D

Measure	Priority	Scenario (s) most impacted	Sector(s) most affected	Ren. Technology	Cost Effectiveness - Fairness - Competitiveness
Fine estimation of geothermal energy potential	1	ALL	Energy	GEO	
Supporting the deployment of technologies for geothermal electricity production (e.g. ORC technology)	1	ALL	Energy and industry (producers of technology)	GEO	Opportunity for "green growth" for existing and new enterprises
Supporting the deployment of new technologies for renewable energy production, storage and energy efficiency	2	ALL	Energy and industry (producers of technology)	ALL	
Fine estimation of the potential for storage (for example hydrogen, compressed air, ...)	1	ALL	Energy	STOGRID	
Participation in international research programs for storage technologies and energy transport technologies	1	ALL	Energy and industry (producers of technology)	STOGRID	
Education: improve skills related to energy efficiency and renewable energy jobs	1	ALL	Energy and industry (producers of technology)	ALL	New employment opportunities

Priority : 1 act now and succeed soon ; 2 think now and prepare to act soon ; 3 wait for further developments (better knowledge)

Renewable technology/energy source : GEO : geothermal ; WIND : wind ; BIO : biomass ; STOGRID : storage and grid

10. Conclusion

The main goal of this study is to examine the feasibility and the impact of a 100% renewable energy target on the future Belgian energy system⁶⁵. Although the realisation of such a transformation within a 40-year perspective may at first seem highly ambitious in a nation rather poorly endowed with natural resources and possessing both a highly energy-intensive industry and an energy-greedy residential sector, it appears to be technically feasible. Not only is it feasible, it is even doable without having to change the current “economic paradigm”, even if many uncertainties remain and might alter certain results of the model. Moreover, not just one single pathway results from the exercise, but a multitude of scenarios can be traced. These pathways largely depend on political visions and societal choices that will affect the structure and content of the entire energy system and the way it is perceived. The consequences in terms of investments and infrastructure (grid, land use planning, transport systems etc.) over the entire time horizon are vast and diverse.

Extensive electrification and almost 100% renewable electricity by 2030

Moving to a 100% renewable energy system implies a radical transformation of nearly all sectors of the economy. The model shows that the strongest growth of renewable technologies is concentrated in the period 2030-2050. Nevertheless, some sectors experience thorough impacts earlier on through high growth rates of renewable energy technologies. This is particularly the case in the electricity production sector, which has to be transformed almost completely into a renewable based sector by 2030, since investments in the power generation sector appear to be the least expensive. Furthermore, the results of the model indicate that a 100% renewable energy system needs extensive electrification, causing a doubling or even tripling of the current electricity production by 2050.

Energy imports strongly diminish, but remain important

Transforming the energy system into a 100% renewable system will require considerable investments in demand-side management technologies, storage capacities and energy production installations. On the other hand, a higher share of renewable energy or lower energy consumption implies less fossil fuel purchases, which may reduce the national external fuel bill. Indeed, it is evident that solar, wind, hydroelectric or geothermal energy production installations do not need fuel input to produce useful energy for final consumers. The only exceptions to this rule are biomass and electricity imports which will tilt the balance of payments. Some scenarios import large amounts of electricity produced in neighbouring countries or biomass for energy use shipped from abroad. Nonetheless, the sum of biomass and electricity imports does not equal the current import of fossil fuels in monetary terms, not even in the BIO and GRID scenarios. Therefore, Belgium stands to gain from switching to an all-renewable system from that perspective. In terms of energy, biomass and electricity imports still have a notable share in terms of primary energy in the renewable scenarios. Even so, the share of total imported energy tumbles from 83% in the reference scenario to a range

⁶⁵ It is important to remember that maritime transport and aviation are excluded from the scope of the study.

between 15% and 42% in the renewable scenarios. The most important reductions in energy import dependency occur in the PV and WIND scenarios.

Additional energy system costs are rather stable over the different scenarios

The energy system cost is the sum of all energy expenses in an energy system. It consists of variable, fixed and investment costs. We calculated that the increase of the energy system cost amounts to approximately 20% in 2050, or 2% of Belgian GDP in 2050 (GDP₂₀₅₀). For most scenarios, the additional energy system cost can be broken down into additional investment and fixed costs of roughly 4% of GDP₂₀₅₀ and reduced variable costs of roughly 2% of GDP₂₀₅₀. This result depends, however, on various assumptions, of which the evolution of fossil fuel prices over the next 40 years is the most important. In other words, the 100% renewable energy target implies a societal shift from a fuel-intensive to a capital-intensive energy system. The highest reductions in variable energy costs are observed in the DEM, WIND and PV scenarios with savings over 10 billion € a year. In these scenarios, investments have to double relative to the reference scenario to be able to reduce variable costs by 60%. In the BIO scenario, investments need to increase by at least 50% to obtain variable cost savings of at least 20%. The necessary power sector investments vary between 1.0% (DEM scenario) and 1.7% (PV and WIND) of GDP₂₀₅₀. In conclusion, we can say that from today up to 2050, 300 to 400 billion € of investments are needed to transform our current energy system into a 100% renewable energy system.

Disutility costs and avoided greenhouse gases have an important impact on net costs

The different scenarios offer a broad portfolio of solutions to achieve the 100% renewable energy target. The additional energy system cost of the 100% renewable energy scenarios does not include the cost of having consumption reduced or the benefit of having emissions decreased (or even eliminated). When disutility costs are taken into account, total costs increase, but when the avoided costs of greenhouse gas damage are taken into account, total cost decrease.

Disutility costs or demand losses are difficult concepts, but the easiest way of looking at them is that a loss in demand is a loss of consumption, consumption generating a certain level of utility. When these utility losses are included, the additional cost to transform the energy system into a 100% renewable system amounts to 30% of the energy system cost in the reference scenario. However, even in the DEM scenario which is characterised by reduced energy service demands, increased investments are observed in all sectors of the economy, while the domestic renewable energy potential is fully exploited in order to cover the largest possible share of the (remaining) energy demand. The model shows that curtailing energy imports, combined with a rather limited national renewable potential (as in DEM), requires a drastic reduction of the energy service demand, with a non-negligible impact on total costs.

When including both disutility costs and avoided damage costs of greenhouse gas emissions, some scenarios show a net positive effect of 10 billion € per year, a number that is strongly dependent on GHG damage cost assumptions.

Impact of fuel prices and PV costs

The impact of the most important uncertainties has been quantified by running the TIMES model for variants of the standard scenarios: an alternative reference scenario has been defined, in which fuel prices are supposed to soar to 250 \$/08/boe in 2050: REF_ASPO, an alternative biomass price scenario in which the price for importing biomass decreases from 155 \$/08/boe in 2050 to 78 \$/08/boe and two alternative PV panel costs scenarios: 1000 and 371 €/05/kW_{peak} rather than 500. When comparing the cost of the 100% renewable scenarios with REF_ASPO, it is clear that they are drastically lower in the former scenarios. The impact of the alternative reference brings down total additional costs with some 2% of Belgian GDP in 2050. Decreasing the cost assumption for biomass importation decreases total additional cost with 1% of GDP₂₀₅₀. Increasing or decreasing the cost assumption for PV panels makes the total additional costs go up or down by 0.5% of GDP₂₀₅₀.

Creation of additional employment

Although total system costs may appear considerable, one has to bear in mind that orienting our energy future towards renewable energy sources also entails benefits. Not some minor side benefits, but important gains can and will be created when switching to an all-renewable energy system. In addition to the already mentioned positive effects on the external fuel bill, on import dependency and on damage costs already being cited, other possible (non analysed) effects may relate to local air quality, significant reductions in greenhouse gas emissions, general health benefits as well as lesser to no depletion of natural (fossil) resources and halted future generations' planet impoverishment. One of those positive effects is further analyzed in the course of this study: the creation of additional employment through the renewable value chains. It was estimated that, by the end of 2030, this effect would create 20 000 to 60 000 additional full-time equivalent jobs compared to the reference scenario. At any point in time, the renewable scenarios create more full-time equivalent jobs than the reference scenario. The high end of the interval is taken in by the PV scenario, given that it necessitates many discrete panel installations combined with a large installation component in PV employment. The BIO and DEM scenarios are the second highest job generating scenarios, the BIO scenario mainly through the increased demand for (inland) farming, the DEM scenario through the major boost that is given to the national construction sector and, with it, to its entire value chain. Although it cannot be guaranteed that all created jobs are and remain within our national boundaries, it cannot be denied either that many of these jobs are locally rooted since they imply major installation and maintenance efforts. Moreover, being at the forefront and pursuing a swift and fast transformation towards a 100% renewable energy future does give Belgium a head start, thus accumulating technical expertise and scientific knowhow that can be exported outside our national frontiers, and with it creating export jobs.

A new paradigm on energy perception

This study teaches us that a new paradigm is arising in the way we think about energy. In a world without excess overcapacity of intermittent renewable energy sources and only limited access to biomass and geothermal energy, long-term (seasonal) storage is becoming extremely expensive. This leads us to believe that, in a cost-optimal modelling approach, a

transformation of the energy system towards abandoning strict equilibria and replacing it by installing overcapacity in intermittent renewable energy sources is to be preferred. In other words, it may be more cost-efficient for the Belgian society to adapt in a certain way to the variability of the solar energy flow instead of trying to store enough energy in order to keep our current socio-economic paradigm unchanged. This in turn can impact the current industrial organisation towards more seasonal production oriented sectors, using necessary energy commodities such as electricity only during the cheapest periods of the year when e.g. sunlight is abundantly available and closing down during the darker winter months. This flexibility within the industry can then be perceived as having the same effect as a giant battery in which electricity can be stored in the aggregation state of e.g. steel.

Six critical areas of action

The growth of renewable energy will need to be supported by a wide range of policies designed to overcome barriers to its adoption. Different policies work towards different objectives, but one single policy cannot solve all renewable energy market challenges. The study identifies six critical areas of government action/intervention: institutional framework; energy efficiency; renewable energy production; energy infrastructure; research and development and electrification.

An institutional framework defining the general context in which all specific policies and measures for reaching the 100% renewable target should be included is a prerequisite to any other policy. It clearly is important not only to make the transition to a 100% renewable energy system possible, but also to smooth out the impact of such ambition at all levels of the Belgian society.

Renewable energy production can be supported in multiple ways: by modifying the rules of the energy markets and trade, by promoting equity or debt investment through direct financial transfers, by tax rules or by direct government provision of energy-related services, just to mention a few. Special attention should be given to financing the investments the country will need in renewable energy plants, grid extensions, etc. Given the large amount of investments needed, investment policies should be carefully designed to attract sufficient financing for renewable projects.

In order to achieve the energy consumption reduction foreseen in the pathways to 2050, the main impact will come from the joint implementation of several complementary measures, which mainly include information programs, financial incentives and regulations.

A major shift towards electrification will encourage all economic players to move some parts of their consumption to low electricity price periods. The decision on and implementation of a new working structure that is largely inspired by energy cost considerations will need to be facilitated by broad negotiations between governments, employer federations and trade unions.

As some of the renewable and related technologies are still in the early phase of their development chain, further cost reduction is essential and financing research and development,

alongside market development, is a crucial driver towards such reductions. The emergence of new technologies will also require the improvement of labour qualifications as the availability of workers with the right skills will play a critical role in the transition to 100% renewable energy sources.

The research performed in this study was centred around an attempt to answer one main question, "How to achieve a 100% renewable energy target in Belgium in 2050?", and three related sub-questions "Which technologies are needed?", "What are the costs of these solutions?" and "What are the main obstacles?". Although different solutions and trajectories, with differing levels of detail, are formulated in the present report, this study is not the end of the story. It seems obvious that if this study has provided some answers, it also concludes with many new, open questions beyond the scope of the initial assignment (e.g. storage capacities, sustainable biomass availability, hydrogen technologies, social implications, etc.). These topics most certainly need further investigation as they are crucial to obtain a better understanding of what a 100% renewable future might look like.

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Annex 1: Methodology of the TIMES model

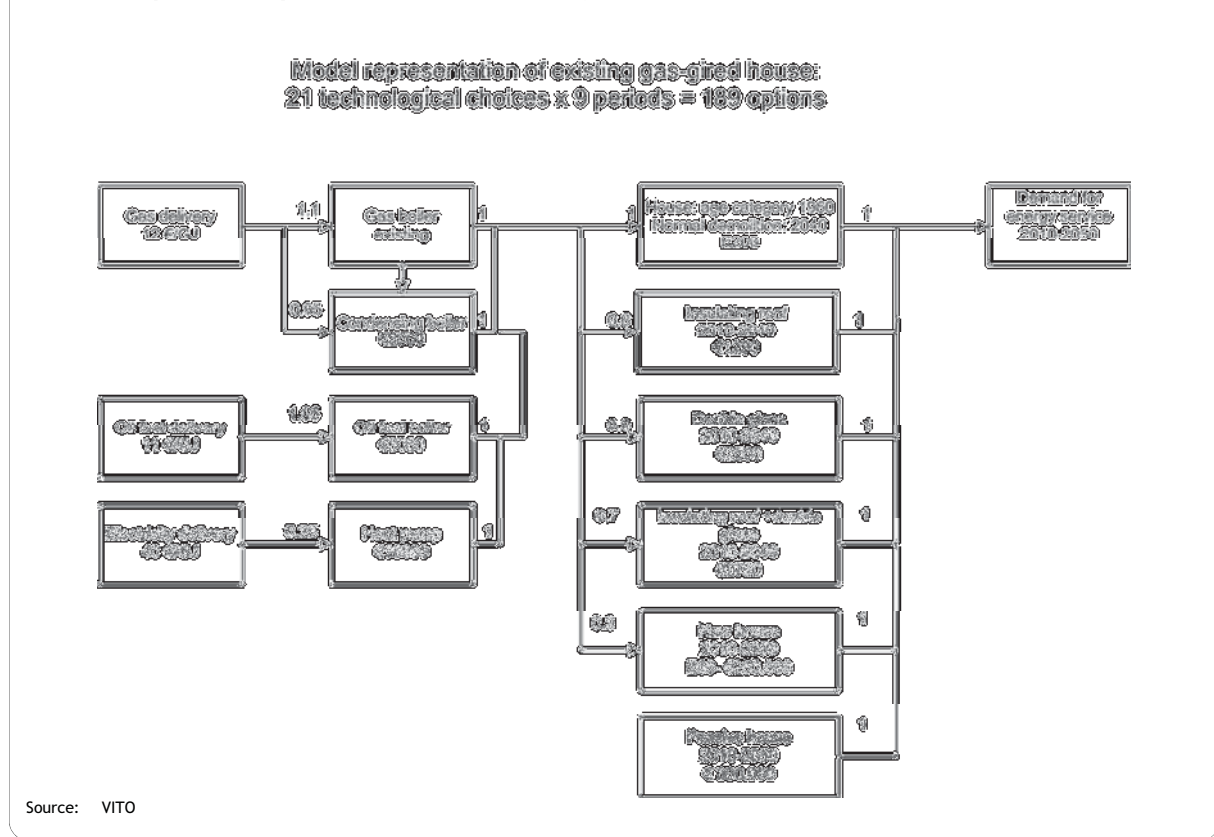
10.1.1. The Demand component: reference energy services

Energy, either as fuel or electricity provides a number of functions to the community which in TIMES modelling terminology are called reference energy services. Typical examples are the room temperature in houses and km driven by cars, tons of steel produced. The fulfilment of these energy services is a basic requirement in the TIMES model approach. Based on demand drivers (GDP, population, size of families etc.) which are obtained externally the user defines trajectories from the starting year up to the horizon of the analysis for the different energy service trajectories. For this purpose other modelling approaches or expert judgement can be used. Reference energy services are a main input in the TIMES modelling.

10.1.2. RES representation of the supply component

The real heart of TIMES is the exhaustive representation of the supply of energy services which we illustrate with an example for residential space temperature in an existing house. In Figure 33 technologies are represented by boxes and energy flows are represented by arrows. Fuel options are connected to heat producing technologies and heat requirements are determined by different insulation requirements. Figures close to the arrows indicate the amount of input required by the technology for producing one unit of output. Investment costs for new technologies (boiler and/or insulation) are indicated, but there is no investment cost for the current situation (gas boiler existing –E200 energy level).

Figure 33 : Representation of supply options to meet energy service demand for residential space temperature in an existing house



Given fuel and investment prices, the mathematical algorithm implemented in TIMES is looking for the cheapest solution to meet the required energy service demand. The figure represents only a small fraction of the model and does not represent the whole complexity of the decision process. In the Belgian TIMES model electricity is not supplied at a given price but it is produced, either by existing or new technologies. So the choice of electricity producing technologies interferes with the options in the residential sector. Similar model structures are designed for all energy demand services and as all energy flows are explicitly represented TIMES always produce a consistent view of the whole energy system.

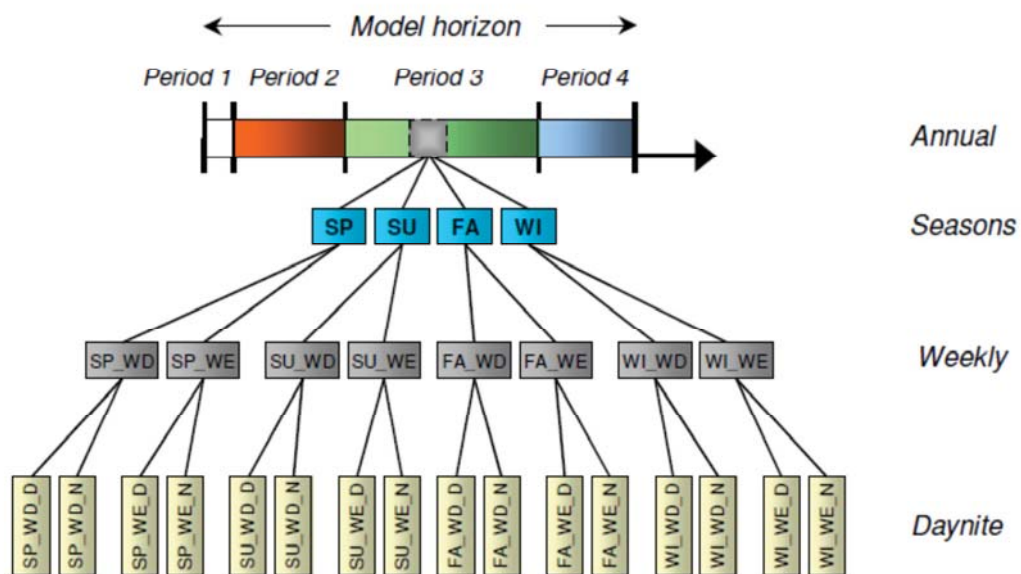
10.1.3. The policy component

Insofar as some policies impact on the energy system, they may become an integral part of the scenario definition. For instance, a No-Policy scenario may perfectly ignore emissions of various pollutants, while alternate policy scenarios may enforce emission restrictions, or emission taxes, etc. The detailed technological nature of TIMES allows the simulation of a wide variety of both micro measures (e.g. technology portfolios, or targeted subsidies to groups of technologies), and broader policy targets (such as general carbon tax, or permit trading system on air contaminants). A simpler example might be a nuclear policy that limits the future capacity nuclear plants. Another example might be the imposition of fuel taxes, or of industrial subsidies.

10.1.4. The time dimension in the TIMES

TIMES is extremely well suited for long term energy policy support as it allows consistent analysis of various scenarios. Typically a simulation horizon covers periods from 30 to 100 years, divided into a number of sub-periods, each of them covering a couple of years. Within one sub-period a higher time resolution is implemented to consider typical conditions determining supply and demand conditions. For instance it is apparent that solar energy is not available at night and heating requirements are concentrated in the winter months. The figure below represents a TIMES model with 16 time slices

Figure 34 : Example of the resolution of the time dimension in TIMES



Source: IER, Stuttgart

10.1.5. Price elastic demand: from reference energy service to policy energy service

A reference scenario depicts a situation in which all reference energy service levels are met disregarding the cost of the energy service. Typically in a reference scenario no stringent environmental constraints are implemented so that “normal prices” for energy service levels result, making the above assumption reasonable. In **Figure 35** below the curve **RD** represents the **R**eference energy service **D**emand. Because it is not price sensitive it is a straight vertical line. The curve **RS** represents the **R**eference energy service **S**upply. This curve consists of three segments representing the availability of three different technologies at increasing costs. The reference scenario defines the marginal cost of the energy service at level P_r . In this case this cost is determined by technology 2.

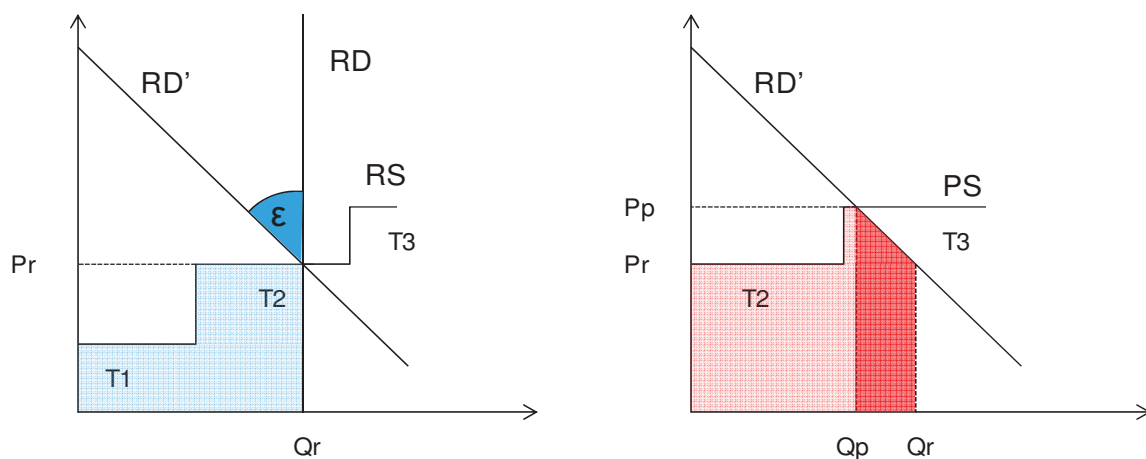
Developing a policy scenario involves two additional operations. The first one is to make the energy service demand price sensitive. In figure this is represented by turning the curve **RD** anticlockwise to **RD'**. The angle ϵ defines the elasticity. Note that this does not change the

solution as the demand curve still crosses the supply curve at the same point. The second action is to introduce the policy. Here we assume an embargo on technology 1 for environmental reasons. This shifts the supply curve to the left to obtain **PS** which is pictured in the right hand side of the figure.

Now the resulting equilibrium marginal costs become **Pp**. The reference energy service level is no longer fully met. The new equilibrium defines the Policy Energy Service level **Qp** which is smaller than the Reference Energy Service.

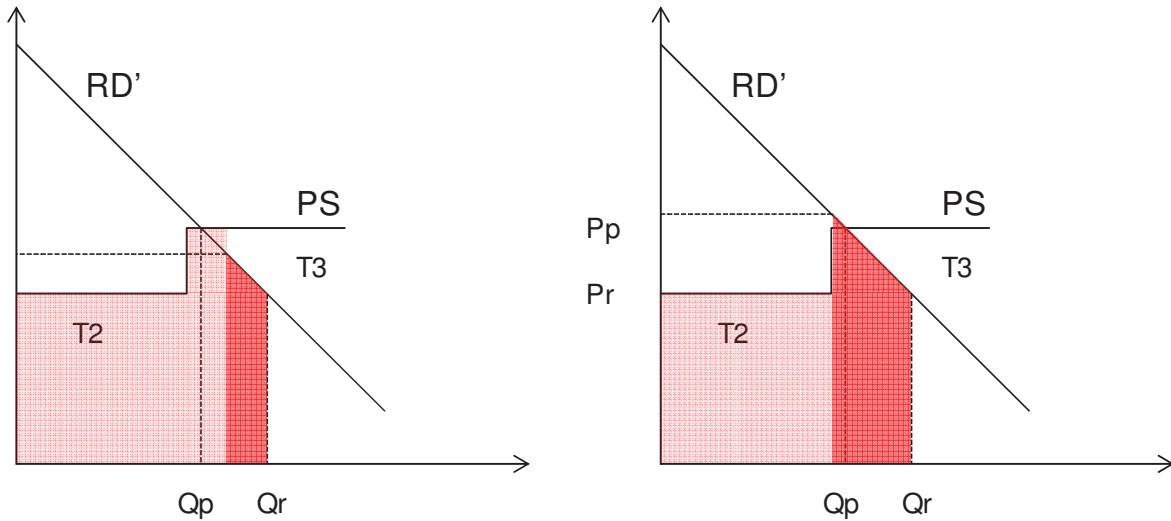
Figure 35 is also useful to define some cost concepts. The **energy system cost** of a scenario (Reference or Policy) corresponds to the money that is effectively spent on producing the corresponding energy service. It is given by the area below the supply cost curve (i.e. the light blue area for the reference scenario and the pink area for the policy scenario). Secondly **the loss in energy service**, i.e. the fact that a smaller amount of energy service is produced, is considered as a cost too. This is called the **Demand Loss or Disutility cost** and corresponds with the dark red area and can also be interpreted as a penalisation for the loss in energy service.

Figure 35 : Elastic demand in TIMES



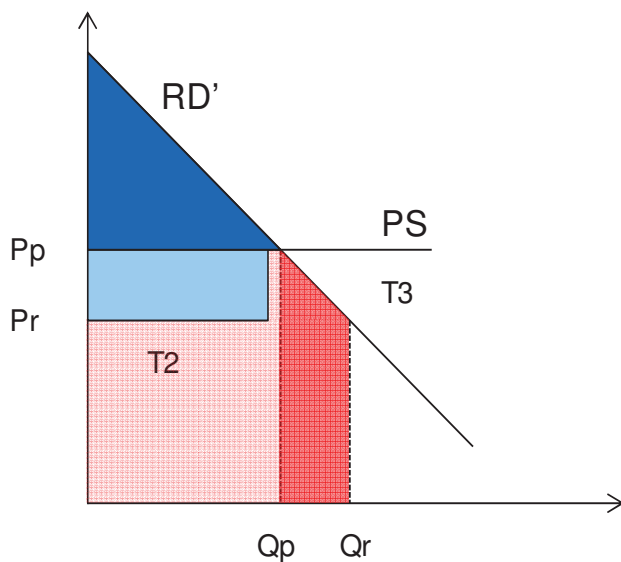
When running in the elastic mode the demand loss must be included in the objective function which can be seen from the following reasoning. Assume that the objective function would only include the pink area (which means that there is no penalisation for the loss of energy service). The solution would systematically point to zero energy service levels at zero costs.

We can also demonstrate that including the penalisation for the loss of energy service is equivalent to determining the point where the demand curve crosses the supply curve (the classical economic view). The left hand side in the following picture illustrates an increase of the energy service. The right hand side illustrates a decrease of the energy service. Both cases demonstrate an increase of the total area (pink + red)



Welfare interpretation of the solution

It is often argued that TIMES maximises the total surplus. The consumer surplus corresponds with the dark blue area and can be interpreted as a kind of virtual profit for those consumers whose willingness to pay is higher than the price Pp . The producers surplus corresponds with the light blue area and is the profit for the producers. As the total colored area (blue + red) is bounded by the demand curve obviously minimizing the red area corresponds to maximising the blue area.



10.1.6. Cost concepts in TIMES

TIMES allows introducing different types of costs which are handled in a different way. Costs in the future are given a smaller weight by discounting them. Here a social discount rate of 4 % is applied. In the following sections we explain briefly the main cost concepts and how the social discount rate applies on these costs.

Cost elements in the energy system cost

Typical cost elements of the energy system cost include investment costs, fixed and variable operating costs, fuel costs, and environmental taxes. Investment costs for technologies are expressed per unit of capacity. These costs are discounted and accounted for in the beginning of the lifetime of new equipment. Fixed operational costs are proportional to installed capacity and are discounted period per period. Similarly variable operation costs, fuel costs and emissions taxes are relative to the use of the technology (or function of emission level) and are accounted on a period per period basis.

Demand loss

Demand loss is always calculated in comparison of a reference situation. Discounting and accounting is period per period.

Sunk costs and depreciation costs

All investments from the past can be seen as sunk costs. Both from a societal or from a private perspective, these past investments are treated as 'no cost' options in investment analysis for new infrastructure or new production units. There is the choice to use or not to use the already existing capacities but there will only be a difference in variable costs as the investment was taken and is irreversible.

Not using or only partially using existing installations can have a high societal cost. A typical example is when the closing of installations requires the construction of new installations. A private company in a competitive environment takes the risk that its installation might be taken out of the market for several reasons. The operator could be left behind with depreciation costs if the capital costs of these installations have not been fully recovered.

In some cases, corrections need to be taken to intervene in the depreciation costs. In the transition phase from regulated to deregulated markets, for example, corrections might be necessary for investments that were made in a regulated market environment. Today, a regulated system applies to the transmission (border-to-border and domestic) and storage of natural gas and to the LNG terminal's activities. More general, corrections might be necessary as well when operation permits are agreed or contracted between companies and governments. In these examples, it could be justified to contribute towards the depreciation costs of stranded investments. If these stranded costs are paid, a transfer takes place. However, the real so-

cial costs are to construct new installations. The Belgian TIMES model takes these societal costs into account and it will minimise these societal costs.

10.1.7. Mathematical formulation

TIMES is formulated as a linear programming problem. This considers an objective function and a number of constraints. The constraints express that in each sub-period supply should be at least equal as demand and capacities should at least equal the use of technologies. Note that this mathematical formulation allows that supply exceeds demand and capacities exceed the use. TIMES minimizes the objective function which is the sum of the discounted energy system costs and the demand loss. The result gives a balanced mix of operational costs, investments cost and reducing demand.

Annex 2: Unit conversions

The report gives a glance of the shifts in the energy system. Typically different energy units are used to describe different types of energy. The report uses the official joule (J) for most of the energy vectors, except for electricity we use the watt-hour (Wh). The text box down gives an idea of the conversions.

Table 26 : Overview of energy and power units

Energy	Derived energy units	Power
Energy unit: joule (J) J = Nm (newton x meter) 1 MJ (megajoule) = 1.000.000 J 1 GJ (gigajoule) = 10⁹ J 1 PJ (petajoule) = 10¹² J	1 kWh (kilowatt hour) = 1 kW (power) during 1 hour (time) 1 kWh = 3,6 MJ 1 MWh = 3.6 GJ 1 TWh = 3.6 PJ 1 Mtoe (mega tonne oil equivalent) = 41,87 PJ 1 toe = 7,33 boe	Power: energy per time unit Power unit = watt (W) W = J/sec 1 MW (megawatt) = 1.000.000 W 1 GW (gigawatt) = 10 ⁹ W 1 PW (petawatt) = 10 ¹² W

Source: VITO.

The table down can be used to convert cost information to the preferred unit.

Table 27 : Conversion of costs' units

Energy	Background exchange rates / inflation
1 €'05/GJ = 3,6 €'05/MWh For 2010: 1 €'05/GJ = 7,84 \$'08/boe From 2020: 1 €'05/GJ = 6,76 \$'08/boe	The dollar exchange rate for current money changes over time; it starts at the value of 1.45 \$/€ in 2009 and is assumed to decrease to 1.25 \$/€ by 2020 and to remain at that level for the remaining period. €2005 = 1,056 €2008

Source: VITO and FPB

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