Scenarios for energy carriers in the transport sector

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Acknowledgement

Earlier this year our Cabinet together with more than forty organizations have endorsed an Energy Agreement for sustainable growth. The core feature of the Agreement is a set of broadly supported provisions regarding energy saving, clean technology, and climate policy. Implementing these provisions is intended to result in an affordable and clean energy supply, jobs, and opportunities for the Netherlands in the market for clean technologies. The Energy Agreement focuses on energy efficiency as a basis for strengthening competitiveness. There are 10 basic components to the Agreement of which mobility and transport is one. Each component in turn comprises several actions. One of the major actions in mobility and transport is the formulation of an integrated long term vision for a sustainable fuel mix for transport (2050). The Ministry of Infrastructure and Environment facilitates this action and is responsible with all relevant stakeholders in this field to report the results to the SER Commission before the end of 2014.

The ministry has put into place a participatory process comprising three phases. In the first that started in September, we worked on our knowledge base and scenarios. The second phase will focus on an integrated vision and the third and concluding phase will deliver a concrete action plan. This process will deliver several products and perspectives for and by all stakeholders.

The product of this first phase is now delivered through this report and provides us several scenarios that will allow us to gain a better understanding of the complexity, developments, insecurities and robust elements in the field of energy, fuels and transport. A international field and market, characterized by change and developments especially over the past few years. With new fuels and techniques coming rapidly into the transport market. The research consortium of TNO, ECN and CE have been valuable partners in harvesting our input and sharing our knowledge through stakeholder sessions that were held and well attended by you all.

These scenarios are but a mere first step and provide us a good point of departure for the next phase in which we will embark upon the actual writing of an integrated vision. This phase will allow us to look more in depth at what is needed to attain a wider application of sustainable fuels in the transport sector, and what the potential is for the long term. The challenge lies in acquiring a comprehensive vision of underlying dependencies and opportunities not only for climate targets but also for other environmental, energy, green growth and safety targets. In the third phase to be concluded towards the end of 2014, we will determine the required actions that all of us need to make in order to achieve this vision.

An integrated vision for a sustainable fuel mix for transport will provide a framework for us all for the short and long term. From January onwards we will embark upon writing the vision with all relevant stakeholders. I look forward to this phase of co-creation and have confidence that we will be able obtain a comprehensive vision around the summer.

Els de Wit
Coordinator Fuels
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Samenvatting

Energietransitie in de verkeerssector
In de verkeerssector is een omslag naar een meer duurzame wijze van transport nodig. Dit gegeven de doelen die de sector zijn opgelegd voor klimaat, luchtkwaliteit en geluid. In het recent ondertekende Energieakkoord voor duurzame groei, onder regie van de Sociaal-Economische Raad (SER), hebben partijen de basis gelegd voor een breed gedragen, robuust en toekomstbestendig energie- en klimaatbeleid. Op het gebied van mobiliteit en transport zijn partijen het eens over ambitieuze doelstellingen, namelijk een reductie van de CO2-uitstoot met 60% per 2050 ten opzichte van 1990[1] en op weg daarnaar toe een reductie tot 25 Mton (-17%) in 2030. In het kader van de beoogde extra energiebesparing van ten minste 100 PJ (finaal) voor de hele economie ten opzichte van het Referentiepad van het akkoord, zijn partijen overeen gekomen dat de transport en mobiliteit sector hieraan een bijdrage zal leveren door naar verwachting 15 à 20 PJ te realiseren in 2020.

Om deze doelen te realiseren, zijn in het Energieakkoord meerdere concrete stappen afgesproken. Een daarvan is dat partijen op korte termijn een gezamenlijke visie op de toekomstige energiemix voor de transport sector opstellen. Een dergelijke visie is nodig, omdat de overgang van fossiele brandstoffen – vooral diesel en benzine – naar nieuwe (duurzame) energiedragers een essentieel onderdeel van de transitie is en er dus grote veranderingen nodig zijn. Deze veranderingen zullen verschillend zijn voor de diverse transportsegmenten. Daarnaast zal er in het streven naar de klimaat- en energiedoelen rekening moeten worden gehouden met belangrijke randvoorwaarden en andere doelen, zoals veiligheid, luchtkwaliteit en een duurzame groei van de economie.

Onze toekomstige energie- en brandstofhuishouding is onzeker en van veel factoren afhankelijk. Daarom is het belangrijk om gevoel te krijgen voor de haalbaarheid van de doelen in relatie tot de randvoorwaarden, als een eerste stap op weg naar de integrale visie. Hiertoe heeft het Ministerie van Infrastructuur en Milieu een consortium van ECN,

[1] Volgens de IPCC definitie. Deze omvat alleen broeikasgasemissies op het Nederlandse territorium en voor de verkeerssector geldt de inzet van biobrandstoffen, elektriciteit en waterstof als nul-emissie. In deze studie wordt dat omschreven als de Tank-to-Wheel - TTW – methode.

CE Delft en TNO opdracht gegeven om samen met nauw betrokken stakeholders scenario's op te stellen voor de toekomstige mix van energiedragers voor de transport sector. In deze scenariostudie staan de volgende onderzoeksvragen centraal:

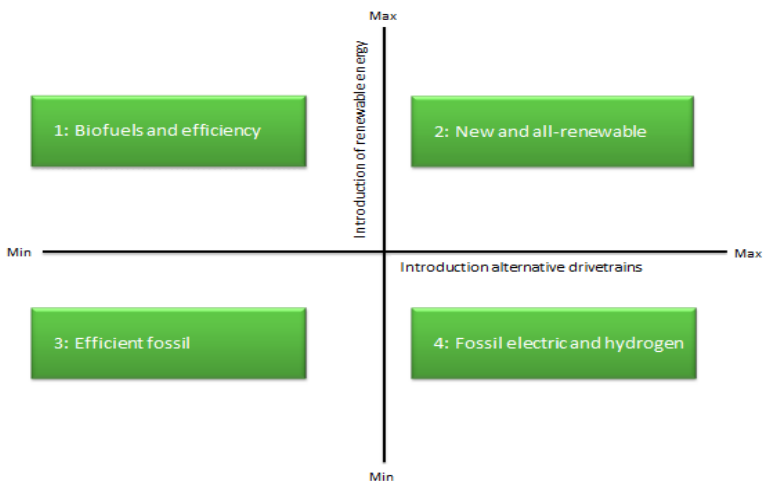
- Hoe kan het klimaatdoel voor de verkeerssector van -60% CO_2-uitstoot in 2050 worden gehaald?
- Welke robuuste elementen kunnen worden aangewezen?
- Aan welke voorwaarden moet zijn voldaan om specifieke energiedragers te laten ingroeien, en wat zijn de belangrijkste onzekerheden?
- Welke andere lessen zijn er uit te trekken?

De tijdshorizon voor dit onderzoek is 2050, met tussenliggende resultaten voor de jaren 2020 en 2030. De nadruk ligt op het wegverkeer, met een kleinere rol voor binnenvaart en mobiele werktuigen. Luchtvaart en zeevaart vallen niet binnen de klimaatdoelstelling die gehanteerd wordt in het SER Energieakkoord, maar ze worden wel meegenomen in het onderzoek. De nadruk ligt in deze studie op technische maatregelen om de doelen te realiseren, zoals de overstap naar andere aandrijflijnen en brandstoffen. Minder aan bod komen niet-technische maatregelen, zoals beïnvloeding van logistieke systemen, modal shift en menselijk gedrag.

Deze resulterende studie is een momentopname van de mogelijkheden om de gestelde doelen te bereiken en dient vooral als discussiestuk in het traject om tot een integrale visie op de toekomstige energiemix te komen. In de aansluitende fase zijn de betrokken stakeholders nadrukkelijk aan zet om met elkaar deze integrale visie te definiëren.

Mogelijke wereldbeelden, gebaseerd op twee dominante onzekere ontwikkelingen
Om gevoel te krijgen voor de haalbaarheid van de doelen en de ordegrootte van effecten, zijn mogelijke wereldbeelden opgespannen en aannames gedaan. De vier plausibele en consistente wereldbeelden van een mogelijke toekomst worden gedefinieerd door de twee parameters, die als minst zekere en meest belangrijke factoren worden beschouwd: het aandeel hernieuwbare energie in het totale energieaanbod en de marktpenetratie van nieuwe elektrische aandrijflijnen in de verkeerssector. De vier wereldbeelden zijn in de vorm van scenario's in **figuur 1** weergegeven in het resulterende assenkruis.

Figuur 1: De vier onderscheidende scenario's voor de energiemix in de transportsector.



De vier wereldbeelden zijn gedefinieerd in de vorm van vier scenario's, die uitdagen om ondermeer na te denken over de verschillende effecten die kunnen optreden, maar ook over de barrières die geslecht moeten worden om bepaalde technologieën door te laten breken. De vier scenario's kunnen als volgt worden geschetst:

1. "Biofuels and Efficiency": in dit scenario wordt aangenomen dat een doorbraak in de elektrificatie van verkeer uitblijft en dat hernieuwbare elektriciteit beperkt beschikbaar is. Daarom ligt de nadruk in dit scenario op het gebruik van biobrandstoffen, hernieuwbare synthetische brandstoffen en zuinige voertuigen om de doelen te halen. In alle verkeerssegmenten is het aandeel van biobrandstoffen rond 50%, met een rol voor zowel vloeibare als gasvormige biobrandstoffen voor weg- en niet-wegverkeer.
2. "New and All-Renewable": in dit scenario leidt de combinatie van aannames over overvloedige hoeveelheden hernieuwbare elektriciteit en de doorbraak van elektrificatie in verkeer tot de toepassing van diverse klimaat-neutrale technologieën. Zowel elektriciteit als waterstof hebben een aanzienlijk marktaandeel in wegverkeer en worden geproduceerd uit hernieuwbare bronnen. De sterke positie van waterstof hangt samen met de belangrijke rol van deze energiedrager in andere sectoren in de energiehuishouding.
3. "Efficient Fossil Energy": Het uitblijven van doorbraken in elektrificatie en technologieën voor de productie van hernieuwbare energie leidt tot de nadruk op extreem zuinige voertuigen. Het gebruik van methaan in dit scenario draagt bij aan de diversiteit aan grondstoffen. Om het 60% broeikasgasreductie doel te halen is ook een aanzienlijke reductie van transportvolume nodig.
4. "Fossil Electric/Hydrogen": De elektrificatie van verkeer is de dominante maatregel om de broeikasgasreductiedoelen te halen. Elektriciteit en waterstof worden geleverd vanuit centrale productiefaciliteiten die gebruik maken van fossiele energiebronnen, vanwege afwezigheid van hernieuwbare energiebronnen. Broeikasgasreductie wordt gerealiseerd door CCS en andere gecentraliseerde technologieën. Methaan wordt ingezet om de emissies in zwaar langeafstandstransport te beperken.

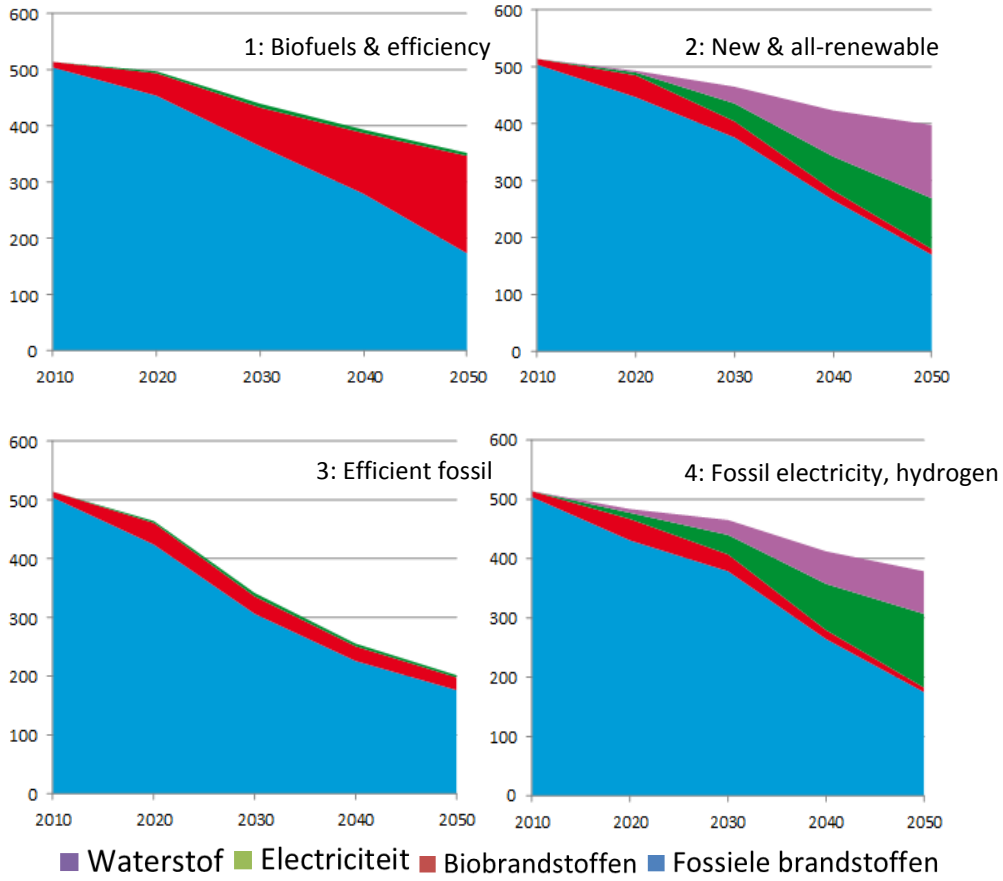
Figuur 2 laat de mix van energiedragers zien die hoort bij deze vier scenario's.

Langs welke wegen zijn de klimaatdoelen voor de verkeerssector haalbaar?

De doelstelling voor de reductie van broeikasgasemissies kan op verschillende manieren worden ingevuld

Een belangrijke uitkomst is dat elk scenario aangrijpingspunten bevat die een reële kans bieden om de klimaatdoelen te halen. Ook zitten er in elk scenario belemmeringen om deze doelen te halen, die weggenomen moeten worden. Op korte termijn zijn deze scenario's even waarschijnlijk. Dat maakt het mogelijk om voor ieder scenario zowel robuuste elementen (ontwikkelingen die plaatsvinden in alle scenario's) als beperkingen, voorwaarden en onzekerheden te identificeren. Dit vormt de basis voor de volgende fase van het visievormingsproces.

Figuur 2: Ontwikkeling van de mix van energiedragers in de periode 2010-2050 in de vier scenario's, uitgedrukt in PJ finaal energiegebruik. Alle scenario's voldoen aan -60% broeikasgasemissie in 2050 volgens de IPCC-TTW methode



De resultaten worden sterk beïnvloed door de definitie en hoogte van de klimaatdoelstelling

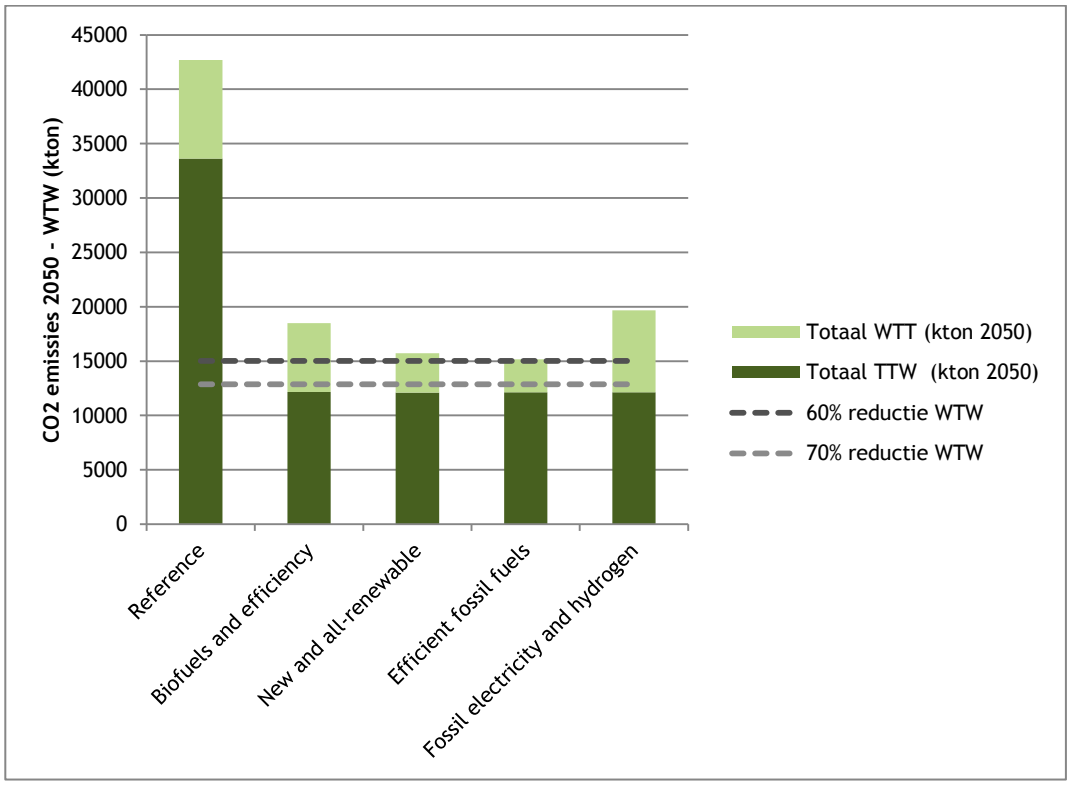
De EU energy roadmap heeft de generieke energie- en klimaatdoelstellingen vertaald naar sectorale opgaven. Voor de verkeerssector betekent dit dat de de ambities zijn gebaseerd op een Tank-to-Wheel (TTW) methode. Dit betekent dat broeikasgasemissies uit de productieketen van energiedragers niet worden toegerekend aan de verkeerssector, maar aan de sector waar deze energiedragers worden geproduceerd. Ook aan deze sectoren worden doelen gesteld, binnen het ETS (bijvoorbeeld elektriciteit) of daarbuiten (landbouwproductie voor biobrandstoffen). Bij het analyseren van effecten is het echter wel zinnig om niet alleen naar TTW, maar ook integraal naar Well-to-Wheel (WTW) effecten te kijken. Bij beleidsbeslissingen over toepassing van bijvoorbeeld waterstof of biobrandstoffen moet tenslotte over de sectoren heen worden gekeken.

In de studie zijn de scenario's zodanig vormgegeven, dat ze in alle gevallen de 60% reductie van broeikasgasemissies in 2050 halen, gebaseerd op TTW. In **figuur 3** zijn de effecten weergegeven als er gekeken wordt naar de WTW reductie van broeikasgassen. Dit is in kaart gebracht om gevoel te geven wat de effecten kunnen zijn voor de energiesector. In de resultaten zijn duidelijke verschillen tussen de scenario's zichtbaar. Dit komt door de upstream emissies bij de productie van biobrandstoffen, elektriciteit

en waterstof. Dit betekent dat de 60% reductiedoelstelling van het Energieakkoord (conform IPCC TTW definities), zich in de meeste scenario's vertaalt in minder dan 60% WTW emissiereductie voor transport. Dit verschil tussen TTW en WTW impacts kan worden verkleind door innovaties die de upstream CO_2 emissies in deze ketens verminderen. In scenario 3, waarin met name fossiele brandstoffen worden gebruikt, wordt de minste druk op de energiesector gelegd om hun reductiedoelen te halen. In alle andere scenario's wordt de druk verhoogd.

Scenario 2 ("New and all-renewable") biedt, als de belemmeringen kunnen worden overwonnen, de meeste mogelijkheden om nog ambitieuzere klimaatdoelen te halen, vanwege een snelle groei van nieuwe productie(technologieën) van hernieuwbare energie en elektrische aandrijving van voertuigen. Met name waterstofvoertuigen zouden een groter marktaandeel kunnen hebben dan aangenomen, hoewel de aangenomen groeisnelheid al ambitieus is.

Figuur 3: Totale CO_2 emissies (Well-to-Wheel, WTW) in 2050



De CO_2-doelen voor 2030 vragen extra inspanning
Bij het ontwerpen van de scenario's is in eerste instantie alleen uitgegaan van het inzetten van technische maatregelen, en niet op extra gedragsmaatregelen bovenop die in het referentiescenario. Hierbij bleek dat in scenario 3 de doelstellingen voor de broeikasgasemissiereductie dan niet haalbaar zijn. Daarom zijn in dit scenario additionele maatregelen toegevoegd, in de vorm van reductie van de (groei van) transportvolume.

De 2020 doelstelling van 15-20 PJ is in alle scenario's wel binnen bereik. Voor het halen van de 2030-ambitie zijn in alle scenario's gedragsmaatregelen nodig, zoals transportvolumebeleid. Dit heeft te maken met de ingroeisnelheid van zuinige voertuigen in het wagenpark. In het algemeen geldt dat de introductie van nieuwe

energiedragers en transportmiddelen pas na 2020 tot een merkbaar effect leidt, wanneer hun marktaandeel toeneemt. Op korte termijn kunnen acties nodig zijn om de marktintroductie voor te bereiden, hoewel de impact op energiegebruik en CO_2-emissies aanvankelijk nog beperkt is. Tegen 2030 wordt het effect van de nieuwe energiedragers en voertuigen zichtbaar in de CO_2-emissies, maar het sterkste effect is zichtbaar in de periode tussen 2030 en 2050, door een verdere toename van de marktaandelen.

Robuuste elementen in de scenario's

Zuinige voertuigen en een hoger ketenrendement is in alle gevallen een goede weg
Het zuiniger maken van voertuigen is een robuuste optie. In scenario's waarin conventionele technologie de basis vormt, is deze optie noodzakelijk om de doelen te kunnen halen. In scenario's met nieuwe energiedragers zorgt de introductie van zuinige voertuigen ervoor dat nieuwe technologieën minder snel hoeven te worden uitgerold. Echter, het zuiniger worden van voertuigen gebeurt slechts in beperkte mate autonoom. Een sterke ondersteuning vanuit EU-beleid is een noodzakelijke voorwaarde om de ingezette ontwikkeling van zuinige voertuigen ook na 2020 gaande te houden. Efficiëntieverbeteringen alleen zullen overigens niet genoeg zijn. Er zijn ook nieuwe energiedragers en/of aanzienlijke reducties in mobiliteitsgroei nodig om de doelen te halen.

De aangenomen reductie van broeikasgassen in 2050 betekent dat er mogelijk nog een significant aandeel voor fossiele brandstoffen, zoals benzine en diesel zal overblijven. Dit is uiteraard afhankelijk van hoe de toekomst zich in werkelijkheid gaat ontvouwen.

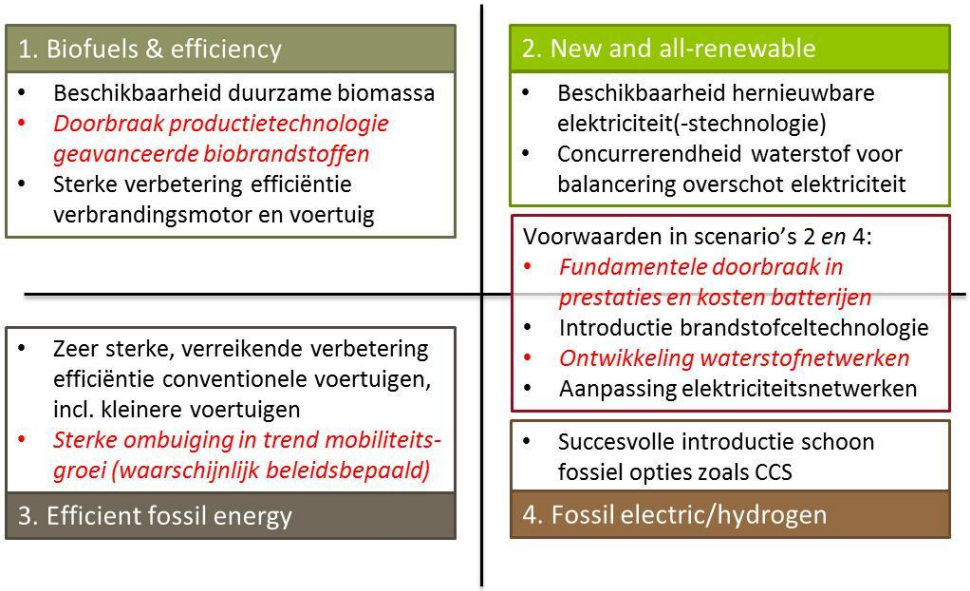
Elektrificatie van stedelijk verkeer
Door verbetering van conventionele technologie in de verkeerssector zijn er al forse reducties van luchtverontreinigende emissies en brandstofverbruik gerealiseerd, maar het is de vraag of dat voldoende is in stedelijke gebieden en bij eventuele toekomstige verdere aanscherping van de luchtkwaliteitseisen. Elektrificatie van stedelijk verkeer is aantrekkelijk en robuust voor zowel broeikasgasreducties, verbetering van luchtkwaliteit en voor de vermindering van geluidshinder. Bij elektrificatie gaat het om volledig elektrische voertuigen, plug-in hybrides, elektrische voertuigen met range-extender en brandstofcelvoertuigen op waterstof. Aandachtspunt is de realisatie van voldoende laadpunten in dichtbevolkte gebieden.

Voor het zware lange afstandtransport en de binnenvaart lijkt methaan een no-regret optie
In het zwaar wegtransport voor lange afstand en de binnenvaart zijn minder duurzame alternatieven beschikbaar dan in personen- en bestelauto's. Door het toepassen van methaan en biobrandstoffen voor deze zware transportvormen kan al op de korte termijn een begin worden gemaakt met de transitie. De toepassing van methaan biedt beperkte voordelen als het gaat om de reductie van broeikasgassen, maar is een mogelijke opstap naar de toepassing van biomethaan en zorgt voor diversificatie in de mix van energiedragers c.q. grondstoffen; zo biedt methaan een verbetering van de energievoorzieningszekerheid. Ook kan de aanwezigheid van een uitgebreide infrastructuur voor aardgas een opstap vormen naar decentrale waterstofproductie.

Noodzakelijke voorwaarden en onzekerheden

Naast de gemeenschappelijke kenmerken, heeft ieder van de scenario's eigen voorwaarden en onzekerheden. De belangrijkste zijn samengevat in figuur 4. de robuuste elementen die voor alle scenario's gelden, zijn er in ieder scenario specifieke technologieën waarvan de ontwikkeling onzeker en/of voorwaardelijk is. Deze voorwaarden zijn per scenario samengevat in **figuur 4**.

Figuur 4: Noodzakelijk (onzekere) voorwaarden in de verschillende scenario's. Voorwaarden in rood (cursief) markeren doorbraken, terwijl voorwaarden in zwart (niet cursief) incrementele verbeteringen vereisen.



Hieronder volgt een overzicht van de voor de dominante technologieën vereiste condities. Voor alle nieuwe technologieën geldt, dat een grootschalige acceptatie door consumenten afhankelijk is van de uiteindelijke concurrentiepositie van die technologie.

- Op de korte termijn, liggen de meest logische kansen voor **elektrificatie** van het wegverkeer in stedelijk gebied, vanwege de relatief beperkte behoefte aan energieopslag in batterijen bij korte afstanden. Een grootschalige uitrol voor stedelijk gebied en de toepassing voor langere afstanden is nog niet zonder meer mogelijk. Een voorwaarde is een grootschalige uitrol van laadinfrastructuur in stedelijk gebied. Daarnaast vereist de toepassing voor langere afstanden doorbraken in batterijcapaciteit en -kostenverlaging. Er wordt gewerkt aan nieuwe batterijconcepten, bijvoorbeeld gebaseerd op lithium-silicon of lithium-lucht. Een momenteel veel onderzocht alternatief is de ontwikkeling van bovenleidingen op de belangrijkste transportcorridors (bijvoorbeeld het TEN-T netwerk), of het opladen middels inductie vanuit het wegdek.
- Voor de toepassing van **waterstof** in het verkeer is een succesvolle uitrol van een tankinfrastructuur een voorwaarde. Hiervoor is een bijbehorende EU-samenwerking nodig. Een belangrijk aandachtspunt is de perceptie van de veiligheid door het publiek. Er zijn geen grote doorbraken nodig op voertuiggebied om waterstofvoertuigen op de weg te krijgen, maar de hoge initiële kosten vormen nog wel een drempel, waaraan veel aandacht wordt besteed. Deze barrière wordt mogelijk geslecht door te starten met een relatief grootschalig

introductieprogramma, het liefst gecoördineerd in de EU. Dat geeft voldoende kritische massa om de (technologische) leercurve te doorlopen. Ook de kosten van waterstof kunnen een beperking vormen, gezien het relatief lage Well-to-Wheel rendement in vergelijking met batterij elektrische voertuigen. Als waterstof kan worden geproduceerd uit een overschot aan elektriciteit (power-to-gas), dan kunnen de productiekosten concurrerend worden. Of dit realiteit wordt hangt af van ontwikkelingen in de energiesector, zoals de elektriciteitsmix en ontwikkelingen in (smart) grids.

- Voor geavanceerde **biobrandstoffen** en hernieuwbare synthetische brandstoffen zijn doorbraken in de productieprocessen en de opschaling daarvan belangrijke voorwaarden. Een ander belangrijk aandachtspunt is de mate van duurzaamheid van biobrandstoffen. Een mogelijke oplossing is het gebruik van laagwaardige (afval) grondstoffen in plaats van gewassen. Een andere oplossing kan gevormd worden door een betrouwbaar certificeringssysteem, waarin ook (indirect) landgebruik en koolstofprestatie meegenomen worden. Radicaal nieuwe technologieën zoals het gebruik van aquatische biomassa en *solar fuels* kunnen het potentieel vergroten, maar de onzekerheid rondom deze (nieuwe) processen is nog groot. Een belangrijke voorwaarde is de beschikbaarheid van duurzame biomassa, vanwege concurrentie om biomassa tussen transportsectoren en andere sectoren. De sterk groeiende luchtvaarsector, met weinig alternatieven voor verduurzaming, zou namelijk beslag kunnen leggen op een deel van de beschikbare biomassa.
- De toepassing van **methaan** is al mogelijk voor veel transportsegmenten. Er zijn grootschalige activiteiten in gang gezet voor de uitrol van een infrastructuur, waarbij de veiligheid het belangrijkste aandachtspunt is. Een ander aandachtspunt is het potentieel om op termijn gebruik te maken van methaan uit duurzame bronnen. Ook hier is de beschikbaarheid van biomassa mogelijk beperkt en is er concurrentie tussen sectoren.

Een nadere precisering en uitbreiding van bovenstaande voorwaarden en onzekerheden is een centraal onderdeel van de tweede fase van het visietraject.

Terugvalopties en beperking van transportvolume

Een belangrijke vraag is welke terugvalopties er zijn, als er aan bepaalde voorwaarden voor nieuwe technologieën niet voldaan wordt. Dit geeft een idee van mogelijke nieuwe robuuste elementen. Als technologische doorbraken op het gebied van geavanceerde biobrandstoffen en betere batterijen achterblijven, dan zijn extreem zuinige voertuigen nodig om aan de gestelde doelen te voldoen. Waterstof kan in dat geval een terugvaloptie zijn, evenals *power-to-fuel* opties, hoewel onzeker. Als in specifieke scenario's het halen van de doelen vooral afhangt van extreem zuinige voertuigen, dan is de enige terugvaloptie het beïnvloeden van gedrag, zoals een reductie van (de groei) van transport. Lagere mobiliteitsgroei kan komen door stagnatie van economische groei of door inzet van beleid. Waarschijnlijk zijn drastische reducties van volumegroei alleen haalbaar door een combinatie van gerichte fiscale instrumenten en door vergaande veranderingen en innovaties in het mobiliteitssysteem, inclusief modal shift, veranderingen in consumentenvoorkeur (zoals ontkoppeling van gebruik en bezit), concepten die de noodzaak tot reizen en vervoeren beperken, en bijbehorende ruimtelijke ordening.

Internationale ontwikkelingen onmisbaar bij de meeste onzekerheden en voorwaarden
De voertuig- en brandstofmarkten zijn sterk internationale markten, met een relatief beperkte rol van de Nederlandse industrie. De (keuze)mogelijkheden voor Nederland worden mede bepaald door internationale ontwikkelingen en strategische beslissingen van de Europese Unie en in VN verband en landen als Duitsland, Frankrijk, de VS, China en Japan. Een volledige review van de ontwikkelingen in deze landen valt buiten de scope van deze studie, maar een snelle scan geeft een gemengd beeld: geen van de landen heeft eenduidige keuzes gemaakt voor specifieke opties, maar er zijn wel accentverschillen zichtbaar. Het is van belang deze ontwikkelingen te monitoren in volgende fasen van het visietraject.

Wat laten de scenario's nog meer zien?

De introductie van nieuwe technologieën laat een kostenpiek zien in 2030
Alle scenario's laten in 2030 een piek zien in de Total Cost of Ownership van alle gebruikers tezamen, door een combinatie van hoge energieprijzen en de initiële kosten van nieuwe technologieën. Deze piek is het laagst bij scenario 3, waarin geen fundamenteel nieuwe technologieën worden geïntroduceerd en de groei van het mobiliteitsvolume al vóór 2030 afneemt. De kostenreducties door leereffecten en schaalvergroting zorgen ervoor dat in 2050 de kosten per kilometer niet sterk verschillen tussen de scenario's. Opgemerkt moet worden dat zuinige voertuigen en een reductie van het verkeersvolume de kostenpiek verlagen en zo een bijdrage leveren aan de transitie richting de doelen in 2050. De totale TCO in scenario 3 kon niet worden ingeschat in deze studie, vanwege de forse reductie in transportvolume in dat scenario. Naast grote veranderingen in ruimtelijke structuren en de economie zal dit ook additionele prijsmaatregelen vereisen, zoals emissiehandel of een kilometerheffing, met significante effecten op de TCO; in feite verandert de rol van mobiliteit in de samenleving fundamenteel in dit scenario.

Kansen voor groene groei en energiezekerheid variëren, maar kunnen worden geïdentificeerd
Met name de scenario's waarin radicaal nieuwe technologie nodig is (dat zijn alle scenario's behalve scenario 3), bieden kansen voor groene groei, maar waar die kansen zich voordoen verschilt per scenario. Alle scenario's laten een daling van de transportkosten zien in 2050 ten opzichte van met het referentiescenario. Dit betekent specifiek voor scenario's 1, 2 en 4 dat vanuit een macro-economisch perspectief de economische groei groter kan zijn dan in het referentiescenario. Voorbeelden van marktsegmenten met groene groei mogelijkheden zijn in het onderzoek beschreven. Het is echter niet mogelijk binnen de scope van het onderzoek het "beste" groene groei scenario aan te wijzen.
Ook op het onderdeel energievoorzieningszekerheid zijn er duidelijke verschillen tussen de scenario's te zien. In het algemeen geldt dat energiebesparing en koolstofarme technologieën vrijwel overal ter wereld beschikbaar zijn, in tegenstelling tot olie. Dit betekent dat scenario's met de nadruk op zuinige voertuigen (1 en 3) goed scoren op energievoorzieningszekerheid. Ook de scenario's met de nadruk op koolstofarme technologieën (2 en 4) scoren goed, maar op andere gronden. Het gebruik van methaan draagt ook bij aan energie diversificatie (scenario 1, 3 en 4).

Veiligheid als belangrijke randvoorwaarde voor de implementatie van nieuwe technologieën
Externe veiligheid en ook de perceptie van het publiek, is van essentieel belang. Scenario's die steunen op de introductie van gasvormige brandstoffen zijn het meest gevoelig voor externe veiligheidsaspecten (waterstof in scenario 2 en 4, methaan in o.a. scenario 3). Vanwege de huidige activiteiten rondom LNG mag worden verwacht dat de (mogelijke) problemen met methaan, in welke vorm dan ook, op korte tot middellange termijn zijn opgelost. Voor waterstof is dit recentelijk in gang gezet en is (de perceptie van) externe veiligheid een belangrijk aandachtspunt. Dit geldt met name in de situatie waarin waterstof in centrale faciliteiten wordt geproduceerd is en er een wijdvertakt distributienetwerk vereist is.

Openstaande vragen

De klimaatambities in internationale luchtvaart en zeevaart moeten worden meegenomen
Luchtvaart en zeevaart zijn snel groeiende sectoren en lijken minder mogelijkheden te hebben om broeikasgasemissies te reduceren dan bijvoorbeeld wegtransport. In het EU Witboek voor Verkeer worden doelstellingen van 40% genoemd voor de broeikasgasreductie van deze transportsectoren in 2050, vergeleken met business-as-usual. Mocht het nodig blijken om voor de gehele verkeerssector, dus inclusief internationale lucht- en scheepvaart, in 2050 een reductie van 60% te halen, dan zou het deel van de sector dat is begrepen in het SER Energieakkoord een reductie van 85% moeten halen (ten opzichte van 1990). Deze studie kijkt naar reducties die verder gaan dan 70%.

Daarnaast: De zeevaart en luchtvaart zullen een deel van de beschikbare hernieuwbare energiebronnen gebruiken, in het bijzonder vloeibare biobrandstoffen, omdat dit naast efficiency verbetering, de belangrijkste weg is om de uitstoot van broeikasgassen van de luchtvaart te verminderen. De invloed daarvan op de beschikbaarheid van biobrandstoffen voor de overige gebruikersgroepen is onzeker. Aan de ene kant zal er concurrentie ontstaan om een eindige voorraad duurzame biobrandstoffen, dit zal de inzet van biobrandstoffen in het wegverkeer beperken. Dit aspect is meegenomen in de studie. Aan de andere kant kan een grote vraag naar biobrandstoffen uit de luchtvaart innovatie en doorbraken versnellen, waardoor het aanbod van duurzame biobrandstoffen kan toenemen. Hiervan zou ook het wegverkeer profiteren. Dit aspect is in de studie niet meegenomen. Tenslotte zijn op olie gebaseerde brandstoffen aan elkaar gekoppeld, gezien de verhoudingen waarin ze in de raffinagesector worden geproduceerd, waarin niet onbeperkt gevarieerd kan worden.

Deze studie kent twee beperkingen. In de scenario's is slechts **een beperkte mate van detaillering naar subsectoren** aangebracht. Zo is het segment vrachtwagens en bussen niet nader onderverdeeld in stedelijk, regionaal of internationaal transport. Dit maakt onze conclusie over bijvoorbeeld stedelijk vervoer vrij voorlopig. In het bijzonder voor het identificeren van kansrijke niches voor specifieke technologieën kan een verdere uitsplitsing waardevol zijn. De analyse van de noodzakelijke uitrol van nieuwe **infrastructuur** en de daaraan verbonden kosten, vooral van belang voor elektricifering op basis van accu's en waterstofbrandstofcellen, is oppervlakkig gebleven. Dit verdient verdere aandacht als adaptieve strategieën voor de uitrol van infrastructuur worden uitgewerkt.

Op weg naar een integrale visie

Deze scenariostudie sluit de eerste fase af van het traject naar een integrale Nederlandse visie op energiedragers voor verkeer.
Op basis van deze studie zal een startdocument gemaakt worden wat de basis input voor de tweede fase zal geven. Dit vormt het beginpunt van een intensieve uitwisseling en ideeënopbouw tussen alle betrokken stakeholders in de tweede fase.

Deze scenariostudie heeft de focus op een aantal mogelijke wereldbeelden, waaruit een aantal robuuste elementen, een aantal meer algemene voorwaarden en een aantal belangrijke onzekerheden met betrekking tot die wereldbeelden kon worden afgeleid. In de volgende fase zal veel meer focus liggen op concrete belemmeringen c.q. kernonzekerheden die hiermee samenhangen. Om dat te kunnen doen zal gekeken worden naar specifieke combinaties van brandstofsporen en gebruikscategorieën (stedelijke personenvoertuigen, lange afstand vrachtverkeer etc). Op basis daarvan zullen vragen gesteld worden hoe specifieke barrières geslecht kunnen worden en hoe we het beste met de kernonzekerheden om kunnen gaan. De antwoorden op deze vragen zullen door de gezamenlijke stakeholders gegeven worden. Uiteindelijk zal dit moeten resulteren in keuzes voor no-regret opties die anticiperen op de geïdentificeerde onzekerheden. Belangrijk hierbij is hoe de keuzes voor specifieke opties *nú* aansluiten bij de ontwikkelingen die zich *straks* op langere termijn zullen c.q. kunnen voordoen en hoe de keuzes voor verschillende brandstofsporen elkaar kunnen versterken.

Om het beleid voor alternatieve brandstoffen succesvol te laten zijn en de duurzame doelen te bereiken zal er een goede aansluiting op het energiebeleid moeten zijn. Daarom zullen ook de barrières en onzekerheden in de energiesector onderdeel zijn van de discussies in de tweede fase van het visie traject.

De tweede fase op weg naar de integrale visie en het actieplan begint in januari 2014, met het doel om de integrale visie gereed te hebben in de eerste helft van 2014 en de bijbehorende actieplannen in de tweede helft van 2014. Het is belangrijk dat dit tijdpad gehaald wordt, omdat visie en planvorming op het terrein van alternatieve brandstoffen voor transport binnenkort een verplichting zal worden. Dit vloeit voort uit nieuwe EU regelgeving (Clean power directive 17004/13) welke naar verwachting in de loop van 2014 van kracht zal worden.

Summary

The transport sector will face an energy transition
The targets set for climate, air quality and noise for transport require a transition within the sector. In the recently signed Energy Agreement for sustainable growth, directed by the Socio-Economic Council (SER), Dutch parties have laid out the basis for a broadly supported, robust and future-proof energy and climate policy. In the area of mobility and transport, parties have agreed on ambitious targets, viz. a reduction of CO_2 emissions by 60% in 2050 compared to 1990[2] and an intermediate reduction to a level of 25 Mton CO_2 (-17%) by 2030.In the context of the overall energy efficiency ambition of 100 PJ additional (final) savings by 2020 compared to the agreement's reference scenario, parties have agreed that transport and mobility are expected to contribute 15-20 PJ to this target.

In order to meet these targets, the Energy Agreement contains various concrete steps and measures. One of these is that parties will develop a joint vision on the future energy mix in the transport sector. Such a vision is needed because the shift from fossil fuels – mainly gasoline and diesel – towards new (renewable) energy carriers is an essential part of the transition and this entails major changes. This changes will differ between the various transport modi. Also, essential conditions and other targets regarding safety, air quality and sustainable economic growth will need to be taken into account when paving the way to the energy and climate targets.

The future energy and fuel situation is uncertain and depends on several factors. Therefore, it is important to explore the feasibility of the energy and climate targets in relation to the conditions, as a first step towards an integral vision. For this reason, the Dutch Ministry of Infrastructure and Environment commissioned a consortium consisting of ECN, CE Delft and TNO to construct scenarios for the future mix of transport energy carriers together with closely related stakeholders. Key points of attention are:

[2] According to the IPCC definition. Only emissions in the Dutch territory are taken into account. Emissions related to the production of biofuels, electricity and hydrogen are not ascribed to the transport sector. In this report this is called the Tank-to-Wheel approach.
In the SER Energy Agreement also an intermediate target of 25 Mton CO_2-equivalents by 2030 is included. This corresponds to a 17% reduction compared to 1990.

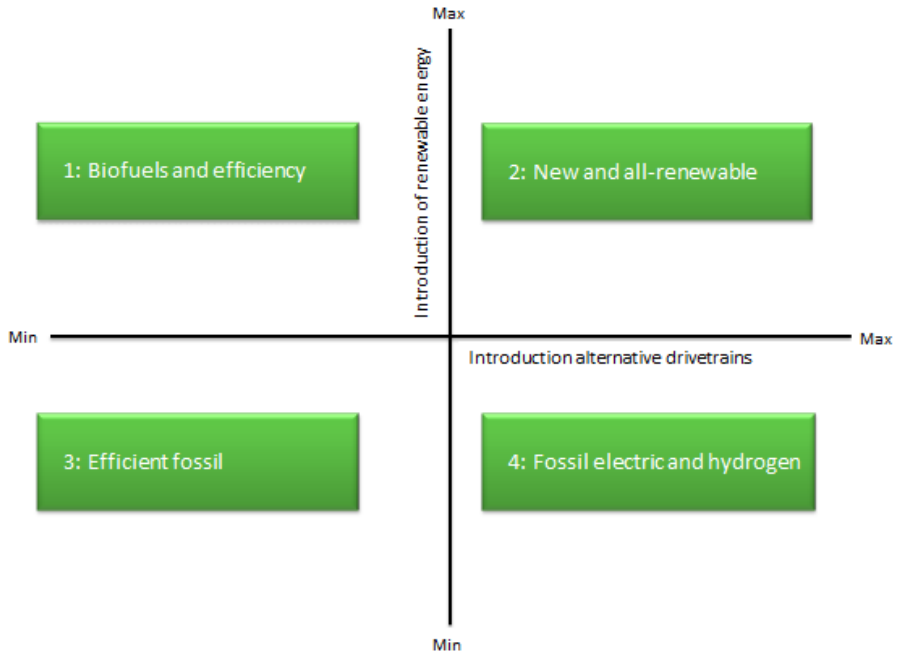
- How can a low-carbon objective of -60% CO_2-emissions be met by 2050?
- Which elements in the scenarios are robust?
- What are key conditions and uncertainties for energy carriers to emerge?
- What other lessons can be drawn from the scenarios?

The time horizon for this study is 2050, with intermediate results for the years 2020 en 2030. In line with the definition of the greenhouse gas reduction targets in the SER Energy Agreement, the dominant modality considered is road transport, with a minor role for inland shipping and mobile machinery. Aviation and maritime shipping are not included in the target definition, but are taken into account in the study. The study focuses on technical measures to reach the targets, such as the shift towards other drivetrains and fuels. It pays less atention to non-technical measures, such as changes in logistical systems, modal shift and human behaviour.

This study describes the current status of possibilities to reach the targets set and mainly serves as a basis for discussion in the trajectory to come to an integral vision on the future energy mix. In the next phase, the involved stakeholders will need to jointly define this integral vision.

Possible futures based on two key uncertainties
In order to get a sense of the feasibility of targets and the order of magnitude of corresponding impacts, possible visions of the future are constructed and corresponding assumptions were made. The four plausible and consistent storylines of possible futures are defined by what are considered the two most important and least certain parameters that influence the future mix of energy carriers in the transport. These two key parameters are the shares of renewable energy in the total energy supply and the penetration of new electric drivetrains in the transport sectors. The four views are presented as scenarios in **Figure 1**

Figure 1: The four alternative fuel scenarios.



The four world views were vdefined as four scenarios, which invited to explore the various impacts that occur in each of them, but also the barriers that need to be eliminated in order for some technologies to break through. The scenarios can be described as follows:

1. "Biofuels and Efficiency": due to the absent breakthrough of transport electrification and limited availability of renewable energy sources, the focus in this scenario is on the use of biofuels and strong improvement of powertrain efficiency to reach the goals. In all subsectors, the share of biofuels increases to around 50%. In this share there is a role for both liquid and gaseous biofuels for road and non-road transport.
2. "New and All-Renewable": in this scenario the breakthrough of transport electrification in combination with abundant availability of renewable energy sources – power generation is entirely renewable by 2050 - leads to the application of a variety of climate-neutral technologies. Both electricity and hydrogen have significant shares in road transport and are produced from renewable sources. Hydrogen is boosted by the role of these energy carriers in other parts of the energy economy.
3. "Efficient Fossil Energy": The absence of breakthroughs in transport electrification and in technologies for producing renewable energy leads to the focus on a significant increase of powertrain efficiency. The use of methane in this scenario increases energy diversity. To reach the 60% greenhouse gas reduction target, also a significant decrease in transport volume growth is required in this scenario.
4. "Fossil Electric/Hydrogen": Transport electrification is the key measure to reach the greenhouse reduction target in this scenario. Electricity and hydrogen are distributed from centralized production facilities using fossil energy sources, due to the lack of renewable energy. Greenhouse gas mitigation is realized through CCS and other centralized technologies. Methane is used to reduce greenhouse gas emissions in long distance heavy transport.

Figure 2 shows the mix of the various energy carriers in each scenario

Various ways towards meeting low-carbon ambitions

Meeting the long-term climate ambition is possible in several ways

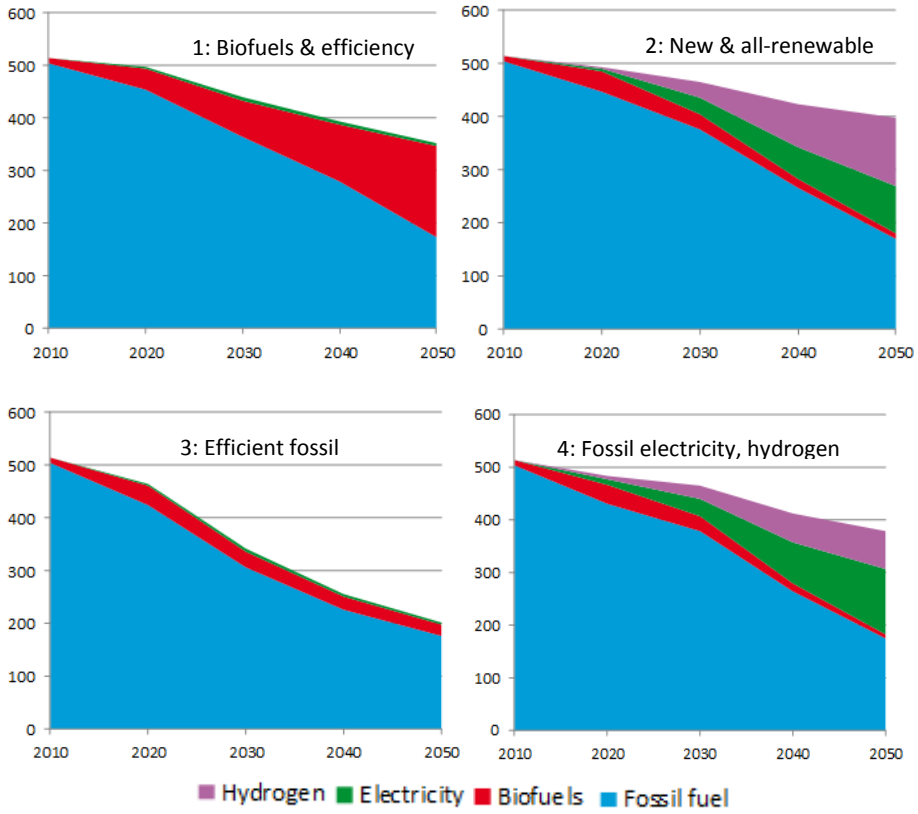
One of the key findings of the scenario study is that each scenario contains elements that offer a realistic opportunity to reach the greenhouse gas reduction targets. Also, each scenario contains barriers for meeting these targets that need to be eliminated. In the short term, all scenarios are equally probable. Therefore, for each scenario both robust elements (developments that occur in all scenarios), as well as constraints, requirements and uncertainties could be identified. This provides the basis for the next phase in the vision formation process.

The definition of the target strongly influences results and robustness

In the EU energy roadmap, the overall targets have been translated into sectoral reduction wedges. For the transport sector, this means that greenhouse gas reduction targets need to be based on a Tank-to-Wheel (TTW) scope. As a consequence, upstream emissions of greenhouse gases in the production chain are not attributed to the transport sector but to the sector in which the energy carriers are produced. These

sectors have their own reduction wedge, either within the ETS (e.g. electricity production) or outside it (agriculture producing biofuel feedstocks). When analysing impacts, it is however relevant to also look at the full-chain Well-to-Wheel (WtW)[3] effects . When considering policies that lead to the introduction of e.g. hydrogen or biofuels, these cross-sectoral effects will need to be taking into account.

Figure 2: Development of the energy mix in the four scenarios in 2010-2050 in PJ of final energy consumption (all meeting the -60% CO_2 target according to IPCC-TTW)



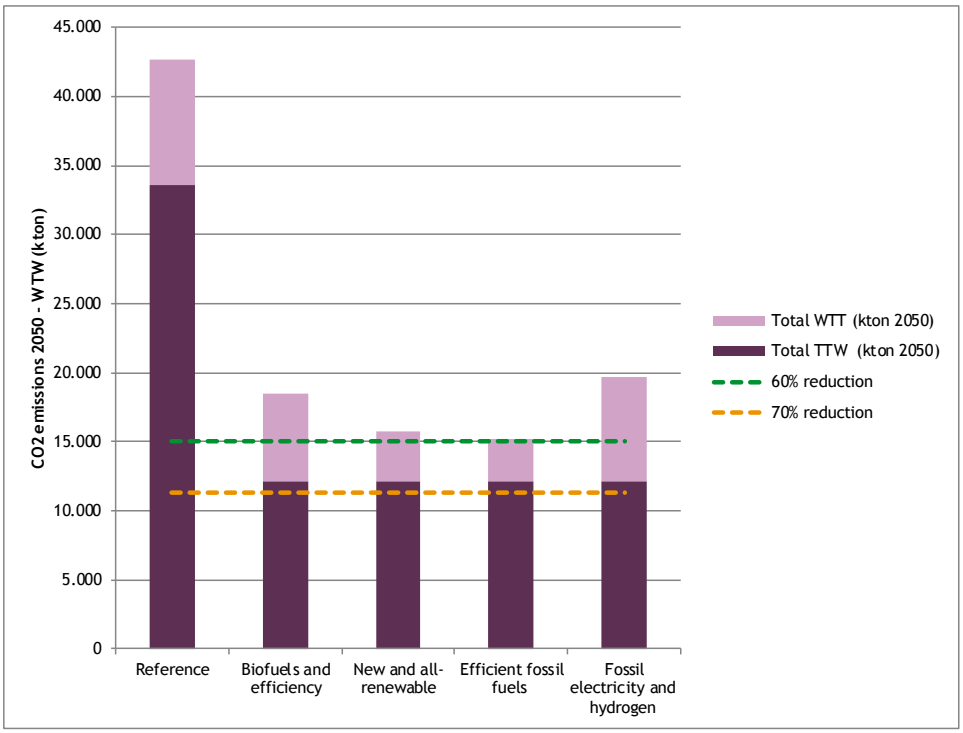
In the study, the scenarios are designed in such a way that all of them reach the 60% reduction target by 2050, defined in TTW terms. **Figure 3** shows the reductions in WTW terms. This is analysed to give a sense how the energy sector could be influenced. Some clear differences between the scenarios can be observed. These are mainly caused by upstream emissions in production of biofuels, electricity and hydrogen. This means that the 60% reduction target for transport as defined by the Energy Agreement in line with IPCC TTW definitions, will in most scenarios result in less than 60% emission reduction for transport on a WTW basis. This difference between TTW and WTW impacts can be reduced by corresponding efforts to improve upstream CO_2 emission profiles of these energy chains. In scenario 3, in which fossil fuels remain strongly dominant, the additional pressure on other sectors due to technology shifts in transport remains limited. In the other scenarios, this pressure increases.

On the basis of an increased uptake of new technologies in renewable energy production and electrification of powertrains (assuming barriers are eliminated),

[3] Under the Well-to-Wheel (WtW) approach greenhouse gas emissions in the entire production chain of energy carriers for transport, including biofuels, electricity and hydrogen, are ascribed to the transport sector.

scenario 2 ("New and All-renewable") shows the highest potential to meet more ambitious greenhouse gas reduction targets. Particularly hydrogen fuel cell vehicles could have a larger potential market share than assumed, although the assumed share already requires ambitious ramp-up rates.

Figure 3: Total CO_2 emissions (WTW) in 2050



Meeting the 2030 CO_2 objective seems difficult

In the design of the scenarios, the starting point was to consider technical measures only. Behavioural measures on top of those in the reference scenario, were not considered initially. In scenario 3 the targets for the greenhouse gas emission reduction in 2050 could not be reached by technical measures. For this reason, the transportvolume in this scenario was reduced significantly.

The 15-20 PJ energy efficiency gain by 2020, also part of the Energy Agreement, is within reach in all scenarios. In three of the four scenarios, the short-term development rates of new technologies are not sufficient to keep the ambition from the Energy Agreement to limit transport CO_2 emissions to 25 Mton by 2030 within reach. This means that in all scenarios additional behavioural measures are required, such as policy on transportvolume.

In general, the introduction of new fuels and vehicles starts having a noticeable effect only after 2020, as their roll-out develops and market share increases. In the short term, actions may be needed to prepare for their introduction, but impacts in terms of efficiency gains and CO_2-emission reductions will be limited initially. By 2030, the impacts of new fuels and vehicles becomes visible in the amount of CO_2 emissions, but the strongest effects are visible in the 2030-2050 period, resulting from further increases in market shares.

Robust elements in the scenarios

Energy efficiency and a higher chain efficiency important in all scenarios
Improving energy efficiency is a robust option that supports the reduction target. In scenarios with the focus on conventional technology, improving the energy efficiency is crucial for reaching the targets. When a shift to new energy carriers is made in addition, a general increase in energy efficiency of conventional technologies reduces the required penetration rate of these new technologies. However, energy efficiency improvements do not occur autonomously and a strong policy incentive at the EU level is a critical condition further sustain the efficiency improvements required beyond 2020. Furthermore, efficiency improvements alone will not be sufficient. In addition, new energy options and/or significant reductions in mobility growth are required to meet the targets.

The assumed reduction of CO_2-emissions implies that even in the 2050 timeframe, petrol and diesel will still have a substantial share in the energy mix in all subsectors. Again, this strongly depends on how the future will develop.

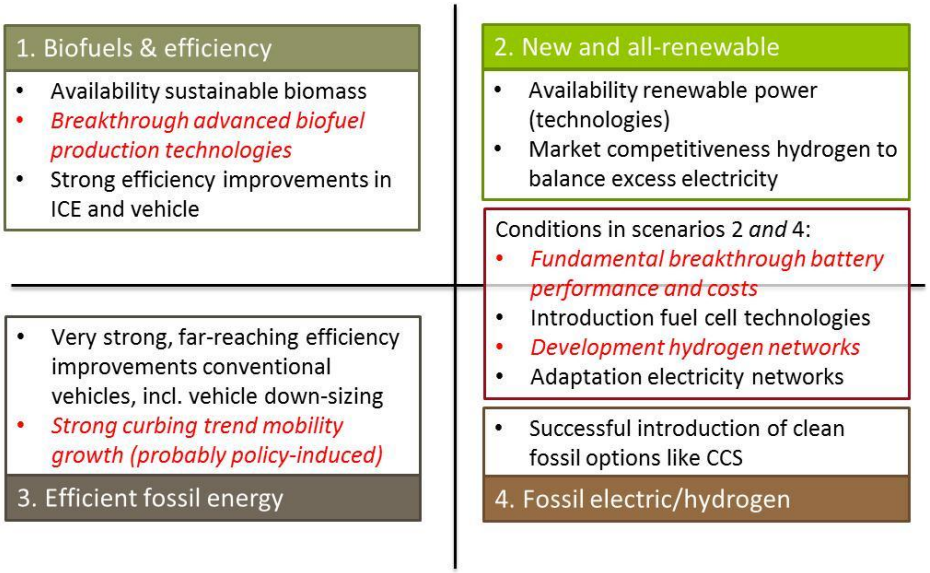
Electrification of urban transport
Conventional energy technology in transport has already experienced significant reductions of pollutant emissions and fuel consumption. However, it is uncertain whether this will be enough to meet air quality standards for urban areas, especially in the case of these standards possibly being tightened in the future. The electrification of urban transport is an attractive and robust option for both greenhouse gas reductions, air quality improvement and noise reductions. Vehicles concepts that can be expected include small, full electric cars, plug-in hybrids, electric cars with range extenders and hydrogen fuel cell vehicles. A point of particular interest is the possibility for end users to recharge in densely populated areas.

Methane is a no-regret option for heavy duty long distance transport and inland shipping
Heavy duty (long distance) transport and inland shipping do not show a clear winning solution and fewer sustainable options are available than for cars and vans. The use of methane and biofuels for heavy duty transport modes can initiate a transition in the short term. Methane offers a limited greenhouse gas reduction potential, but is a potential stepping stone for the use of biomethane and enhances the diversification of resources thus improving energy security. In addition, the presence of a natural gas infrastructure can be used as a stepping stone for decentral hydrogen production.

Key conditions and uncertainties

Next to the developments that are robust across the different scenarios, each scenario has its specific conditions and uncertainties. The most import ones are summarized in **Figure 4**.

Figure 4: Key (uncertain) conditions for each scenario to materialise. Conditions in red italics are considered breakthroughs, otherconditions (in black) may be realised by more gradual developments.



Consideration of these conditions (on key technologies) results in the following synthesis. For all alternative technologies, large scale public acceptance strongly depends on the competitiveness of the technology on the market.

- On the short term, urban areas show the best opportunities for the **electrification** of road transport, due to the limited need for energy storage for short distance urban trips. Large roll-out of electric transport in both urban areas and long distance transport is not yet easily feasible. A condition for this option is substantial new charging infrastructure, which is currently initiated in urban areas. Furthermore, for application in longer distance road transport, a breakthrough in battery capacity and cost reduction are key conditions. New battery concepts are currently investigated, e.g. based on lithium-silicon or lithium-air. A conceivable alternative would be the development of overhead catenary wires on the main transport corridors (e.g. the TEN-T core network) or on-road charging by induction.
- For the use of **hydrogen** in transport a successful implementation of a refueling infrastructure a condition. Therefore, European co-operation is required to achieve this. An important aspect for hydrogen is the public perception of safety aspects. Essentially, no vehicle technology breakthroughs are needed anymore for fuel cell vehicles to be introduced, but their initial high costs will still be a hurdle, so research is currently focusing on these cost reductions, to which much attention is paid. This can be overcome by relatively large-number introduction of the technology in order to kick-start technological learning, preferably EU-coordinated as this delivers more critical mass. Also the cost of hydrogen could be a constraint, which is linked to the relatively low Well-to-Wheel energy efficiency (compared to battery electric vehicles). When hydrogen can be produced by excess capacity of electricity (power-to-gas), the hydrogen production costs may become competitive, but whether this will become reality depends on developments in the power sector such as the electricity mix, and developments of (smart) grids.
- Breakthroughs in the production processes of advanced **biofuels** and their scale-up are important conditions for this option. Another point of interest is the safeguarding the sustainability of the biomass production. One solution might be

the use of low-grade (residual) materials instead of dedicated. Another solution might be the presence of a reliable certification systems that also include (indirect) land use change and carbon neutrality aspects will need to be in place. Moreover, radically new technologies such as the use of aqueous biomass and solar fuels can improve the potential for biomass as feedstock, but the uncertainty related to these processes is high. Also, the demand for biomass from other sectors (e.g. industry) and aviation/maritime shipping is an important uncertainty for the potential role of biomass in road and rail transport, inland navigation and mobile machinery.

- The use of **methane** is already feasible in many transport modes. Large scale activities have been initiated for the roll-out of a gas infrastructure, in which the safety aspect is a key factor. Another important point of interest is the feasibility to produce methane from renewable resources. Again, the availability of biomass resources and competition between the different sectors might play a limiting role.

Further clarification and extension of the above mentioned conditions and uncertainties is a central part of the second phase of the vision process.

For many uncertainties and conditions, international developments will be pivotal
As vehicle and fuel markets are international by nature, and the Netherlands hardly has any OEMs, the possibilities in the Netherlands will be influenced by international developments and strategic choices of the EU, UN and countries such as Germany, France, the USA, China and Japan. While a full review of developments in these countries is out of scope for this study, a quick-scan gives a mixed picture: while no countries have made clear-cut choices for specific options, some differences can be observed. It seems important to monitor these developments as part of an adaptive programming approach.

What do the scenarios further show us?

The introduction of new technologies shows a cost hurdle in 2030
All scenarios are similar in showing a TCO cost hurdle in 2030 due to the combination of increasing energy prices and the upfront costs for new technologies. Cost reduction through learning effects means that by 2050, costs per km do not vary greatly between the scenarios. It should also be noted that improvements in energy efficiency and the reduction of transport volume reduce the cost hurdle and support the required transition towards the 2050 goals. The total TCO in scenario 3 could not be calculated in this study because of the high reduction in transport volume in that scenario. Besides significant changes in spatial and economic structures, this will also require pricing measures such as emission trading or kilometre charging, with significant effects on the TCO. In fact, the role of mobility in society changes fundamentally in this scenario.
erspectives for green growth and energy security vary but can be identified
In particular, the scenarios which include radical innovative technologies (all but scenario 3), contain opportunities for green growth, but with different aspects in each scenario. In all scenarios the costs of transport in 2050 are reduced compared to the reference scenario. Specifically for scenarios 1, 2 and 4 this means that from a macro-economic perspective economic growth could be higher than in the reference scenario. Examples of market segments with green growth opportunities are described. However, within the scope of this study it is not possible to identify the “best” green growth scenario.
Also energy security shows clear differences between the scenarios. In general, energy efficiency improvements and low-carbon technologies are available virtually

everywhere, in contrast to oil. In that respect, scenarios with a focus on the reduction of primary energy use (1 and 3) score well on energy security. Also, scenarios with a focus on low-carbon technologies score well (2 and 4), but for a different reason. The use of methane can also contribute to energy diversity (scenario 1, 3 and 4).

Safety aspects are a critical boundary condition for the implementation of new options
External safety and public acceptance of safety are of essential importance. Scenarios with substantial introduction of gaseous fuels (hydrogen in scenarios 2 and 4, methane in scenario 3) are most sensitive to external safety issues. Due to the current activities surrounding LNG, it is a necessary condition for large scale roll-out that the issues with methane in whatever form are solved in the short or medium term. For hydrogen, the external safety aspect has recently become an important point to which attention should be paid. This is mainly the case for centralized production, requiring a wide distribution network.

Open questions

The role of international aviation and maritime transport needs to be taken into account
Shipping and aviation are fast growing sectors with greenhouse gas reduction potentials which appear to be more limited than, for example, in road transport. The EU White Paper target for these transport modes states 40% reduction of greenhouse gas emissions in 2050 compared to business as usual. In that case, to achieve 60% reduction for the overall transport sector (including aviation and shipping), the combined subsectors in the SER energy agreement (predominantly road transport) would need to deliver about 85% emissions reduction compared to 1990 levels. The study however does not cover reductions beyond 70%.

Furthermore, it needs to be taken into account that the aviation and maritime sector will use a part of the available renewable resources, particularly liquid biofuels, as this seems to be the primary route for the aviation sector to reduce its greenhouse gas emissions (together with energy efficiency improvements). The impact on the role of biofuels in transport is uncertain. On one hand, competition with aviation and maritime shipping for a finite amount of sustainable biomass will limit the role of biofuels in road transport; we have taken this into account in our analysis. On the other hand, a need for biofuels in aviation will stimulate technology breakthroughs and innovation increasing the sustainable biomass resource base, from which biofuels in road transport might profit as well. This impact however, was beyond the scope of our study. Finally, oil-based fossil fuels are interrelated, given the ratios by which they are produced in the refinery sector, ratios that cannot be varied at will.

This study shows two limitations worth mentioning. The scenarios **do not contain great submodal detail**. For example, trucks and buses were not subdivided into e.g. urban, regional and (inter)national distance submodes. This keeps our conclusions about for example urban options relatively tentative. Particularly when searching for specific niches for specific technologies, a further subdivision can be helpful. The analysis of the **role and costs of infrastructure**, particularly important for battery and hydrogen fuel cell electric driving, has remained relatively superficial. In further analyses, specific barriers will need to be identified and compared in order to design optimal and adaptive strategies for infrastructure roll-out .

Towards an integral vision

This scenario study finalises the first step of the process towards an integral Dutch vision on energy carriers for the transport sector. Based on this study, a starting document will be compiled which forms the basis input for the second step in the process. This will be the beginning of an intensive generation and exchange of ideas between the involved actors of the second phase. This scenario study focused on several possible images of the future from which robust elements, general preconditions and important key uncertainties related to these scenarios could be identified.

The next phase will focus on the required barriers and key uncertainties which come along with these future images. Specific combinations of fuel chains and user categories (urban passenger cars, long distance heavy duty trucks, etc) will be separately discussed. Based on these discussions, questions will be raised on how to eliminate specific barriers and how to deal with key uncertainties. The involved stakeholders in the process will jointly provide anwers to these questions. This will finally need to result in choices for no-regret options that anticipate on identified uncertainties. Important is to consider how *current* specific choices link to developments *in the long term* which might occur in the future and how choices of various fuel chains can strengthen each other.

In order to have successful alternative fuel policies and to reach sustainable targets, it is required to have a strong connection with the overall energy policy. For this reason, barriers and uncertainties in the overall energy sector will also be part of the discussions of the second phase of the development of the integral vision.

The second phase of the road towards the integral vision and action plan is due to start in January 2014, with the objective of having the integral vision ready in the first half of 2014 and the action plans in the second half of 2014. It is important to meet the designed time frame, since the efforts in the field of alternative fuels will soon become obligatory. This is caused by the new EU-regulation (Clean Power Directive, 17004/13) which is expected to be published in the course of 2014.

Glossary, definitions

Dutch territory emissions	Air pollution emissions (NO_x, PM_{10}, $PM_{2.5}$ and CH_4) based on the emissions resulting from kilometres driven on Dutch territory.
BEV	Battery Electric Vehicle
BPM	Belasting Personenauto's en Motorrijwielen, Purchase Tax on passenger vehicles
CCS	CO_2 capture and storage
CNG	Compressed Natural Gas
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
HD	Heavy Duty
H2	Hydrogen
ICE	Internal Combustion Engine
IPCC-TTW emissions	Tank-to-wheel emissions calculated according to the IPCC-guidelines. According to this definition, alternative energy carriers, like electricity, hydrogen and biofuels, do not result in any IPCC-TTW CO_2 emissions.
IPCC-energy values	These energy values consider the amount of fuel which is fuelled on Dutch territory (and not per se *driven* on Dutch territory). It furthermore excludes bunker fuels for among others aviation and shipping.
LNG	Liquefied Natural Gas
MRB	Motorrijtuigenbelasting, Annual Vehicle Tax
(uncertain) Parameter	Key aspect of future developments that is chosen to distinguish scenarios from each other.
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Vehicle
Reference scenario	Standard scenario of 'as usual' development, taking into account current policies but not assuming any new ones.
Scenario	Internally consistent view of the future, expressed in developments on which the user of the scenario does not have significant direct influence.

Scenario axis	Parameter chosen to span up scenarios. Two axes form a cross of axes, leading to four scenarios in the four quadrants of the cross.
TCO	Total Costs of Ownership
TTW emissions	See IPCC-TTW emissions
WTT emissions	Well-to-tank emissions: emissions from upstream production of energy carriers up to the moment the fuel has been distributed into a vehicle.
WTW emissions	Well-to-wheel emissions: full chain emissions from upstream production to downstream application in a vehicle.

1

Introduction

The targets set for climate, air quality and noise for transport require a transition within the sector. In the recently signed Energy Agreement for sustainable growth, directed by the Socio-Economic Council (SER), Dutch parties have laid out the basis for a broadly supported, robust and future-proof energy and climate policy. In the area of mobility and transport, parties have agreed on ambitious targets, viz. a reduction of CO_2 emissions by 60% in 2050 compared to 1990[4] and an intermediate reduction to a level of 25 Mton CO_2 (-17%) by 2030.In the context of the overall energy efficiency ambition of 100 PJ additional (final) savings by 2020 compared to the agreement's reference scenario, parties have agreed that transport and mobility are expected to contribute 15-20 PJ to this target.

In order to meet these targets, the Energy Agreement contains various concrete steps and measures. One of these is that parties will develop a joint vision on the future energy mix in the transport sector. Such a vision is needed because the shift from fossil fuels – mainly gasoline and diesel – towards new (renewable) energy carriers is an essential part of the transition and this entails major changes. This changes will differ between the various transport modi. Also, essential conditions and other targets regarding safety, air quality and sustainable economic growth will need to be taken into account when paving the way to the energy and climate targets.

The future energy and fuel situation is uncertain and depends on several factors. Therefore, it is important to explore the feasibility of the energy and climate targets in relation to the conditions, as a first step towards an integral vision. For this reason, the Dutch Ministry of Infrastructure and Environment commissioned a consortium consisting of ECN, CE Delft and TNO to construct scenarios for the future mix of transport energy carriers together with closely related stakeholders. Key points of attention are:

- How can a low-carbon objective of -60% CO_2-emissions be met by 2050?
- Which elements in the scenarios are robust?

[4] According to the IPCC definition. Only emissions in the Dutch territory are taken into account. Emissions related to the production of biofuels, electricity and hydrogen are not ascribed to the transport sector. In this report this is called the Tank-to-Wheel approach.
In the SER Energy Agreement also an intermediate target of 25 Mton CO_2-equivalents by 2030 is included. This corresponds to a 17% reduction compared to 1990.

- What are key conditions and uncertainties for energy carriers to emerge?
- What other lessons can be drawn from the scenarios?

The scenario analysis, looking at a wide variety of performance indicators, results in insight in robust elements in the future mix of energy carriers which are relatively independent of exogenic factors and thus form a solid basis for policy measures and development steps required on the short term. Even more important is that the scenario analysis needs to result in a clear view on the things we do not know today. These uncertainties and the way to handle them are key elements in the next phase: defining a joint vision on energy carriers for transport.

On September 24th 2013 the first meeting with stakeholders took place, with the primary objective to share the goals and process of the scenario study and to collect relevant input. Taking this input into account, four scenario storylines were defined and discussed in an intermediate stakeholder meeting on October 17th. In the second large meeting with stakeholders on November 14th, the first results of the scenario analysis were shared and discussed, as well as the input data used in the calculations and the selected shares of technologies and energy carriers in the various scenarios.

In this report, which is the conclusion of the first phase in the trajectory towards a joint vision on energy carriers for transport in the Netherlands, the key findings of the scenario analysis are discussed. In the second phase the key uncertainties and robust elements resulting from the scenarios will be clarified and extend and used as starting point for the construction of the vision.

This document will start with a description of the methodology for the scenario analysis in chapter 2, followed by a definition and storyline of the four chosen scenarios, including the selected mix of energy carriers resulting from the storylines in chapter 3. Additionally, the results of the scenario analysis according to the chosen key indicators will be shown in chapter 4. Finally, the results will be discussed in chapter 5, followed by the conclusions in chapter 6. The annexes give detailed insight in the methodology, reference scenario and used input data.

2

Methodology

This chapter describes the methodology and approach of this scenario project: the overall approach (2.1), the approach for scenario development (2.2), the approach for analysing the scenarios and defining the result indicators (2.3) and how this approach relates to international trends and studies (2.4).

2.1 Overall approach

The overall process of building and analysing scenarios requires several steps and choices, which are briefly described in this paragraph and will be described in more details in the following paragraphs.

The boundary condition of this study is the target to decrease the greenhouse gas emissions in the transport sector by 60% in 2050 compared to 1990-levels, using the IPCC methodology for calculating greenhouse gas emissions (being IPCC-TTW).

From this, the starting point is the development of the reference scenario to which the alternative scenarios can be compared. Keeping this reference path for all scenarios constant offers the possibility to compare the impact of the four scenarios. For this comparison, relevant performance indicators have been selected and defined in cooperation with stakeholders.

A next step in the process is the construction of the scenario storylines. More than one scenario is constructed because the future cannot be explored using one scenario. The scenarios need to reflect possible future images, based on the things we do not know today. For this reason, the most important and least certain parameters influencing the future mix of energy carriers in the transport sector were discussed and selected during stakeholder sessions. Combining two of these parameters results in two axes and four quadrants, where each quadrant reflects an extreme image of the future. These extreme images of the future result in four plausible and consistent storylines how the energy and transport situation might look like in the future. Based on these storylines,

for each scenario a mix of energy carriers is selected per relevant transport mode (e.g. passenger cars, trucks, inland ships) that is considered consistent with the main characteristics of the scenario. Theses mixes of energy carriers are tuned in such a way that all scenarios reach the primary goal of 60% greenhouse gas emissions reduction by 2050.

The next step is to assess the scenarios using the performance indicators. With these performance indicators, the effects of the four scenarios on important aspects can be calculated or described. Examples of quantitative indicators are well-to-wheel CO_2-emissions (in contrast to the starting point, being tank-to-wheel), total costs and pollutant emissions. Examples of qualitative indicators are green growth, energy security and external safety.

The final step is the analysis of the scenario results, focusing on robust elements and major uncertainties. The robust elements are recognizable in all scenarios and thus form a basis for measures which are so-called “no-regret”.

2.2 Approach for scenario exploration and development

Generating useful scenarios is not a straightforward activity. It is merely a craft, not a scientific discipline. Generally, scenarios can only be made useful when they are fit for purpose, in this case generating input for a future strategy on the energy mix of the transportation sector.

In this study first a ‘reference scenario’, or baseline, has been constructed. This scenario shows the energy mix in transport in a ‘business as usual’ future, with only current policies involved and no fundamental changes in the sector. This scenario merely serves to show the size of the challenge to reach the -60% greenhouse gas emission target, and to identify several scenario input data, such as the growth in mobility (see sections 3 and 4).

As a next step in this study, we took a relatively conventional approach, selecting two key uncertainties (parameters), constructing a cross of axes defined by opposing values for these parameters, and thereby producing four scenarios. These scenarios were generated as follows:

- First, the project team generated a longlist of uncertain future developments (parameters) that would influence the transport sector and its energy mix.
- This longlist was aggregated in a shortlist of six parameters.
- The shortlist was presented in the first stakeholder consultation session, on September 24 in The Hague. Participants provided feedback on this shortlist, and proposed two additional parameters (see annex A for an overview of parameters proposed).
- In the session, a poll was held on parameters that were considered most relevant (i.e. uncertain and influential to the energy mix in transport). During the meeting, a

tentative set of scenarios was generated on the basis of two of the three parameters with the highest vote.

- A second session was held on October 17 at TNO in Delft, with stakeholders who had expressed interest in supporting the scenario generation process. In subgroups, participants discussed three alternative sets of two parameters (see annex A for details). Even though the approach routes were fundamentally different, the exercise resulted in scenarios very similar to the preliminary ones produced in the first session. As a consequence, the project team decided to use the two key parameters with the highest vote from the first stakeholder session for the selection of the four scenarios and to use the results of the second stakeholder session to improve their consistency and enrich their storylines.

2.3 Approach for scenario analysis and performance indicators

The analysis was carried out using CE Delft's REST-NL model. This model is a modified and extended version of CE Delft's REST model that was previously developed for the European Commission, in order to cover the Netherlands. The data in the reference scenario are from the Referentieraming 2012 (the "vastgesteld en voorgenomen beleid" scenario, taking into account appointed and intended policies) up till 2030, see section 3.1. For the various road transport modes, data used from the Referentieraming includes transport volume (vkm), energy use and emissions. For non-road modes no data on transport volume is available from the Referentieraming and therefore only data on energy use and emissions are taken from the Referentieraming (Verdonk and Wetzels, 2012). As a consequence the modelling approach for calculating the impacts on non-road modes is different from the approach for the road transport modes.

In addition to the Referentieraming the model includes detailed input sheets per scenario and modules that calculate the various performance indicators listed above. All costs are expressed in Euro price level 2010. The cost analysis is limited to the following vehicle types: cars, vans, trucks, buses, special vehicles and inland shipping. The scenarios are comparatively assessed for the year 2050, but also results for the intermediate years of 2020 and 2030 results are presented in chapter 5.

Four scenarios were elaborated, both qualitatively and quantitatively. Each scenario consists of the following elements:

- Storyline (qualitative)Input data, e.g. vehicle efficiency development and mobility growth (quantitative)
- Shares of energy carriers in the various transport modes
- Performance indicators of main impacts (quantitative)
- Analysis of other impacts (qualitative).

All four scenarios are designed to deliver an IPCC-TTW greenhouse gas (GHG) emission reduction of 60% in 2050 compared to 1990.

The *storyline* describes how the world would develop in that particular scenario. This includes developments of the European and global economy, demography and technology as well as geopolitical developments. The storylines were built around the key elements retrieved from the stakeholder engagement process and further elaborated by the project team. These storylines can be found in section 3.4.

The *input data* for each scenario are a consistent set of quantitative assumptions per transport mode. The main assumption for each scenario is the energy mix per relevant transport mode in terms of the share of each energy carrier in the transport demand, expressed as the share in vehicle-km driven on gasoline, diesel, electricity, hydrogen, etc. Also, the development in mobility growth is an important input. Furthermore, a broad set of assumptions was made, e.g. on energy and vehicle costs, WTT and TTW emissions, and other relevant input. The full set of inputs (scenario-dependent and scenario-independent) can be found in Appendix C.

The *shares of the various energy carriers* in each scenario are consistent with the storyline, taking into account maximum realistic shares of each energy carrier in 2050 . The maximum shares were based on expert judgement by the project team supported by a series of previous studies on GHG emission reduction scenarios for transport. These constraints are the results of:

- Time needed for vehicle technology innovation (e.g. in battery technology)
- Speed of market uptake of new vehicle technology (shares in fleet sales, fleet renewal rates)
- Speed of implementation of new energy technology (e.g. of hydrogen infrastructure, renewable energy production, CCS, etc.)
- Maximum available sustainable biomass potential.

Based on the input data and the other parameters, the following *performance indicators* have been calculated for each scenario and (where useful) per transport mode:

- Total final energy consumption per energy carrier
- TTW CO_2[5] emissions
- WTT and WTW CO_2 emissions
- Air pollutant emissions of NO_x and PM (TTW, WTT and WTW)
- Average total cost of ownership (TCO) for users (€/vkm)
- Total tax revenues (from fuel taxes and vehicle-related taxes)
- Indicative impacts on social costs (solely based on user costs without taxes and the social cost of pollutant emissions).

The methodology used in the model for calculating these various performance indicators and the methodology for the assessment of qualitative impacts can be found in Appendix A.

Results on costs and taxes are limited to road transport, because of a lack of data on reliable cost estimates for the other modes of transport and the small share of these

[5] The share of non-CO_2 emissions in the total greenhouse gas emissions (in terms of CO_2-equivalents, based on Global Warming Potential) is insignificant in all scenarios (less than 1%) and therefore not taken into account.

other modes in the GHG emissions (only 10% in 2010) and their (very) small share in the total costs.

Finally, we made a *qualitative assessment* of three other impacts: options for green growth, external safety impacts, and energy security impacts.

2.4 Other scenario studies

In scenario studies several approaches are distinguished. In this project we combine a *Prescriptive* approach and an *Exploratory* approach. A fixed target of -60% in 2050 and develop roadmap(s) based on back-casting (Prescriptive approach) is combined with a plausible and consistent storyline starting with relevant trends and uncertainties identified by experts and stakeholders and quantitatively analysed (Exploratory approach). In phase 2 this will be complemented by a *Consensus building* approach: the development of a shared vision of the future by a heterogeneous group – to prevent dominancy of fixed positions.

In *Getting into the right lane for 2050* The Netherlands Environmental Assessment Agency (PBL, 2009) a *Prescriptive* approach is followed. Starting from a business-as-usual growth scenario and a CO_2-target of -80% WTW for transport in 2050 reduction measures are added up till the CO_2- target is reached. One of the restrictions is a balance between the three pillars considered: low-carbon fuels, energy efficiency and reduction of mobility growth (including modal shift). Via backcasting critical steps are identified and policy recommendations are drafted. The 2050 situation presented is familiar: strong emphasis on efficiency improvements across all vehicles, dominancy of electric drivetrains in urban areas and biofuels for long haul transport. The scope of the PBL study did not include further investigation of different scenarios to get to the -80% target or the constructing different energy mixes for 2050 or intermediate years.

In the *New Lens* scenarios issued in 2013, Shell follows the *Exploratory* scenario approach. Two visions for 2100 are given based on developments of the world economy, market order, political order, oil price, world dynamics, etc. and aimed at understanding and illustrating the impacts on the world energy system. One of the scenarios strongly relies on natural gas (Mountains scenario) and in the other one solar energy (PV) is dominant by 2070 (Oceans scenario). In both scenarios the CO_2 emission is the result of the developments chosen. As a consequence the emissions are well above the 2050 targets in this study, and only by 2100 emissions reach near zero. The *Mountains* scenario foresees for transport a strong introduction of gaseous fuels in electric drivetrains, whereas innovation, solar energy and efficient vehicles are key in the *Oceans* scenario. In both storyline and technological developments the Shell scenarios show resemblance to two of the scenarios in our study, however especially growth rates (of introduction of new energy carriers or efficient vehicles) in the Shell scenarios are much lower due to the absence of a CO_2 constraint.

In the *Energy Technology Perspectives 2012*, the IEA outlines the changes needed to reach a sustainable energy system, defined as an energy system compatible with a two

degrees global warming target. This is the same background the -60% target for transport in our study stems from. A four degrees and a six degrees situations are added to better understand and illustrate the transitions needed to reach the two degrees target and serve a similar goal as the reference scenario in our study. In the two degrees situation several scenarios are constructed for differences (ranges) in technological or economic developments: *slower CCS progress, different demand developments in industry, alternative pathways for hydrogen use.* Our approach has a strong resemblance with this IEA study both in starting point (CO_2-target) and character of the uncertain future developments considered. Major findings of the IEA study are: decarbonisation of the electricity generation is the most important system-wide change, strong energy efficiency improvement is key but also on the critical path (decisive policy action needed) and energy security and climate change mitigation are allies. Again, the 2050 situation for transport is familiar: up till 2030 efficiency in all vehicles will bring most progress, after 2030 a strong growth of electric powertrains (incl. plug-ins) and biofuels for air and maritime transport. The introduction of hydrogen strongly depends on the economy wide developments: the transportation sector on its own will not generate sufficient momentum for the development of a hydrogen system.

3

Scenarios: General description, storylines, energy mix

This chapter summarizes how we how we interpreted the -60% objective (3.1), defined the reference scenario (3.2),), and how we came to four scenarios for meeting this objective (3.3). Furthermore it describes the storylines and the characteristics of the four scenarios (3.4), and summarises some macro assumptions in the scenarios (3.5).

3.1 Definition of the 60% CO_2 reduction target

As mentioned in chapter 1, this study elaborates on possible energy mix scenarios in order to reach -60% CO_2-emission reduction in the transport sector by 2050[6]. This target of -60% is based on the White Paper (EC, 2011a) which states that '*in order to drastically reduce world greenhouse gas emissions (…) a reduction of at least 60% of GHGs by 2050 with respect to 1990 is required from the transport sector, which is a significant and still growing source of GHGs'*. Although this 60%-target is getting increasingly common in policy discussions, there seems to be uncertainty in the definition of 'transport'.

Aviation and maritime transport are often excluded in the 60%-target, but it is questionable whether this assumption is correct. In the Impact Assessment accompanying the White Paper (EC, 2011b), the sectorial reduction for transport was analysed to be -54 to -67%, including CO_2-aviation, excluding maritime. Excluding both aviation and maritime would require an overall reduction of -61 to -74% in the other sub-sectors according to this assessment. Commissioned by the Ministry of Infrastructure and Environment, this study investigates the target of 60% CO_2 reduction excluding both maritime and aviation, since aviation will be regulated via the ETS.

[6] Compared to 1990-levels.

However, it is important to realize that in the end a more stringent reduction target for 2050 may be required by the European Commission for the transport modes considered in this study (i.e. all modes but maritime shipping and aviation), when feasible reductions in aviation and maritime turn out to be below 60%. Therefore, feasibility of reaching deeper reductions will be investigated in the sensitivity analysis in this study.

Another important consequence of the IPCC-method is that for alternative energy carriers like electricity, hydrogen and biofuels, the tank-to-wheel emissions are zero by definition . This calculation method is referred to in the report as "IPCC-TTW" CO_2 emissions. It is important to realise that especially for biofuels the physical tank-to-wheel emissions are not zero, but are compensated for by CO_2 absorption up in the chain. As the 60%-target in the SER Energy Agreement relates to IPCC-emissions, we used IPCC-TTW CO_2 emissions in our calculations.

3.2 The reference scenario

The basis of our scenarios is a reference scenario, a 'business as usual' development pathway in which the effects of current and intended policies are taken into account, and no new policies are assumed. This reference scenario also provides several basic inputs to our calculations. The reference scenario is based on the *Referentieraming 2012' and PBL transport projections until 2030.* Details on the construction of the reference scenario can be found in Appendix B.

Figure 5 shows the energy use of the different modalities in the transport sector by 2050 in the reference scenario. It illustrates that passenger cars, vans and trucks together still dominate the transport sector by 2050. According to this reference scenario the overall energy use of the transport sector will be 523 PJ (IPCC values).

Figure 5: Energy use transport sector by 2050 (PJ)

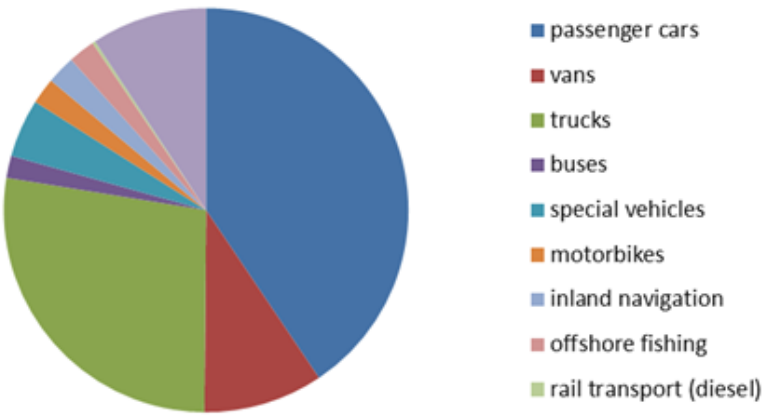
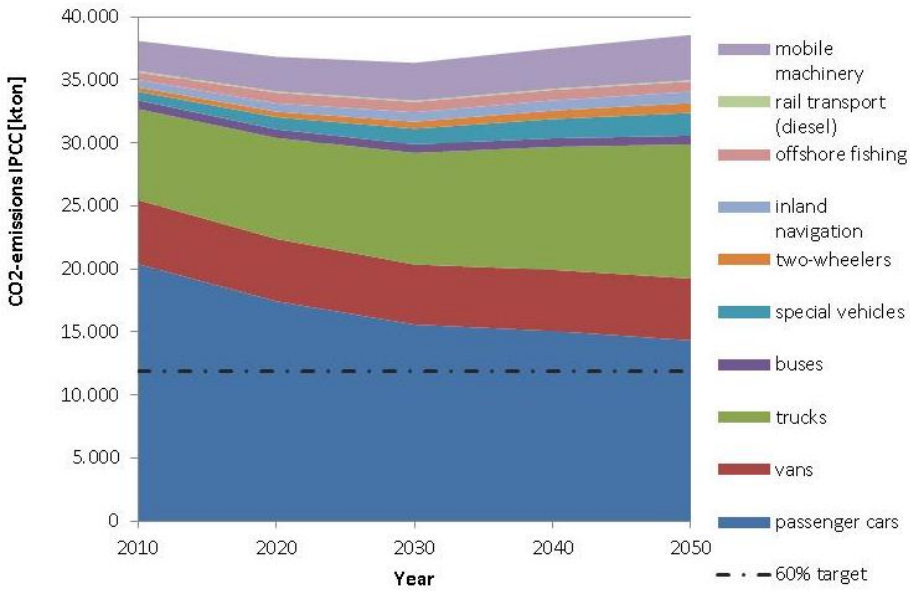


Figure 6 illustrates the development of the CO_2 emissions up to 2050 and the share of CO_2 emissions of the different transport modalities. The dotted line indicates the 60%-target for the transport sector. It shows that a large gap exists between the overall projected CO_2-emissions (~38.6 Mton) and the level of the 60%-target (~11.9 Mton).

Figure 6: CO_2 emissions transport sector



The figure illustrates that an overall decrease in CO_2 emissions is observed up till 2030, which is largely due to the stricter emission standards to be introduced in 2020/2024 for passenger cars and vans. In the years after 2030 the overall increase is mainly due to the assumed growth (and linear extrapolation towards 2050) in the fleets for trucks and mobile machinery.

The energy mix in 2050 of the reference scenario is shown in the table below. The percentages reflect for each transport mode the share of vehicle-kilometres driven per energy carrier. The percentage of biofuels represents a general blending percentage for all fossil fuels (based on energy consumption instead of vkm). The percentages in the reference scenario are a snapshot in time and do not necessarily reflect very recent developments.

Table 1: Share of energy carriers per mode in 2050 in the reference scenario (% of vkm)[7]

	Passenger cars	Vans	Trucks	Buses	Two-wheelers	Special vehicles (incl NRMM)	Inland shipping	Rail diesel
Gasoline	58%	0%	0%	0%	100%	2%	0%	0%
Diesel	26%	87%	100%	100%	0%	98%	100%	100%
LPG	2%	1%	0%	0%	0%	0%	0%	0%
Methane	3%	4%	0%	0%	0%	0%	0%	0%
Hydrogen	0%	0%	0%	0%	0%	0%	0%	0%
Electricity	11%	8%	0%	0%	0%	0%	0%	0%
Biofuels (% energy)	8.5% of all fossil fuels (gasoline, diesel, LPG, methane) will consist of biofuels by blending of biofuels						0%	0%

[7] The shares of gasoline, diesel and LPG include the biofuels that are blended.

3.3 Scenarios: Axes chosen

On the basis of the approach described in section 2.2, a set of scenarios was made on the basis of two parameters:

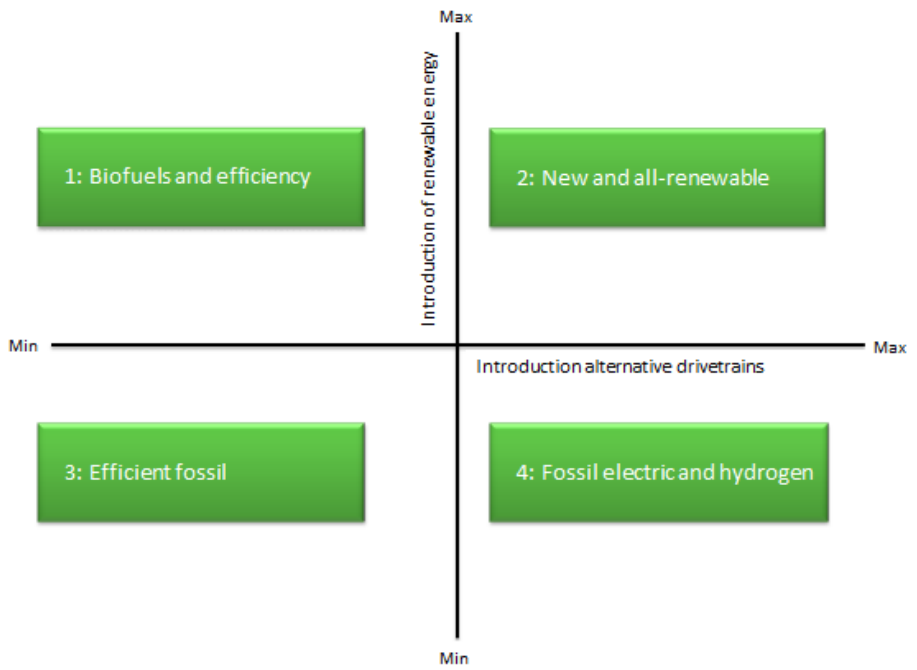
1. The shares of renewable energy in the total energy supply, with as extremes:
   - A future in which renewable energy becomes mainstream, with very high shares of renewables in e.g. the power sector, and relatively abundant availability of sustainable biomass for e.g. chemicals and fuels. Underlying assumptions for this extreme are e.g.:
     - Production cost reductions and performance improvements of wind, solar and bio based products above projections
     - Availability of sustainable biomass reaches the upper end of current 2050 projections
     - Technologies available for grid integration of intermittent electricity from renewables develop favourably, both in terms of performance and costs.
   - A future in which renewable energy remains relatively marginal, with relatively minor shares of renewable power, heat, and (liquid and gaseous) fuels, essentially because of less favourable developments in the issues described above.
2. The penetration of new electric drivetrains in the transport sector, powered by batteries and/or hydrogen fuel cells, with as extremes:
   - A future in which electric drivetrains conquer significant shares of vehicle sales, because of favourable developments in performance and costs of batteries and fuel cells. Underlying assumptions are:
     - The fuel cell technology, which now seems to be at the verge of roll-out, delivers more learning-by-doing cost reductions than projected, and prices of metals like platinum do not reach inhibitive levels. The same assumption applies to hydrogen storage.
     - Battery technologies experience a breakthrough in capacity, costs, charging time and reliability. This opens up other markets for battery electric vehicles with longer ranges against reasonable costs.
     - Necessary rollout of a hydrogen infrastructure is successful and does not block vehicle roll-out. Safety issues in fuelling stations and vehicles are effectively dealt with.
     - Power infrastructure is adapted to accommodate further growth of battery electric vehicles.
     - For both options, vehicles and mobility concepts are developed in such a way that they match with end user needs and adaptation capabilities.
   - A future in which electric drivetrains remain marginal or absent in transport, essentially because developments are less favourable on the elements mentioned above.

Note that these axes are already relatively aggregated. It is conceivable, for example, that solar-PV is introduced successfully, while advanced biofuels remain marginal. Or that fuel cells develop favourably, while battery technologies do not experience the required break-through in performance and costs. In the specification of the scenarios,

this was kept in mind, but in order to be able to encompass sufficient overall developments, it was decided not to disaggregate either of the axes.

The cross of axes that these two parameters generate is shown in **Figure 7**.

Figure 7: The four alternative fuel scenarios



These scenarios were further enriched by other uncertain parameters identified in the process. These improved storylines were then used to specify the energy mixes of each transport mode in the four scenarios.

This led to the following four scenarios, illustrated in **Figure 7**:

1. Biofuels and efficiency (the upper left quadrant)
2. New and all-renewable (the upper right quadrant)
3. Efficient fossil (the lower left quadrant)
4. Fossil electric and hydrogen (the lower right quadrant).

These four resulting scenarios are described in detail in section 3.4.

3.4 Scenario descriptions

The tables on the following pages describe the scenarios in keywords, a general storyline, an indication of the energy economy the key characteristics of the transport sector, and the specification of the shares of the energy sources in the various transport subsectors.

The table below shows which combinations of energy carriers/powertrains and chains were taken into consideration in the specification of the scenarios. Hydrogen is applied

only in combination with fuel cell electric vehicles. Hydrogen in internal combustion engines has not been considered in this study. Biofuels are assumed to be advanced biofuels from mainly (agricultural and forestry) residues.

Table 2: Fuel/vehicle chains taken into consideration in this study

	Passenger cars	Vans	Trucks	Buses	Two-wheelers	Special vehicles	Inland shipping	Railway	Mobile machinery
Fossil - conventional	X	X	X	X	X	X	X	X	X
Fossil - efficient	X	X	X	X	X	X	X	X	X
LNG/CNG	X	X	X	X		X	X	X	X
Full-electric	X	X	X	X	X	X		X	X
Plug-in hybrid	X	X	X	X		X			
H_2 fuel cell	X	X	X	X		X			X
Biofuel	X	X	X	X	X	X	X	X	X

Please note that the quantification of the shares of energy sources in each subsector is not only derived from the storyline, but is also set to meet the -60% objective, in combination with the assumptions on mobility growth and vehicle efficiency gains (see chapter 4).

1. Biofuels and efficiency

Keywords: focus on upstream innovations, biofuels, efficiency

General scenario storyline

In this scenario, considerations on climate change and energy security lead to a strong development of renewable energy technologies. Economic growth follows a moderate reference pathway, which is sufficient to generate the innovations needed for further breakthroughs in solar-PV, (offshore) wind, and sustainable biomass-to-energy. These upstream innovations dominate over downstream development such as electrification, which does not take off. Global exchange of ideas and concepts is also sufficient to support the development of new climate-neutral fuels. Within the EU, further convergence into one energy market provides an effective basis for further market rollout of renewables. This process is further strengthened by wide and enduring public support for renewables, which introduction also affects the balance of power between 'big industry' and citizens. Globally, the importance of BRIC and 'next eleven' economies increases. Oil producing regions remain relevant, although biobased products are a mature alternative to oil products.

Key characteristics of the overall energy economy

Zooming in on the energy sector, climate change mitigation objectives are mainly met by a clear dominance of renewables in all sectors. Power generation is entirely renewable, dwellings and offices have managed to become climate-neutral by a combination of energy efficiency improvements and decentralized renewables such as solar-PV, heat pump and seasonal storage of heat and cold. An energy- and resource-efficient industry has become strongly biobased.

The energy economy of the transport sector

Strong growth of biofuels: technologies for advanced biofuels break through, new feedstocks such as algae become mainstream and 'solar fuels' (hydrocarbons directly produced from solar energy) enter the mix. Because electric drivetrains do not break through, the transport sector focuses on further efficiency improvement of internal combustion technologies on the basis of liquid and gaseous (bio)fuels. This leads to strong downsizing of engines and vehicle efficiency improvements, in passenger transport as well in freight transport.

In this scenario, the growth of mobility follows a moderate (scenarios) path: fundamental review of mobility given CO_2 reduction targets is not necessary.

Key characteristics of the various subsectors in transport

In all subsectors, the share of biofuels increases to shares around 50%, overall use of biofuels is only limited by its (relatively abundant) availability. This also implies the introduction of flex-fuel passenger vehicles that run on high blends of gasoline and ethanol. Biobased diesel fuels are assumed to be almost entirely fungible with fossil diesel. Partly biofuels consist of biomethane blended with fossil natural gas. The role of other fuels remains roughly as it is today:

- In passenger vehicles, gasoline is the second fuel in terms of share, with smaller roles for diesel, methane and a minor role for electricity. The diesel share decreases slightly in order to make the overall gasoline-diesel shift of the entire energy mix match better with the gasoline-diesel split of EU refineries. For this reason, the dominant stream of biofuels are diesel substitutes, just as they are today in Europe.
- In vans, trucks and buses, fossil diesel is the second fuel in terms of share, given its current dominance and efficiency, with varying smaller contributions of methane and electricity (the latter only in vans for urban distribution, a niche in which range limitations can be more easily overcome).
- In inland shipping, tens of percents of demand are met with methane, in the form of LNG. This is a further development of the initiatives of today in this field.

Specification of the shares of energy sources in the various transport subsectors

	Passenger cars	Vans	Trucks	Buses	Two-wheelers	Special vehicles	Inland shipping	Rail diesel	Mobile machinery
Gasoline	58%	0%	-	-	100%	3%	-	-	3%
Diesel	25%	84%	95%	95%	-	98%	74%	100%	98%
LPG	1%	1%	-	-	-	0%	-	-	0%
Methane	10%	12%	5%	5%	0%	0%	26%	0%	0%
Hydrogen	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electricity	6%	4%	0%	0%	0%	0%	0%	0%	0%
Biofuels (% energy)	55% of all fossil fuels (gasoline, diesel, LPG, methane) will consist of biofuels by blending of biofuels						55%	50%	

2. New and all-renewable

Keywords: Focus on upstream and downstream innovations, renewables, electric drivetrains

General scenario storyline

In this scenario, considerations on climate change and energy security lead to a strong development of all kinds of climate-neutral energy technologies, including renewables and new vehicle drivetrains. This scenario is rich in innovations, with overall leads to economic growth above reference scenario, particularly in BRIC and 'next eleven' economies. Partly because these economies also face environmental issues such as urban air pollution, electric propulsion experiences a major breakthrough. In this dynamism, the role of oil producing regions becomes less important. International cooperation further strengthens innovation and diffusion of new ideas. Within the EU, strong convergence into one energy market provides an effective basis for e.g. the development of a hydrogen infrastructure, and further market rollout of renewables. Relations between government, industry and citizens are partly redefined, and as a consequence citizen engagement is effectively organized. This strongly helps solving issues related to safety (of e.g. hydrogen), public support for renewables, and end-user friendliness of new concepts.

Key characteristics of the overall energy economy

Zooming in on the energy sector, this scenario includes a manifold of new technologies in the energy sector. Power generation is entirely renewable, dwellings and offices have managed to become climate-neutral by a combination of energy efficiency improvements and decentralized renewables such as solar-PV, heat pump and seasonal storage of heat and cold. Hydrogen is introduced in the energy economy as an effective way to balance mismatch between power demand and supply. Industry also taps from this resource, next to biomass.

The energy economy of the transport sector

Breakthroughs in battery and fuel cell technologies allow for strong introduction of electric propulsion in road transport, in order to meet the climate objectives. Both electric power and hydrogen are renewable, and hydrogen in transport is boosted by the role of this gas in other parts of the energy economy. Passenger and short/range freight transport become strongly electricity based. In long-distance transport, biofuels are introduced, but their role can remain modest without compromising the overall climate target in transport. Also in other (smaller) sectors and niches, conventional fuel-vehicle combinations remain.

In this scenario, economic growth provides a need for more mobility. However, the high shares of novel and expensive new options in transport have a decoupling effect on mobility growth, particularly in long-distance freight transport. With optimisation of logistics and technologies like 3-D printing this makes mobility growth consistent with the reference.

Key characteristics of the various subsectors in transport

In many subsectors, electric drivetrains are introduced up to significant shares. Hydrogen gets an additional stimulus as it is also introduced in the overall energy mix to balance and store excess intermittent renewable energy generated by wind and PV-solar.

- In passenger cars, vans, and buses, electric propulsion becomes the dominant option, with a share of more than three quarters.
- In trucks the share of battery and fuel cell electric vehicles remains lower, as in long-distance freight transport the efficiency gain of electric driving is lowest compared to diesel, and range and infrastructure challenges of batteries and hydrogen fuelling are largest. Biofuels also play a role in trucks. Potentially, more biofuels are available, they are not needed to meet the climate target.
- Most buses for urban and regional transport go electric, but long-range touring cars remain relying on diesel.
- In inland shipping, some biofuels are introduced, partly as bio-LNG. This role can remain modest as major emission reductions are already achieved in other subsectors.

Specification of the shares of energy sources in the various transport subsectors

	Passenger cars	Vans	Trucks	Buses	Two-wheelers	Special vehicles	Inland shipping	Rail diesel	Mobile machinery
Gasoline	10%	0%	-	-	30%	3%	-	-	3%
Diesel	10%	20%	33%	20%	-	57%	100%	100%	57%
LPG	0%	0%	-	-	-	0%	-	-	0%
Methane	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hydrogen	40%	40%	27%	30%	0%	10%	0%	0%	30%
Electricity	40%	40%	40%	50%	30%	30%	0%	0%	10%
Biofuels (% energy)	8.5% of all fossil fuels (gasoline, diesel, LPG, methane) will consist of biofuels by blending of biofuels						20%	20%	

3. Efficient fossil energy

Keywords: Stagnation in innovation of alternative technology, efficiency, mobility reduction, methane, fossil energy

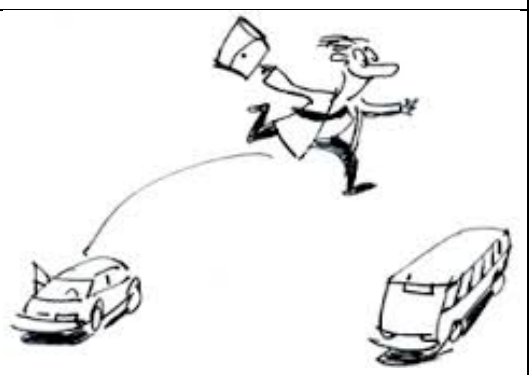
General scenario storyline

In this scenario, general global development falters, leading to major stagnation in the further development and introduction of new technologies to combat climate change. Global economic growth remains below reference scenario development: developed economies have difficulties solving the issues that come with their maturity, and developing economies face growth reductions because of social, political and environmental turmoil. This means that conventional technologies and oil remain dominant, which further strengthens the role of oil producing regions. Although international climate change mitigation agreements stand, cooperation on innovation remains limited, requiring relatively drastic measures to combat CO_2 emissions using mostly conventional technologies. Also within the EU, a lack of coordination on the energy market remains. Because of a lack of effective governance and commercial innovation, bottom-up social innovations to help saving the climate flourish, leading to unexpected new concepts based on conventional technologies. In general, this scenario contains various elements of stagnation and crisis.

Key characteristics of the overall energy economy

Zooming in on the energy sector, this scenario mostly makes use of conventional technologies. CO_2 reductions in power generation is only partly based on renewables, CCS also plays a role. In dwellings and offices, energy efficiency is key, as well as in industry. To a limited extent, biomass plays a role as well in energy supply of these sectors, e.g. through biomethane (green gas).

The energy economy of the transport sector



Because the availability of alternative options for the transport sector is very limited, the focus is on drastic energy efficiency improvements, including downsizing. Partly, methane is introduced because of its lower carbon content compared to fossil oil. This also enables the introduction of biomethane (green gas) into the transport sector, also in the form of bio-LNG in long-distance road transport and inland water transport.

Modest economic growth and additional pricing measures reduce mobility significantly. In combination with social innovations, this leads to a lower growth in vehicle kilometers, e.g. due to car sharing, carpooling and an increased role for the all-Dutch bicycle. As far as the dire economic situation allows, mobility for commuting is also reduced by changes in spatial management and housing policy, reducing average commuter distances.

Key characteristics of the various subsectors in transport

No major fuel and drivetrain changes take place in this scenario.

- Throughout all subsectors, energy efficiency is pushed to its technical limits. This provides an essential part of the emission reductions needed to meet the climate target.
- Additionally, methane is introduced in almost all subsectors by tens of percents. This is because the carbon intensity of methane is slightly lower than that of liquid fossil fuels. Besides, new dual-fuel engine technologies (based on real-time blends of liquid fuel and methane) lead to additional efficiency gains.
- The share of biofuels is assumed to be relatively modest, and equally split between the subsectors. Like all renewable options, the availability of biofuels is limited in this scenario.

Specification of the shares of energy sources in the various transport subsectors

	Passenger cars	Vans	Trucks	Buses	Two-wheelers	Special vehicles	Inland shipping	Rail diesel	Mobile machinery
Gasoline	41%	0%	-	-	100%	2%	-	-	2%
Diesel	25%	70%	50%	40%	-	88%	68%	60%	88%
LPG	2%	2%	-	-	-	0%	-	-	0%
Methane	25%	25%	50%	50%	0%	10%	32%	40%	10%
Hydrogen	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electricity	7%	5%	0%	10%	0%	0%	0%	0%	0%
Biofuels (% energy)	15% of all fossil fuels (gasoline, diesel, LPG, methane) will consist of biofuels by blending of biofuels						15%	25%	

4. Fossil electric/hydrogen

Keywords: Focus on downstream innovations, electric drivetrains, fossil energy, CCS

General scenario storyline

In this scenario, climate change mitigation efforts lead to breakthroughs in downstream use of energy, more than in the generation of renewable energy. Economic growth follows an moderate (reference scenario) pathway, which is sufficient to generate the innovations needed for further introduction and growth of downstream technologies such as high-capacity batteries and hydrogen fuel cells. Global exchange of ideas and concepts is also sufficient to support this. Within the EU, further convergence into one energy market provides an effective basis for an integrated rollout of a hydrogen infrastructure, and of a CO_2 network required for CCS. The energy economy remains largely based on centralized production units, and the role of decentralized (renewable) energy stays subordinate. Globally, the importance of BRIC and 'next eleven' economies increases. Oil and other energy majors remain relevant.

Key characteristics of the overall energy economy

In the energy sector, greenhouse gas mitigation ambitions are mostly realized through CCS and other centralized technologies, particularly in the power generation sector. Hydrogen also plays a role in reducing CO_2 emissions of dwellings and offices, partly replacing methane. In industry, energy efficiency and again CCS play an important role. To a limited extent, biomass plays a role as well in energy supply of these sectors, e.g. through biomethane (green gas) and biobased industrial processes.

The energy economy of the transport sector

Because of the large-scale introduction of battery and fuel cell technologies, electric propulsion is a major option. The necessary electricity and hydrogen mainly come from fossil resources. Next to the efficiency improvement by electric propulsion, CCS in power and hydrogen production is essential for reaching climate change mitigation goals. Methane (to a limited extent biomethane) is used for reducing CO_2 emissions in long-distance road transport and inland water transport. Bio-LNG is also applied to long/distance freight transport and inland water transport.

In this scenario, the growth of mobility follows a moderate (reference scenario) path: a fundamental review of mobility is not necessary, given the balance between CO_2 reduction targets and reduction options at hand.

Key characteristics of the various subsectors in transport

Like in scenario 2, electric propulsion becomes dominant in passenger cars, vans and buses. In comparison with scenario 2, scenario 4 leans more on battery electric vehicles, as the general role of hydrogen in this scenario is less important than in scenario 2.

- In passenger cars, the remaining demand is met by gasoline and (to a lesser extent) diesel. This also keeps the overall gasoline-diesel shift of the entire energy mix match better with the gasoline-diesel split of EU refineries
- In vans, this remaining fuel is diesel, as is today.
- In trucks, the share of battery and fuel cell electric vehicles remains lower, as in long-distance freight transport the efficiency gain of electric driving is lowest compared to diesel, and range and infrastructure challenges of batteries and hydrogen fuelling are largest.
- For the same reasons, local and regional buses mainly run on electricity and hydrogen, but touring cars remain on diesel.
- In inland shipping, methane also enters the mix.

As the limitedly available biomass is needed to reduce emissions in industry, the role of biofuels is marginal in all subsectors in this scenario.

Specification of the shares of energy sources in the various transport subsectors

	Passenger cars	Vans	Trucks	Buses	Two-wheelers	Special vehicles	Inland shipping	Rail diesel	Mobile machinery
Gasoline	12%	0%	-	-	40%	1%	-	-	1%
Diesel	10%	20%	31%	40%	-	49%	65%	0%	49%
LPG	0%	0%	-	-	-	0%	-	-	0%
Methane	0%	0%	15%	0%	0%	0%	35%	0%	0%
Hydrogen	23%	23%	15%	20%	0%	10%	0%	0%	40%
Electricity	55%	55%	39%	40%	40%	40%	0%	0%	10%
Biofuels (% energy)	8.5% of all fossil fuels (gasoline, diesel, LPG, methane) will consist of biofuels by blending of biofuels						8.5%	8.5%	

3.5 Macro parameters in the scenarios

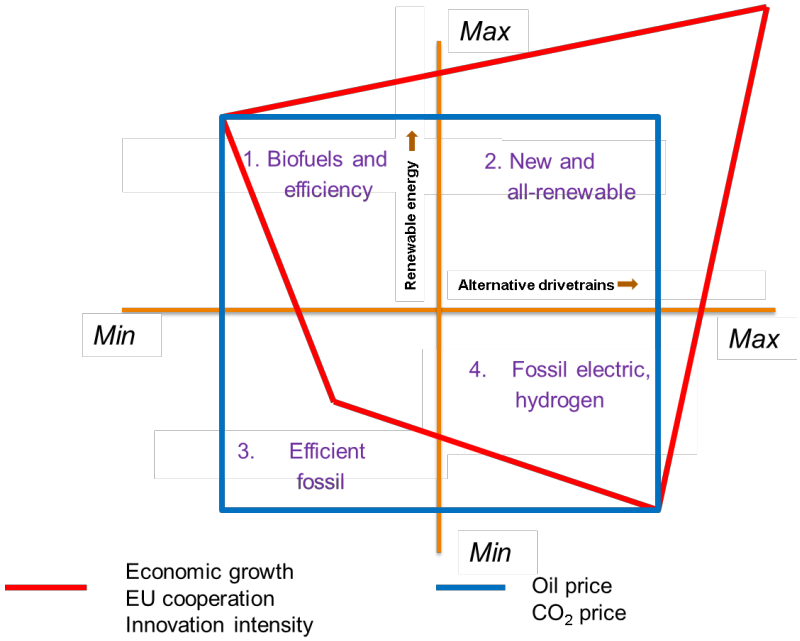
The two axes chosen turned out to be fit for purpose, having a strong influence on the future mix of energy carriers for transport and being a good basis for plausible and consistent storylines. The other parameters identified lead to either similar energy mixes or lacked distinctive characteristics. The parameters that lead to similar energy mixes were used to enrich the storylines of the scenarios and to strengthen their consistency and plausibility.

Figure 8 shows how the other parameters coincide with the parameters chosen.
In the *New and All-renewable* scenario both renewables and new alternative drivetrains are successful. This is consistent with strong innovations in economy and society, strong economic growth and positivism and thus strong cooperation in Europe. In the *Efficient fossil* scenario however, economic growth falls short (of the reference scenario) and so does innovation. As a consequence cooperation in Europe is limited to only urgent policy measures.

The *Biofuels and efficiency* and the *Fossil electric and hydrogen* scenarios are average (i.e. comparable to the reference scenario) on economic growth, cooperation and innovation.

It was decided to keep the oil price unchanged in all scenarios as there were no distinctive arguments either for higher or lower prices. Higher economic growth might increase oil demand - and thus prices – but the -60% greenhouse gas target for 2050 is only plausible if the whole world strives for meeting the climate change targets and limits the demand for oil. In this case higher energy demand will be supplied by renewable energy.

Figure 8: Relative position of some other macro parameters in the four scenarios



4

Scenario outcomes

This chapter contains the key results of the scenario analyses on the various performance indicators: energy mix (5.1), CO_2 emissions (5.2.), costs (5.3.), air quality (5.4), green growth (5.5), external safety (5.6) and energy security (5.7).

4.1 Energy mix in each of the scenarios

Figure 9 shows the final energy mix by 2050 for the different scenarios. It clearly illustrates their key characteristics:

- Strong efficiency improvements and mobility growth reduction in Scenario 3 (Efficient fossil) leads to the smallest energy demand in this scenario. Scenario 3 has even a lower energy demand than the transport sector has today.
- For the same reason of efficiency improvement, Scenario 1 (Biofuels and efficiency) also has a smaller primary energy demand
- With their substantial shares of electricity and hydrogen, scenarios 2 and 4 shows the largest diversity in fuel shares.
- As electricity and hydrogen are also relatively efficient, total energy demand is smaller than the reference scenario.

Figure 10 shows the development in the fuel mix of the four scenarios over the period 2010-2050. Some essential developments are:

- Scenarios 1 and 3 show a more gradual reduction of greenhouse gases, while 2 and 4 show and increased reduction of energy use after 2030. This illustrates that the dominant energy demand reduction options in Scenarios 1 and 3 grow towards their maximum capacities, while in scenarios 2 and 4 the reduction options still need initial years to roll out and could result in larger reductions after 2050.

- If biofuels break through, their strongest growth will be after 2020. In scenarios 3 and 4, this period after 2020 shows a slight decline in biofuels, as advanced biofuels do not set off and conventional biofuels are reduced because of sustainability issues.

Figure 9: Total final energy mix per scenario in 2050

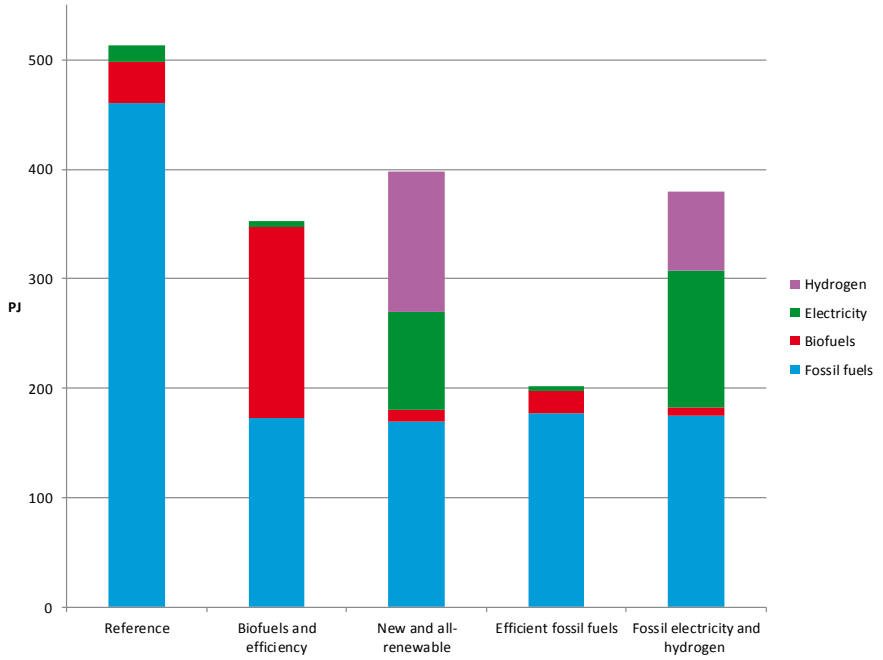
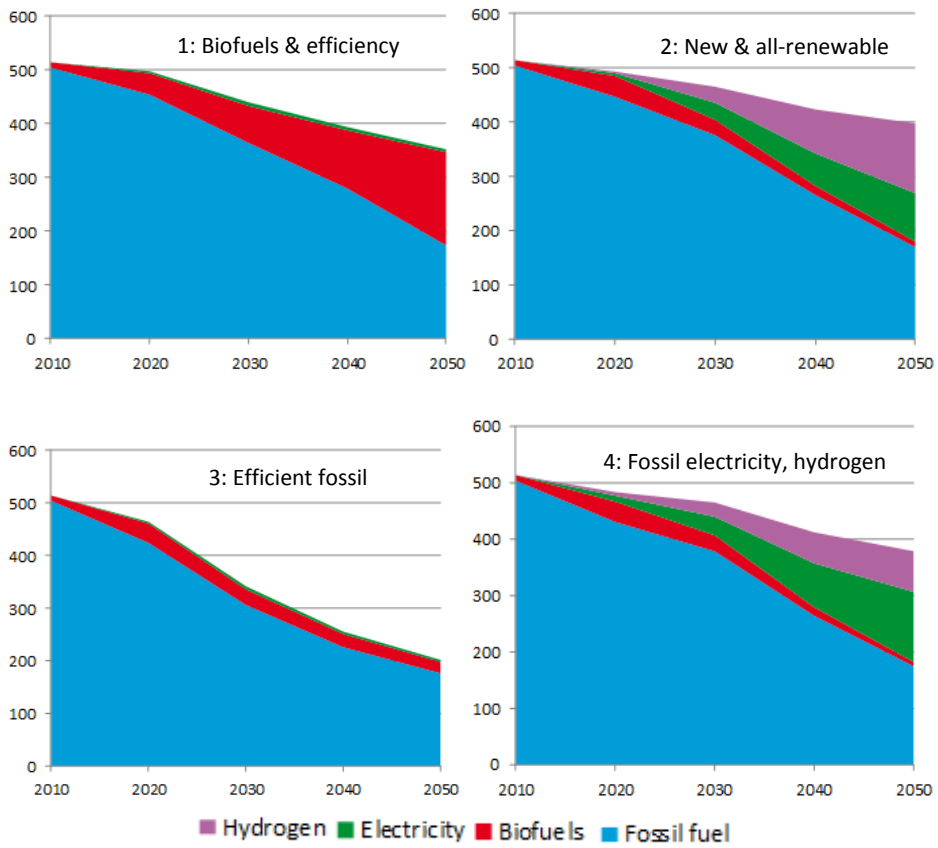


Figure 10: Energy mix in the four scenarios in 2010-2050



4.2 Greenhouse gas emissions

Figure 11 shows to TTW emissions in 2050 for the four scenarios. By definition, they all meet the -60% target, but they do so in different ways. For example, in Scenarios 2 ad 4, emissions from passenger cars, vans and buses are reduced relatively strongly, because these transport modes will in these scenarios be suitable for high shares for hydrogen and electricity. In return, reductions in the 'other' categories are relatively modest. In Scenarios 1 and 3, emission reductions are more proportional across all transport modes.

Figure 11: Total CO_2 emissions (TTW) per transport mode in 2050

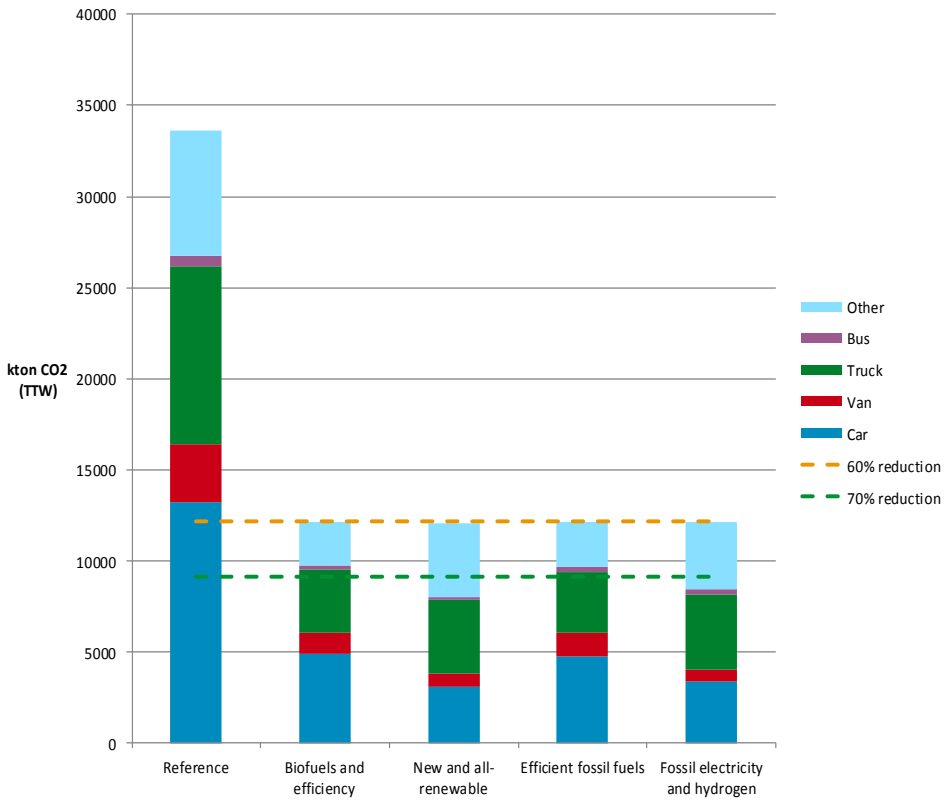


Figure 12 shows the well-to-wheel emissions of the scenarios, which are clearly different from the tank-to wheel emissions. On a well-to-wheel basis, only scenario 3 (efficient fossil) realises 60% CO_2 reduction, and scenario 2 (new and al-renewable) nearly does. In scenarios 1 and 4, additional well-to-tank emissions of the large shares of the newly introduced technologies (biofuels and fossil-produced hydrogen and electricity, respectively) lead to more upstream emissions.

Figure 12: Total CO_2 emissions (WTW) in 2050

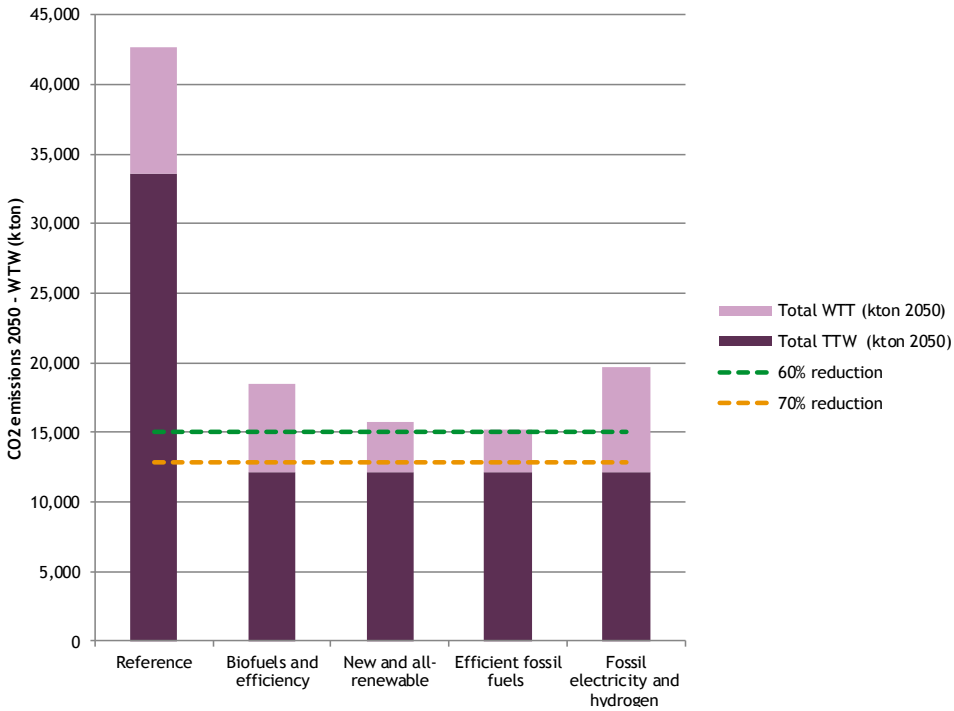
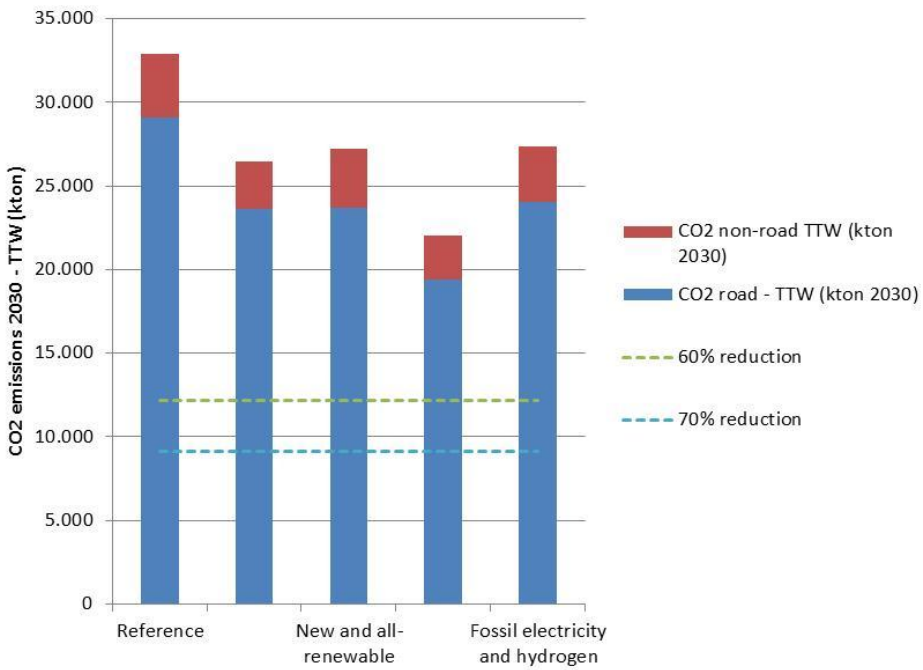


Figure 13 shows that the 2030 target of less than 25 Mton CO_2 emissions (TTW) of the 'SER Energieakkoord' is not within reach in most scenario's. Scenario 3 shows the lowest TTW CO_2 emissions, due to the high efficiencies and limited (growth of) transport volume.

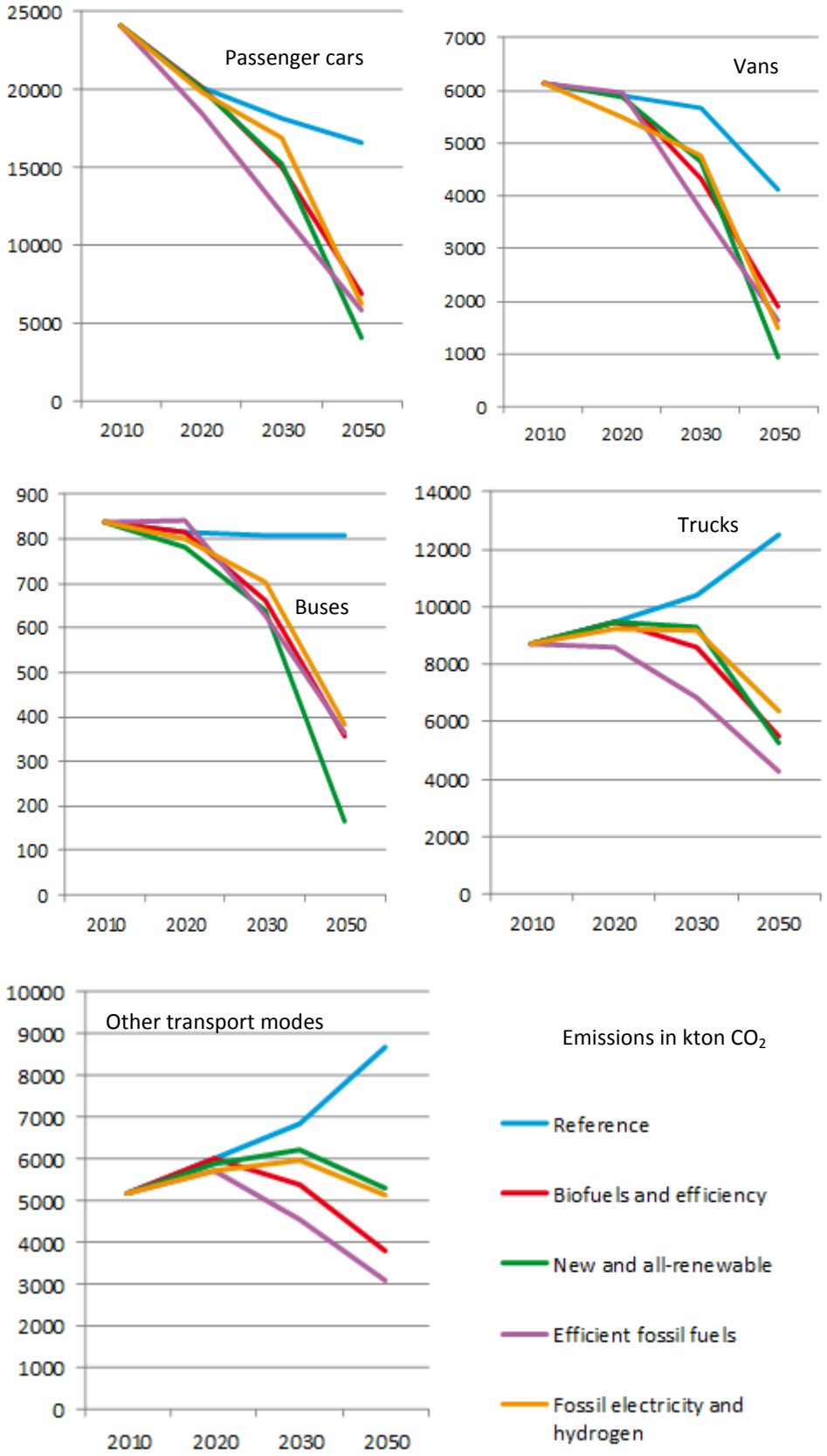
Figure 13: Total CO_2 emissions (TTW) in 2030



CO_2 emission developments over time differ between scenarios and between transport modes. **Figure 14** illustrate this.

- In all transport modes, emissions are curbed down.
- In passenger cars and vans, the scenarios lead to the same order of magnitude of emission reductions
- In buses, the New and all-renewable scenario (2) gives the strongest emission cuts, given the high shares of (renewable energy-driven) battery and fuel cell electric vehicles.
- In trucks, a relatively high share of electric vehicles in scenario 4 (fossil electric, hydrogen) ramps down emissions strongest
- In other transport modes, Scenarios 1 and 3 realise the strongest emission cuts, also needed to reach the overall -60% target.

Figure 14: Development of total CO_2 WTW emissions from various transport modes in 2010-2050



4.3 Costs

In this section the impacts on costs are presented. This is limited to road transport. First, the total costs of ownership are presented. Next, the tax revenues and social costs are presented.

4.3.1 Total cost of ownership

Figure 15 and **Figure 16** show the Total costs of ownership and the total costs per vehicle km, respectively, for the four scenarios and the reference, in 2050.
Key message is that by 2050 the TCO, both in total and per km,do not differ very strongly between the various scenarios. By 2050, the cost in (battery and fuel cell) electric vehicles have been reduced so strongly that there is only a ~10% vehicle cost per km difference with the scenarios based on conventional ICE drivetrains.

In **Figure 15**, Scenario 3 (efficiency fossil) is not included because the high reduction in transport volume in that scenario will require pricing measures such as emission trading or kilometre charging, with significant effects on the TCO. Estimating these are beyond the scope of this study. In Appendix F, TCOs for the various transport modes are shown.

Figure 15: Total cost of ownership TCO) of road transport in 2050 per scenario, price level 2010

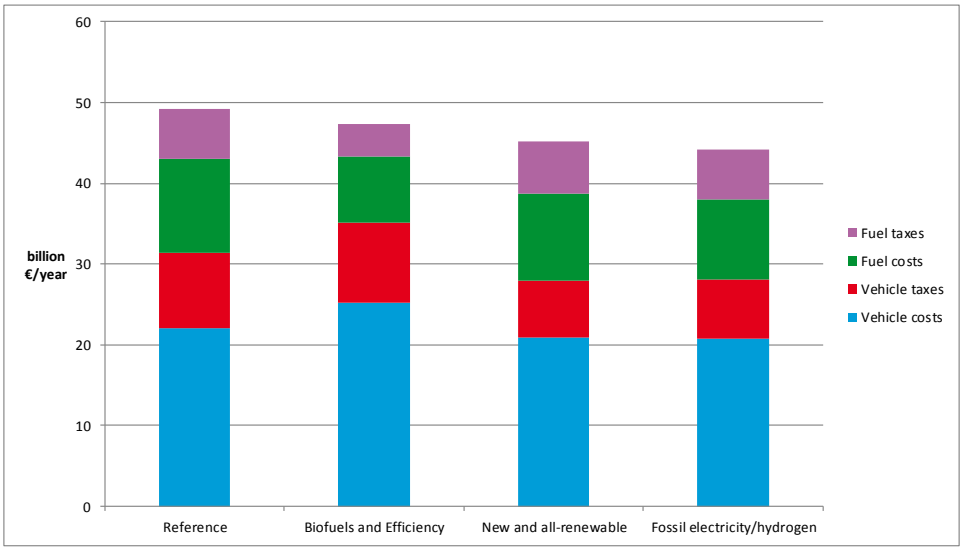


Figure 16: Cost in Euro per vkm for road transport per scenario in 2050, price level 2010

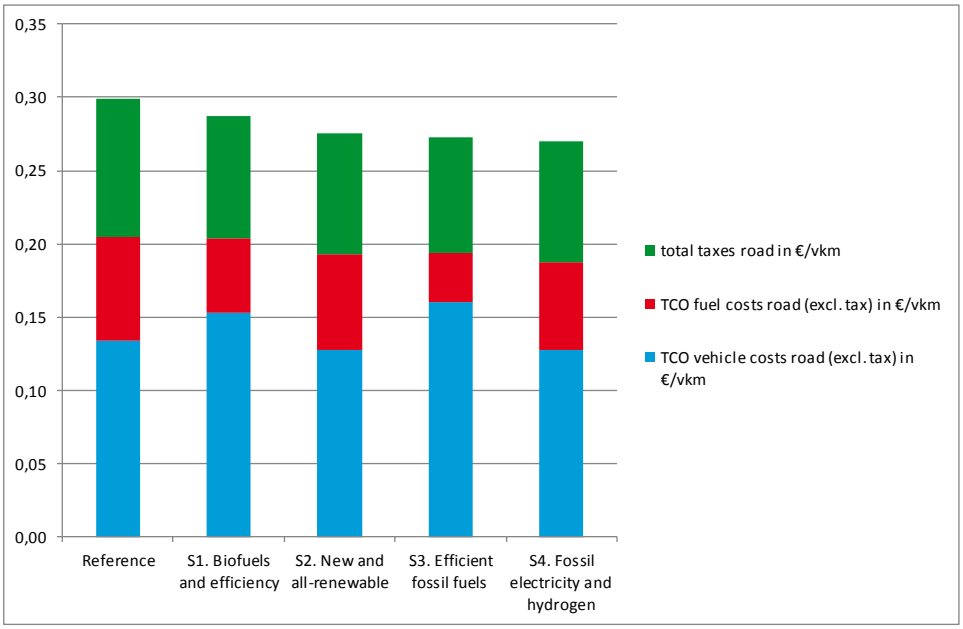
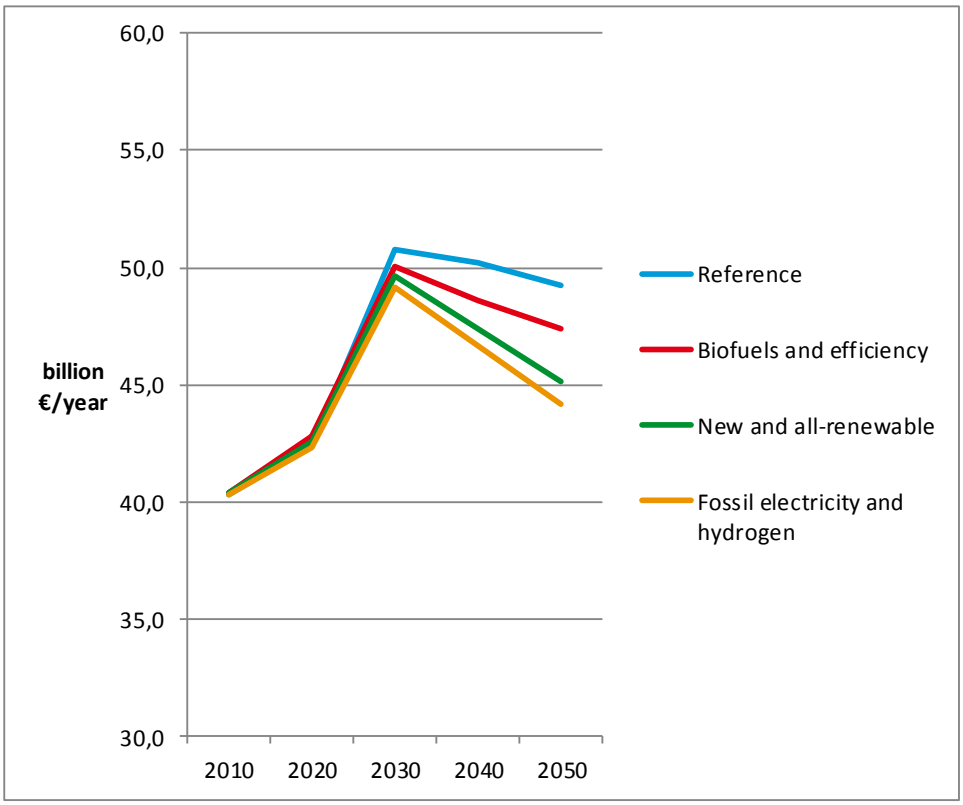


Figure 17 shows the TCO development between 2010 and 2050 in the various scenarios. For all scenarios, a cost increase until 2030 can be observed, with a decline in 2030-2050. This is due to two factors:

- Fossil fuel prices (see Chapter 4, derived from the IEA Blue Map scenario) are assumed to increase in 2010-2030 and decrease in 2030-2050. This is mainly because in the first period, increased scarcity of (cheap) fossil energy dominates prices, while in 2030-2050 the further introduction of carbon-neutral options decreases the demand, particularly for oil.
- New technologies for biofuels and (battery and fuel cell) electric drivetrains start in 2020 with small shares and high costs. Their market shares increase towards 2050 and their technology costs converge towards the conventional competitors. This combination of developments also leads to a cost development with a peak around 2030 and a gradual decrease afterwards.

All in all, **Figure 17** shows that in order to introduce new technologies into the transport sector, a cost hurdle will need to be taken in the period 2020-30. Note that also the reference scenario shows a cost hurdle in 2030 and is highest in TCO, due to the dominance of relatively expensive fossil fuels and limited efficiency increases.

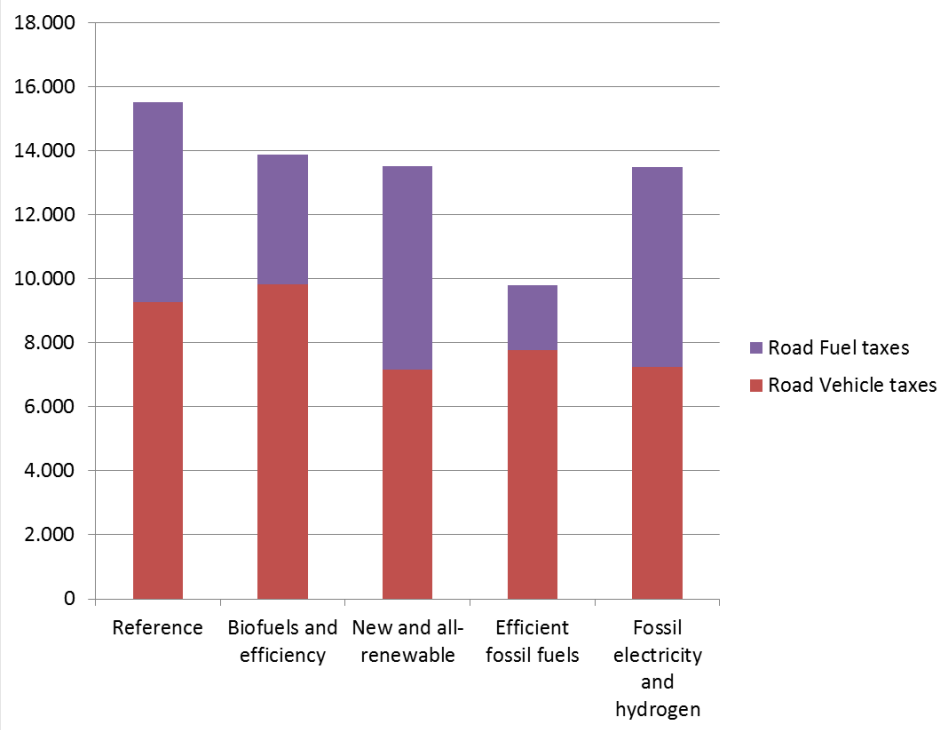
Figure 17: Development of total cost of ownership (TCO) of road transport in the period 2010-2050 per scenario, price level 2010



4.3.2 Tax revenues

Figure 18 shows the total tax revenues for the various scenarios. In all scenarios (except scenario 3) the revenues are about 2 billion Euro per year lower than in the reference scenario in 2050 and also somewhat lower than the total tax revenues in 2010 (which are about 14.5 billion Euro). In scenario 3, the decrease in tax revenues is much higher, because of the strong fuel efficiency improvements and the lower transport demand. However, these lower revenues from fuel and vehicle taxes in scenario 3 will be (more than) compensated by additional pricing measures in that scenario which will be needed for achieving the strong reductuion in transport volumes.

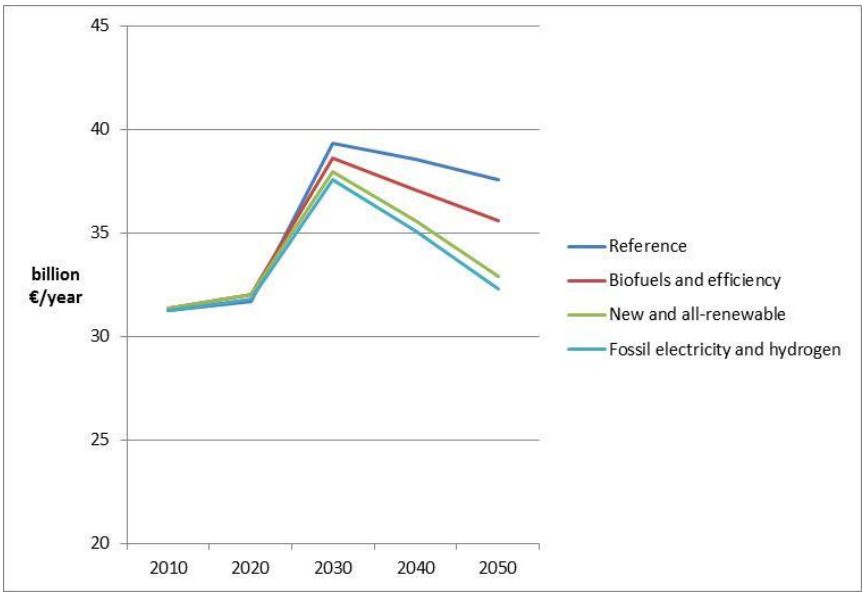
Figure 18: Total revenues of fuel and vehicle taxes* of road transport in 2050 per scenario, price level 2010



* These revenues do not include revenues from additional pricing measures for curbing down transport volumes, which will be needed in scenario 3.

4.3.3 Social costs

Figure 19: Development of social costs in the period 2010-2050 per scenario, price level 2010*



*The social costs shown here include only vehicle costs, energy costs and external costs of emissions.

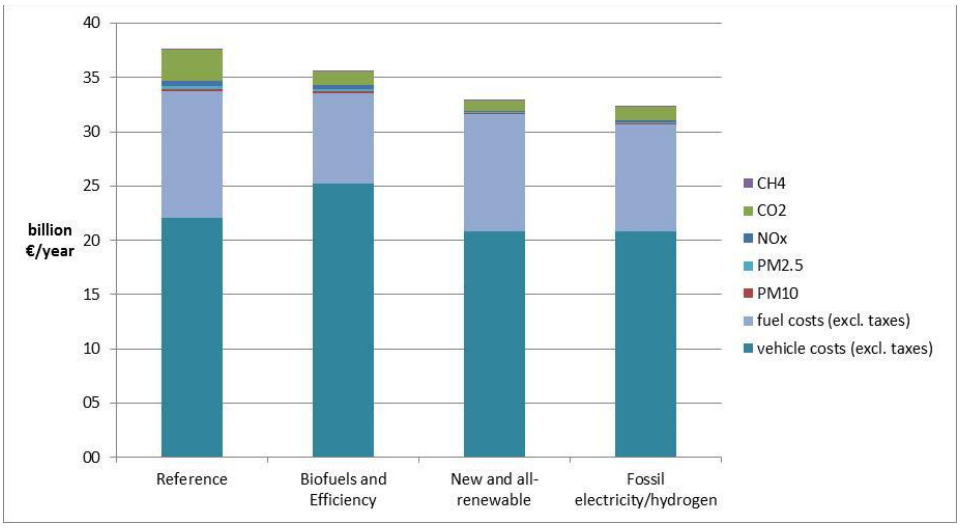
Figure 19 shows the development of the social cost of road transport in the various scenarios. This includes:

- Energy and vehicle costs (excl. taxes)
- External costs of emissions.

This means that various social costs are not included here, in particular the costs of transport infrastructure, the external costs of safety, noise, congestion and the costs related to welfare effects of changes in transport demand.

The differences between the various scenarios are relatively small, except for the Efficient Fossil Fuels scenario. However, the decrease in social cost in this scenario is for a large part due to the decrease in transport volume. This volume reduction has also an impact on social cost, but these costs cannot be quantified. **Figure 20** shows the build-up of social costs by 2050 for each scenario. Of the costs of emissions to air, CO_2 costs dominate over the other emission costs.

Figure 20: Total social costs of emissions to air and vehicle costs and fuel costs per scenario in 2050, price level 2010*

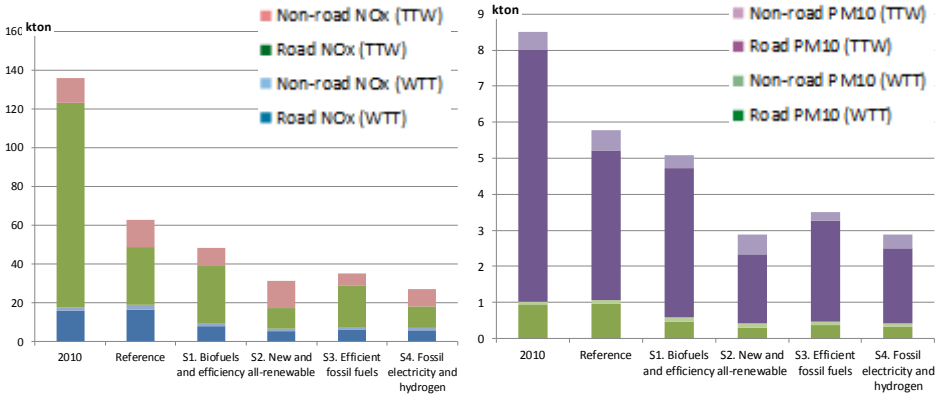


*The social costs shown here include only vehicle costs, energy costs and external costs of emissions.

4.4 Air quality and noise

Figure 21 shows that NO_x and PM_{10} emissions remain relatively high in the two scenarios without breakthrough of (battery or fuel cell) electric vehicles (Scenarios 1 and 3), in which internal combustion remains the incumbent technology. TTW emissions clearly dominate WTT emissions.

Figure 21: WTW emissions of NO_x and PM_{10} in 2050 in the various scenarios, compared to 2010.



Besides impacts on pollutant emissions, some scenarios will also have some impacts on ambient noise levels. These impacts on noise are expected to be limited. Electric and fuel cell vehicles have hardly any engine noise and will therefore have some noise benefits. However, at driving speeds of 30 km/h and more, engine noise is just minor compared to noise from driving wind and tyres. Furthermore, heavy road vehicles and also rail transport are important sources of noise. So some noise reduction can be expected in urban areas when significant shares of electric and/or fuel cell vehicles enter the fleet, particularly when this also includes trucks and buses (see also the large EV study for DG Clima, (CE Delft, 2011)).

4.5 Perspectives for green growth

Green growth is an important concept in the motivation of the SER agreement on energy. As a consequence it should be an important guiding principle for the choices to be made in the vision for the Netherlands on the mix of energy carriers that will be best suited for meeting the targets with respect to sustainability and other criteria, taking account of boundary conditions for the Dutch situation. The concept of green growth, however, is not yet well defined. In a very wide and more or less macro-economic interpretation green growth is about the absolute decoupling of economic growth from environmental impacts and depletion of scarce resources [CPB 2012]. If GDP grows while at the same time the overall impacts on environment are reduced, this growth can be considered green. In a narrower, more micro-economic interpretation, green growth is about earning money with the greening up of economic activities. The Dutch economy could grow if it is successful in developing sustainable products and services. Choices made with respect to the energy mix for transport in the Netherlands obviously determine the extent to which Dutch companies can develop new products and services, bring these to a level of technical and economic maturity on the Dutch market, and subsequently export these products and services outside of the Netherlands.

A detailed assessment of the mechanisms through which a future energy mix for transport may contribute to economic growth in the Netherlands, let alone a

quantification of the net effects, is beyond the scope of the scenario exercise. For that reason the green growth potential of the four scenarios developed in this report is assessed in a more indicative way. A very preliminary attempt at a quantitative comparison of the scenarios from a macro-economic perspective can be based on results from CE Delfts REST-NL model with respect to CO_2 emissions and costs. A qualitative assessment is made by identifying how the energy carriers and associated technologies featured in the four scenarios might generate opportunities for the Dutch industry and knowledge infrastructure to develop new products and services and strengthen their international competitive position.

A wider discussion of the concept of green growth and the mechanisms through which environmental measures can lead to green growth can be found in Appendix E.

4.5.1 Comparison of macro-economic green growth indicators

From a macro-economic perspective the green growth potential of scenarios can be assessed by quantifying their scores on a number of indicators which can be divided in what one might call “green indicators” and “growth indicators”.

For the four scenarios the following green indicators are assessed in sections 5.2 and 5.4:

- CO_2 emissions: From a macro-economic perspective both the direct emissions based on IPCC definitions and well-to-wheel emissions are useful indicators;
- Emissions of air polluting substances.

Growth indicators assessed in chapter 5.3 include:

- total cost of ownership (ΔTCO): net additional costs to the user (incl. taxes);
- societal costs (excluding taxes and including external costs for air pollutant emissions).

Both growth parameters relate to the costs of transport (from a user or societal perspective). If costs of transport are reduced in a scenario, relative to the reference case, this results in economic benefits for all consumers and companies that directly or indirectly use transport (services).

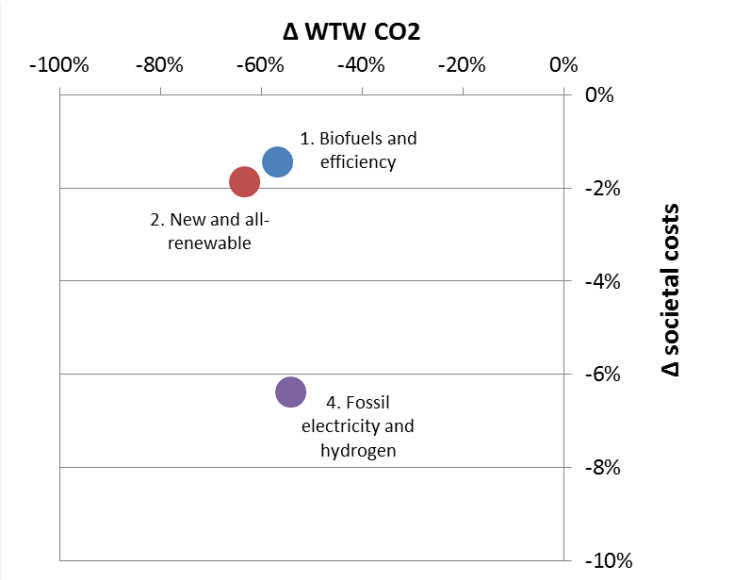
By plotting scores on these indicators together in one graph, scenarios can be compared on their likely compatibility with the ambition to realize green growth from a first order macro-economic perspective. With the latter we mean that only the direct impacts of the technology choices on the costs of transport (from an end user or societal perspective) are taken into account in this comparison. The results for WTW CO_2 emissions versus societal costs are depicted in **Figure 22** for scenarios 1, 2 and 4. Scenario 3 is excluded from this analysis as CO_2 reductions in that scenario are partly realised by reductions in mobility volume and the size and performance of cars. This leads to a reduction in the direct costs of transport which is far greater than the cost reductions observed in scenarios 1, 2 and 4, which are based on the same mobility volume projection as the reference scenario. Reduced mobility volume and changes in

the size and performance of cars, however, lead to wellfare losses which cannot be quantified in the context of this study but definitely go beyond the first order definition of societal costs used for the comparison presented in **Figure 22**.

Although results on TCO are available from the scenario modelling exercise, these results are heavily dependent on the assumptions with respect to the fiscal treatment of vehicles and energy carriers. As these assumptions are considered not to be representative for a future fiscal system that would need to be designed to create a stable market for sustainable alternatives while at the same time providing a stable tax revenue, drawing conclusions with respect to green growth based TCO results generated for this study is considered not appropriate.

From a societal perspective scenarios 1 and 2 have comparable scores with WTW emission reductions around 60% and a small reduction in societal costs compared to the reference scenario. From the latter it can be concluded that by 2050 reaching the 60% reduction target in these scenarios does not go at the expense of economic growth. Scenario 4 combines similar WTW reductions as scenarios 1 and 2 with significantly higher reductions in societal costs, and can thus from a macro-economic perspective be considered to offer the biggest potential for green growth.

Figure 22: Comparison of the four scenarios on their impacts on costs and CO_2 emissions, based on modelling results for WTW CO_2 emissions and societal costs in 2050



4.5.2 Green growth potential in the 4 scenarios

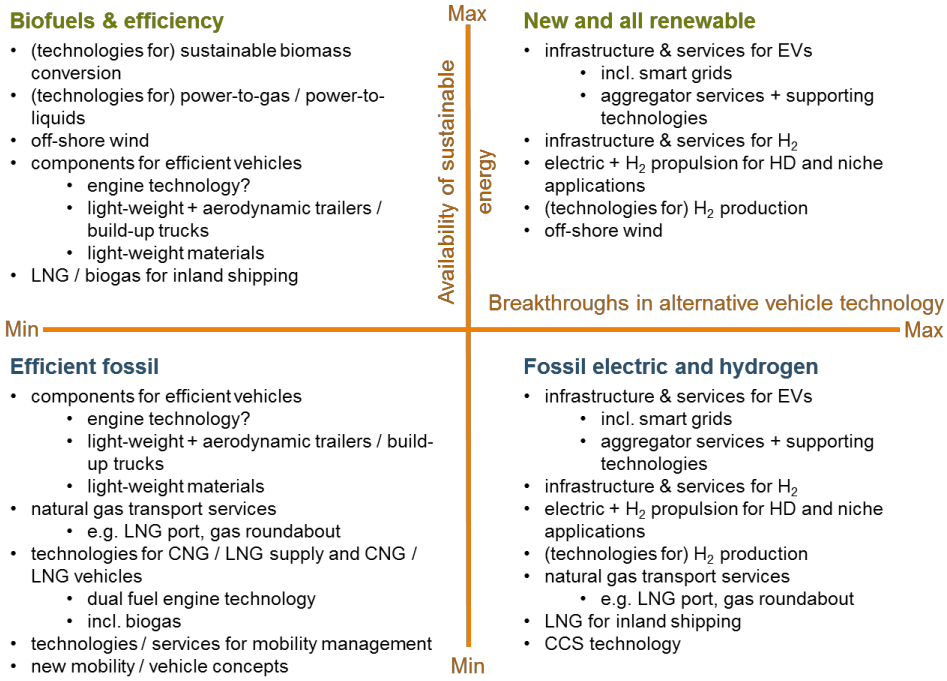
From a micro-economic perspective the green growth potential of scenarios can be indicatively assessed by reviewing whether technologies associated with the dominant energy carriers:

- have the potential to generate added value (in the sense that they make new products and services possible, improve the quality of existing products and services or reduce the costs of existing products and services);
- are compatible with existing competences and expertise of Dutch companies and knowledge centres and therefore offer opportunities for Dutch companies to improve their competitiveness and increase market shares.

With regard to the first point it can be concluded that the added value to the user of many sustainable transport options is limited or absent. As a matter of fact alternatives to petrol and diesel often even represent some drawbacks to the user in terms of more effort for refuelling / charging, limited driving range, limitations in vehicles' load carrying capacities due to more bulky energy storage systems, etcetera. Options with lower local emissions of pollutants and noise may offer some advantages in urban use, e.g. by allowing these vehicles in city centres during time intervals where it is currently not allowed. Electric vehicles and production of hydrogen from excess renewable energy may offer some added benefits to the energy system as storage options for balancing supply and demand but this can at best be considered as a more cost-effective alternative for additional investments that have to be made anyway for the transition to a more sustainable energy system. Overall it can be concluded that no significant economic growth potential is to be expected from aspects of added value associated with using alternative energy carriers in transport.

For those alternative energy carriers, which are compatible with existing competences and expertise of Dutch companies and knowledge centres, Dutch companies may create 'first mover advantages' by developing products and services that support the uptake of these new energy carriers in the Dutch transport system. Whether sales of these products and services on the Dutch market already leads to economic growth depends on whether the products and services provide added value. Irrespective of that, however, having a home market that is a front runner in applying certain new technologies may in principle provide Dutch companies with a competitive advantage in the international market for these sustainable transport solutions.
An overview of possible green growth opportunities in the different scenarios is presented in **Figure 23**. These are briefly motivated below. In order to be able to compare green growth opportunities it would be useful to create an overview of which Dutch companies (or companies partly located in the Netherlands) and knowledge institutes have knowledge and competences relevant to the various identified green growth opportunities. This could be a useful exercise for phase 2 of the pathway to creating a vision on the future energy mix for transport in the Netherlands.

Figure 23: Overview of technologies and services for which the four scenarios may create specific green growth opportunities for the Dutch economy



Biofuels and efficiency

In this scenario the availability of renewable energy is abundant. Due to lack of breakthroughs in electric and hydrogen vehicle technology, application of renewable energy in the transport sector is primarily in the form of liquid and gaseous hydrocarbons. Green growth opportunities therefore relate to the technologies for sustainable biomass conversion and the production of biofuels. Also (technologies for) power-to-gas and power-to-fuels routes offer green growth potential. Both developments can be taken up by existing fuel production companies but very likely also new companies will emerge, e.g. as spin-outs of innovations developed by universities and knowledge institutes. The Rotterdam harbour and the fuel production capacity installed in that region can provide a starting point for the bio-based economy. In the transition period hydrocarbons may be produced through power-to-X routes from off-shore wind energy and the CO_2 emitted by the existing energy industry.

Crucial for a green growth potential associated with the use of biofuels is that value is added within the Netherlands by efficiently converting low value biomass into high value biofuels. Imported biofuels may be expected to have a commodity price that closely follows the price of oil. Profit can be generated if biofuels can be produced in the Netherlands at a cost price below the world market prices for these biofuels. Another important element in this scenario are energy efficient vehicles. The green growth potential of supplying technologies for efficient passenger cars appears limited. Chances appear larger in the development of technology for, and the manufacturing of efficient heavy duty vehicles. The Netherlands has a strong position in aerodynamic improvements of trucks and in light-weight materials which can be expanded in this scenario.

For inland shipping fossil LNG can be a transition fuel, gradually to be replaced by methane from renewable sources. The Netherlands is already building a strong position in this field, which can be further enhanced in this scenario.

New and all-renewable

Also in this scenario the availability of renewable energy is abundant, but due to a favourable developments in the quality and costs of electric and hydrogen vehicle technologies this renewable energy is largely supplied to the transport sector in the form of electricity and hydrogen.

Limited green growth opportunities appear to be associated with technologies for and manufacturing of electric and hydrogen-fuelled vehicles. The Dutch automotive supply industry could increase its international market share, but as their clients are large automotive manufacturers this strongly depends on how the use of these technologies evolves in other European countries and regions outside Europe. The best opportunities for Dutch companies could be in heavy duty and niche applications, including development and production of vehicles for sustainable urban logistics. If the Netherlands could maintain its frontrunner position in the application of electric and hydrogen-fuelled vehicles, it would also be confronted the first with the challenges associated with large-scale uptake of these technologies, e.g. associated with energy infrastructures. Developing products and services that provide solutions for these challenges may generate first mover advantages for Dutch companies. For electric vehicles these include smart grids, the development of aggregator services, and technologies to support these services.

In the field of renewable energy production green growth opportunities are most obvious in off-shore wind in this scenario.

Efficient fossil energy

In this scenario both renewable energy and alternative propulsion technologies do not break through. Long term greenhouse gas reduction targets are met by maximising the energy efficiency of vehicles and by curbing the growth of mobility. If there is potential for green growth in this scenario it has to be related to technologies for efficient vehicles and technologies and services for efficient logistics and mobility management. Also technologies for CNG / LNG supply and CNG / LNG vehicles, including dual fuel engine technology, may provide green growth potential, as do services for natural gas transport such as LNG ports and the role of the Netherlands as gas roundabout in Europe.

The Dutch automotive supply industry could increase its international market share if it would be able to develop competitive solutions for efficient vehicles. In the passenger car market the Dutch industry is strongly dependent on the strategies for foreign OEMs. More opportunities for independent innovation routes, however, may be present in the area of heavy duty and niche vehicles, including e.g. light-weight and aerodynamic trailers and build-ups for trucks.

Curbing mobility growth will require e.g. a wide range of services for mobility management as well as development of efficient logistic solutions. These will have to be supported by ICT technologies. Additional green growth potential may be related to the

development of new mobility concepts, including new vehicle concepts such as “ultra-light mobility” concepts occupying niches between bicycles and cars.

Fossil electric/hydrogen
In this scenario vehicles largely run on electricity and hydrogen generated from fossil sources. As far as vehicles and energy supply infrastructure are concerned, the green growth opportunities in this scenario are very similar to those in the “New and all-renewable” scenario. In addition LNG for inland shipping and CCS technology, required to reduce the well-to-wheel emissions from electricity and hydrogen generated from fossil sources, are areas in which innovations by the Dutch knowledge institutes and industry may lead to green growth opportunities. Similar to the “Efficient fossil energy” scenario also here services for natural gas transport, such as LNG ports and the role of the Netherlands as gas roundabout in Europe, could provide economic growth opportunities.

4.5.3 Conclusions regarding green growth

In all scenarios the cost of transport in 2050 are reduced compared to the reference scenario. Specifically for scenario 4 this means that from a macro-economic perspective economic growth could be higher than in the reference scenario. For scenarios 1 and 2 it can be concluded that by 2050 reaching the 60% reduction target in these scenarios does not go at the expense of economic growth.

From a micro-economic perspective economic growth could occur if Dutch companies benefit from ‘first mover advantages’ as a result of choices made for the future Dutch energy mix for transport. The largest opportunities for that appear to exist in scenarios 1, 2 and 4. In scenario 1 these mainly relate to biofuel production where the Dutch harbours may play a crucial role. In scenario 2 these relate e.g. to products and services for matching supply and demand of renewable energy. In scenario 4 CCS technology may offer some growth potential. In scenario 2 and 4 Dutch companies may strengthen their market position by developing and delivering components for alternative powertrains.

Opportunities for green growth by developing green technologies for vehicles in HD and more or less “niche” applications exist in all scenarios. Required innovations not only relate to the powertrain but also to the weight and aerodynamics of vehicles. These opportunities could be largest in scenarios 2 and 4 in which the majority of vehicles will use alternative powertrains. These new technologies may give rise to new players entering the market for automotive manufacturing. In scenarios 1 and 3, where the internal combustion engine remains dominant, it is more likely that innovations come from existing OEMs which are mainly located outside the Netherlands.

In scenario 3 development of technologies and services for LNG distribution and applications, mobility management and efficient logistics might offer growth potential for Dutch companies. In scenarios 3 and 4, finally, natural gas transport, such as LNG ports and the role of the Netherlands as gas roundabout in Europe, could provide economic growth opportunities.

4.6 Safety issues

In this study, we qualitatively analysed “external safety” issues as one of the key boundary conditions for the implementation of new energy carriers for transport. The brief analysis focuses on the differences between the four scenario’s.

The baseline for safety is the current transport fuel infrastructure. In the case where ‘safety issues’ are mentioned for the future scenarios, it is meant that compared to the current safety situation, the specified scenario will bring additional safety issues. In the overview table, a qualitative judgment is presented of the magnitude of these safety issues in the range of “+” to “+++” (for explanation see table underscript at the end).

A distinction is made between external safety and internal / occupational safety. The first is primarily determined by the large incidents scenarios and therefore important for land use planning, choice of locations and transport routing. The latter is determined by the smaller, higher frequency incidents which are more important for the detailed design of installations, local repression measures and operational procedures.

For the generic safety discussion in this study, the external issues are seen as more important than the local safety issues. Especially since the knowledge and technology to solve the internal / occupational safety is available but the optimal solutions need to be defined.

Also the public opinion towards several topics might be important. This emphasizes that the process of information and consultation of all relevant stakeholders is very important and if not well addressed, can create a problem or even become a showstopper.

The results of the external safety assessment at summarized in **Table 3**. The background arguments can be found in Appendix D.

Table 3: Overview of safety issues for each scenario

Scenario	Components with poss. safety issues	Relevant safety issue expected		Part of the supply chain where the identified safety issues predominantly will arise				
		External Safety	Occupational Safety	Production	Central Storage	Transport/ distribution	Fuel station	Application /usage
Scenario 1	Biofuel (L)	-	-/+	(x)	(x)	(x)	(x)	
	Biofuel (G) pressurized	-	+					x
	Biomethane (G) liquified	o *			x	x	x	
Scenario 2	Hydrogen	+	+	x	xx	xx	xx	x
	Electric	-	-/+					x
Scenario 3	NG / LNG	o *	+		x	x	x	
Scenario 4	Hydrogen	++	+	x	xx	xx	xx	x
	Electric	-	-/+					x

"-/x" = small safety issues to be solved, solutions readily available.
"+" = some safety issues may be expected, feasible solutions are available but need attention to be defined in detail.
"++" = safety issues are foreseen that need serious attention, acceptable solutions (policy-wise and technically) are possible but are not readily available and need to be addressed timely.
"+++" = serious safety issues foreseen, acceptable solutions are not yet within reach and intensive R&D is needed to solve these issues.
*) Safety issues exist but are already being addressed and expectation is that they will be solved before or in 2015.

Al in all, Scenarios 2 and 4 seem to come with more external safety issues, mainly related to the introduction of hydrogen in the fuel mix. Natural gas (CNG/LNG) in Scenario 3 and biomethane in Scenario 1 lead to comparable but less demanding challenges. In a world developing towards either of these scenarios, related safety issues deserve sufficient attention.

4.7 Energy security

In general policy to reduce greenhouse gas emissions is also beneficial in terms of improving energy security, or as the IEA expresses: *energy security and climate change mitigation are allies* [IEA, 2012]. Energy efficiency and low-carbon technologies are virtually everywhere in contrast to oil which is concentrated in a limited number of countries.

According to IEA, energy security in a 2050 timeframe cannot be assessed using one single criterion – traditionally oil-dependency – and introduced a set of criteria [IEA, 2012]. In **Table 4** our scenarios are scored against these criteria. This assessment does not include the need for (short- or long-term) storage capacity for intermittent production facilities (like PV) or other measures to stabilize supply.

Table 4: Indicative scoring of the four scenarios on five energy security criteria

Criteria	Biofuels & Efficiency	New & all renewable	Efficient fossil energy	Fossil electric/hydrogen
Reduced energy dependency (in all scenarios reduction of primary energy consumption)	++ (high efficiency)	+	+++ (lower level of mobility and extra high efficiency)	+
Diversification (in general a 30% improvement for the EU in climate mitigation scenarios – IEA diversification index)	+ (strong focus on biofuels)	++ (electricity and hydrogen)	0/+	+ (fossil based electricity and hydrogen)
Net-import dependency (positive if strong reduction imports)	0 (biofuels import)	++ (domestic PV)	+ (reduction demand)	0 (fossil based)
Number of entry-points (IEA: energy efficiency and low-carbon technology virtually everywhere)	++ (wide availability sustainable biomass and efficiency virtually everywhere)	+++ (PV virtually everywhere)	+++ (efficiency virtually everywhere)	+ (fossil based, diversification to clean coal and gas)
Lower risk to climate change	+ (limited potential beyond -60%)	++ (potential beyond -60%)	+ (no or limited potential beyond -60%)	++ (potential beyond -60%)

Although the various energy security criteria are not comparable, a simple counting of plusses in **Table 4** indicates that the New and all-renewable scenario leads to the most improvements on energy security, and on all aspects of it. The runner-up, the Efficient fossil energy scenario provides strongest improvements on some of the criteria, but to more modest benefits on others.

4.8 Sensitivity analyses and robustness

Volume growth in the reference scenario

The reference scenario has been based on 'Referentieraming, actualisatie 2012' (Verdonk and Wetzels, 2012), and using projections of the developments in the transport sector for 2020 and 2030 in the 'Referentieraming' delivered by PBL. Despite the recent update there is some concern that volume projections in the 'Referentieraming' may be somewhat optimistic in the sense that they are still largely

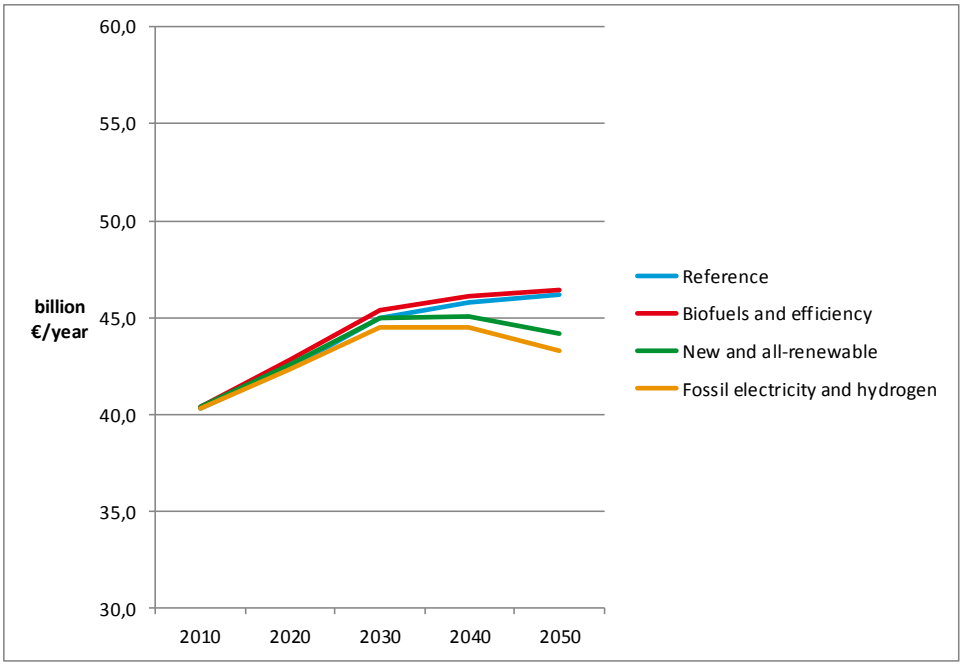
based on economic forecasts and insights from before the crisis. Even when in the longer term average annual volume growth would go back to levels of before the crisis, the impact of the crisis will likely be a downward off-set of transport volumes compared to projections from before the crisis. Also mobility patterns appear to be changing, with some even suggesting the possible occurrence of a "peak car" scenario in which car possession and use would level off at some point.

All in all it seems not unlikely that volume growth between now and 2050 turns out to be less than currently assumed in the reference scenario (and thus also in scenarios 1, 2 and 4). Lower transport volumes in 2050 would mean that less technical measures would be necessary to reach the 60% reduction target. Cost impacts would also be reduced. But by 2050 in all scenarios transport costs are lower than in the reference scenario, this cannot be considered an advantage of lower volume growth.

Impact of assumptions on fossil energy prices on cost developments

In **Figure 17** and **Figure 19** all scenarios (including the reference scenario) show a peak in costs around 2030. A calculation in which fossil fuel prices are kept constant, of which the results for TCO are depicted in **Figure 24** shows that this peak is partly due to the assumed cost development for fossil fuels in the reference scenario, and partly related to assumed high initial costs of alternative propulsion systems and energy carriers a technology-related cost hurdle is particularly visible in scenarios 2 and 4, in which battery and fuel cell electric vehicles are introduced.

Figure 24: Development of TCO when fuel prices of gasoline, diesel and LPG would remain constant after 2020



What if more than 60% reduction in IPCC TTW emissions is necessary?

As discussed before, the 60% target defined in the SER agreement is for the transport sector excluding shipping and aviation. This means that the definition is different from

the 60% target for transport as set by the European Commission. As shipping and aviation are fast growing sectors with CO_2 reduction potentials that appear to be more limited than e.g. in road transport, the EU target of 60% would possibly translate into a higher than 60% reduction for the combined transport subsectors included in the SER agreement. In the future a higher transport target might also be required if progress in other sectors would turn out slower than planned. It is therefore useful to explore the capacity of the various scenarios to also reach a higher IPCC TTW reduction target. Currently, the GHG emissions of aviation and maritime shipping in the EU as a whole are about 25% of those of the transport modes included by the IPCC definition (as also used in this study). However this share is expected to increase significantly because of the high growth in transport demand of aviation and shipping and the emission reductions in road transport (particularly 95 g/km emission standards for cars). In a business as usual scenario, in 2050 the GHG emissions of aviation and shipping are expected to amount about 75% of the land-based transport modes covered by the IPCC definition (AEA et al, 2012). Without additional emission reduction in aviation and maritime shipping, a 60% emission reduction of transport modes covered in this study would correspond to only about 25% reduction of the total GHG emissions of transport including aviation and maritime shipping (compared to 1990). In the case that the emissions of aviation and shipping would be reduced by 40% compared to business as usual (in line with the White Paper targets for these modes), the overall reduction would still be less than 50% compared to 1990. In that case, to achieve a 60% overall (including aviation and shipping), the land-based modes would need to deliver about 85% emission reduction compared to 1990 levels.

- In scenario 1, which largely reaches the 60% by applying biofuels in ICEVs, there is still some room for improvement of vehicle efficiency as the average vehicle CO_2 emissions in 2050 (TTW, with biofuels not counting as zero) are significantly higher than in scenario 3. This could be exploited to reach a 70% IPCC TTW emission reduction target if that would be deemed necessary. It should be noted that, however, that the levels assumed for scenario 3 can only be reached if besides technical measures to improve ICEV efficiency also vehicle down-sizing and e.g. speed reduction or ITS-measures are applied. Further reductions are also available from additional availability of biomass, e.g. through successful introduction of aquatic biomass, solar fuels or power-to-liquids, all relatively premature options. Finally, curbing volume growth would also lead to further reductions in this scenario.
- Scenario 2 and 4, which both rely on large scale application of electric and hydrogen fuelled vehicles, the potential to also reach e.g. 70% reduction of IPCC TTW emissions in 2050 would be determined by the extent to which the uptake of alternative energy carriers can be further increased. Particularly hydrogen fuel cell vehicles have a larger potential market share than assumed here. However, it is questionable whether higher shares could still be realized by 2050, as the current share already requires an ambitious ramp-up rate.
- For scenario 3, quite drastic assumptions have been made on the fuel consumption of vehicles and the development of transport volumes. Further reductions by these means cannot be considered feasible. Within scenario 3, therefore, reaching reductions of IPCC TTW emissions beyond 60%, would only be possible if reduction options used in the other three scenarios would also become available in the context of scenario 3.

Assuming a 60% reduction target for WTW emissions instead of IPCC TTW emissions

The target set for all scenarios in this study is a reduction of 60% in 2050 relative to 1990 of the IPCC TTW GHG emissions of transport. IPCC definitions are used as targets defined on that basis for different countries or sectors avoid double-counting of GHG emissions. The risk of using this definition, if targets are not defined for all countries, is that strategies of countries to reach their IPCC-based targets may not result in the desired WTW emission reductions. For that reason this study also evaluates WTW impacts of the scenarios.

While all scenarios are designed to meet the 60% reduction target for IPCC TTW emissions, **Figure 12** shows that only scenario 3 (Efficient fossil) also reaches 60% reduction of WTW emissions. This is caused by the fact that the alternative energy carriers electricity, hydrogen and biofuels count as zero-emission under the IPCC TTW definition but do have finite levels of WTT emissions associated with their production. In scenario 3 these alternatives are not widely used, so that the energy mix remains fossil-based. In that case a 60% reduction of fuel use leads to roughly 60% reduction in TTW as well as WTW emissions. WTW from fossil fuels may go up if they are produced from more “difficult” sources, but this leverage on the WTW/TTW ratio is less strong than the one resulting from counting alternatives as zero TTW emission options.

Requiring a 60% reduction in WTW emissions is thus equivalent to setting a reduction target for IPCC TTW emissions that is more than 60%, but the level of additional reduction of IPCC TTW emissions would differ per scenario.

As discussed above, scenarios 1 and 2, with abundant availability of renewable energy, do seem to have the potential to also reach 70% reduction of IPCC TTW emissions in 2050. Given the limited difference between their 2050 WTW emissions and a possible 60% WTW target, scenario 2 can “easily” meet a 60% reduction target for WTW emissions solely on the basis of some increased uptake of alternative technologies, if such a target would be deemed necessary. In scenario 1, for which WTW emissions in 2050 are significantly above the 60% WTW reduction target, meeting such a WTW target would seem possible with a combination of some increased uptake of biofuels, additional measures to improve vehicle efficiency and possibly some measures to curb volume growth .In scenario 4 WTW emissions in 2050 are some 30% above the level that would represent a 60% reduction compared to 1990. For this scenario reaching a 60% reduction of WTW emissions by 2050 seems less feasible without additional measures targeted at reducing the volume of passenger and freight transport.

5 Discussion

In this chapter we discuss the key findings and striking points of the scenario results. Section 6.1 discusses the key outcomes of the scenario analyses in Chapter 5. Section 6.2 presents the key conditions and uncertainties related to each scenario, and section 6.3 deals with the robust scenario outcomes coming forward from the analysis.

5.1 Key findings of the scenario analyses

All scenarios meet the -60% CO_2 objective for 2050, but in very different ways
Although all four scenarios show that 60% IPCC-TTW CO_2 emission reduction can be realized by 2050, this reduction is realized in very different ways. Essentially, scenario 3 reaches the technical limits of vehicle efficiency and reduction of mobility growth. In scenario 1, essential limitation is the availability of sufficient sustainable biomass, which could be increased by further innovation. In scenarios 2 and 4, CO_2 emission is mainly limited by the growth rates of new battery and fuel cell electric vehicles, which could also be ramped up. This means that towards and after 2050, further emission reductions are better conceivable in scenarios 1, 2 and 4 than in scenario 3.

The 2030 CO_2 objective seems difficult to meet
In three of the four scenarios, the short-term development rates of new technologies are not sufficient to keep the ambition from the Energy Agreement to limit transport CO_2 emissions to 25 Mton by 2030 within reach. In the only scenario in which this ambition is met (scenario3), this is realised by a strong reduction in transport volume, through systemic changes affecting behaviour. The 15-20 PJ energy efficiency gain by 2020, also part of the Energy Agreement, is within reach. In general, the introduction of new fuels and vehicles starts having a noticeable effect only after 2020, as their roll-out develops and market share increases. In the short term, actions may be needed to prepare for their introduction, but impacts in terms of efficiency gains and CO_2-emission reductions will be limited initially. By 2030, the impacts of new fuels and vehicles becomes visible in the amount of CO_2 emissions, but the strongest effects are visible in the 2030-2050 period (resulting from further increases in market shares). This indicates

that towards 2030, other, more systemic measures will be needed, next to the technical measures considered.

Well-to-wheel and tank-to-wheel emissions differ between the scenarios
In the study, the scenarios are designed in such a way that all of them reach the 60% reduction target by 2050, defined in TTW terms. Some clear differences between the scenarios can be observed. These are mainly caused by upstream emissions in production of biofuels, electricity and hydrogen. This means that the 60% reduction target for transport as defined by the Energy Agreement in line with IPCC TTW definitions, will in most scenarios result in less than 60% emission reduction for transport on a WTW basis. This difference between TTW and WTW impacts can be reduced by corresponding efforts to improve upstream CO_2 emission profiles of these energy chains. In scenario 3, in which fossil fuels remain strongly dominant, the additional pressure on other sectors due to technology shifts in transport remains limited. In the other scenarios, this pressure increases.

In terms of cost per km, most scenarios show a cost hurdle by 2030, but do not differ strongly by 2050
A combination of increasing energy prices and upfront costs for new technologies make that TCOs and costs per vehicle km show a peak by 2030, with a decrease in costs afterwards. This peak is weakest in scenario 3, in which no fundamentally new technologies are introduced. However, cost reduction through technology learning make that by 2050, costs per km do not vary greatly between the scenarios.

Perspectives for green growth vary but can be identified
Particularly the scenarios with innovative technologies in them (all but scenario 3) contain opportunities for green growth, but on different aspects per scenario. In the scope of this study it is not possible to identify the best green growth scenario. In all scenarios the cost of transport in 2050 are reduced compared to the reference scenario. Specifically for scenarios 1, 2 and 4 this means that from a macro-economic perspective economic growth in these scenarios could be higher than in the reference scenario. Examples of market segments with green growth opportunities are:

- Scenario 1: Biomass logistics, biofuels production, vehicle efficiency and LNG introduction in shipping
- Scenario 2: Heavy duty applications of electric powertrains, urban logistics, infrastructure, smart grids, offshore wind
- Scenario 3: Vehicle efficiency, logistics optimisation, mobility management
- Scenario 4: Heavy duty applications of electric powertrains, urban logistics, infrastructure, smart grids, clean fossil and CCS.

Introduction of gaseous fuels in transport seems to be the main factor driving external safety concerns
External safety and public acceptance of safety are of essential importance. Scenarios with substantial introduction of gaseous fuels (hydrogen in scenarios 2 and 4, methane in scenario 3) are most sensitive to external safety issues. Due to the current activities surrounding LNG, it is a necessary condition for large scale roll-out that the issues with methane in whatever form are solved in the short or medium term. For hydrogen, the external safety aspect has recently become an important point to which attention

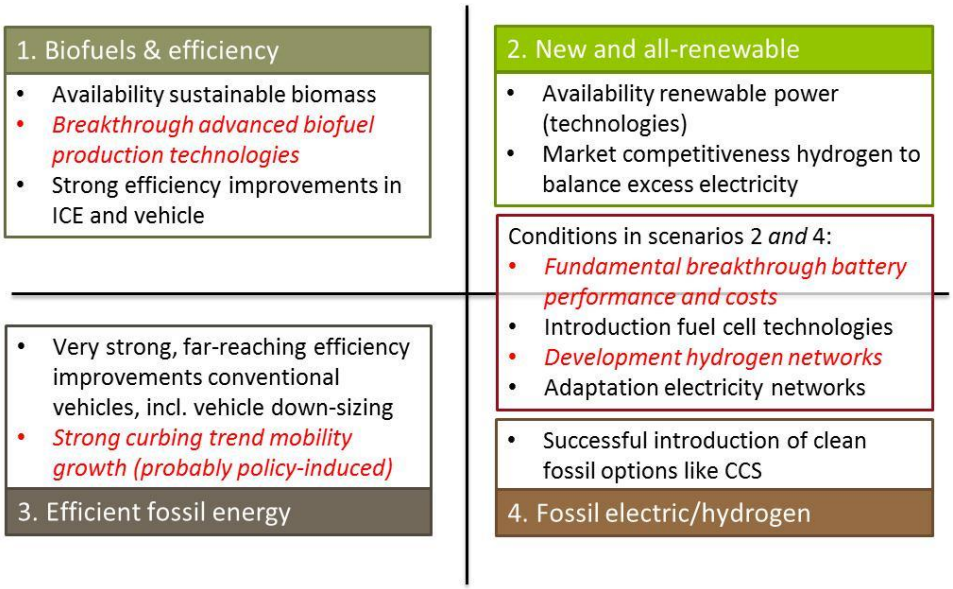
should be paid. This is mainly the case for centralized production, requiring a wide distribution network.

Energy security: new and all-renewable scenario provides most benefits
Although the energy security assessment is qualitative and very indicative, it indicates that the New and all-renewable scenario leads to the most improvements on energy security, and on all aspects of it. The runner-up, the Efficient fossil energy scenario provides strongest improvements on some of the criteria, but to more modest benefits on others. The other two scenarios score lower.

5.2 Key conditions and uncertainties for each scenario

For each scenario, essential (uncertain) conditions for the scenario to materialize can be pinpointed. These are summarized in **Figure 25**.

Figure 25: Key (uncertain) conditions for each scenario to materialise. Conditions in red are considered breakthroughs needed, other conditions may be realised by more gradual developments



Key points in this scheme are:

- In the Biofuels and Efficiency scenario, the crucial breakthrough needed lies in advanced biofuel production technologies. Next to this, the establishment of supply chains of sustainable biomass is an important condition, as well as further efficiency improvement in internal combustion engines and vehicles. Both conditions are relatively uncertain. Particularly for advanced thermochemical routes towards diesel, uncertainties are high. These technologies depend on large scales, which comes with investment risks and requires substantial and reliable biomass supply chains. There are no fundamental issues preventing this to materialize but it does

require strong efforts to realize this. Biochemical production routes can be developed more gradually and at less large scales but also still face major challenges. Furthermore, these routes do not (yet) produce diesel substitutes, which would be favorable in Europe's fuel mix. Key uncertainties for sustainable advanced biofuels are overall availability of biomass, the share that can be expected in road transport, and the degree to which sustainability safeguards can be effectively implemented. In this study, available biomass is assumed to be land-based. If innovative offshore options experience a breakthroughs, or (still very premature) power-to-fuel and solar fuel technologies develop favorably, the resource base for biofuels could be substantially broadened. This would be particularly relevant if CO_2 reductions of more than 60% would need to be achieved in this scenario. Finally, it should be noted that the strong ICE vehicle efficiency improvement required in this scenario is a challenge in itself.

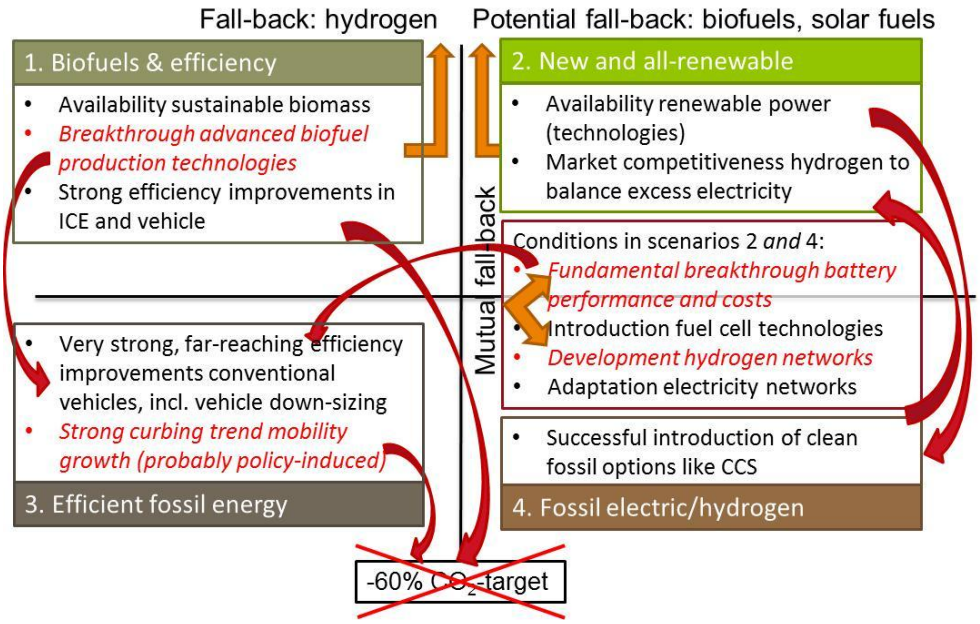
- The New and All-renewable scenario contains the broadest set of technological changes in our overall energy economy, including transport. Its materialization strongly depends on successful introduction of battery and fuel cell electric vehicles, and changes related to a dominant position of renewables in the entire energy economy. Technology uncertainty is highest in battery system capacity, performance and costs. Here, breakthroughs are needed that might require fundamentally different battery concepts. As such, fuel cell technologies face less fundamental technical uncertainty. However, here the main question is on what conditions the end user will be willing and able to drive on hydrogen, and how this fundamental change can take place. The development of renewables is also uncertain still, but as there are many options that will contribute to this, uncertainty is smaller than in e.g. battery technologies. Finally, the supposed broader role of renewables in the energy economy comes with major uncertainties, not only in the performance and costs of renewables, but also in the changes related to a dominant position of intermittent renewable power. For example, it is uncertain how intermittency will be balanced and what role hydrogen could play in that.
- The key conditions for the Efficient Fossil scenario are far-reaching efficiency improvements, and a fundamental decoupling of economic growth with mobility growth. As such, this scenario shows the smallest changes in the energy economy, but the most fundamental changes in the role of mobility in society. Efficiency improvements are partly less uncertain, simply because this is a further strengthening of a technology development that has already taken place for decades, but now will need to be taken to a much more ambitious level. However, for the extreme efficiency improvements assumed in this scenario, substantial downsizing of vehicles, to the level of new extremely efficient vehicle concepts will be needed. Besides, efficiency improvements alone are not sufficient to meet the CO_2 target: substantial reduction of mobility growth is also necessary. This decoupling of economic growth and mobility growth is a more fundamental uncertainty: for some time, policy efforts have already been made to realize this, but with very limited success. This decoupling will probably require fundamental societal changes, e.g. inducing modal shift, improving freight and person logistics, reducing average commuter distances (with a clear link to spatial planning), and introducing road pricing.
- The fossil electricity and hydrogen scenario has comparable conditions regarding battery and fuel cell electric vehicles as scenario 2 (new and all-renewable). Additionally, the successful introduction of low-carbon conventional power

generation options is an important condition. In this scenario, uncertainties in battery technologies and hydrogen end-user acceptance are key, but the role of hydrogen will not be further stimulated by its potential buffering role for intermittent renewables. Regarding low-carbon power generation, both CCS (for coal- and gas-based power generation) and nuclear can play this role, but both options have technological, financial and societal challenges to meet.

Next to these conditions, we also explored what the effect would be if these key breakthrough developments do not take place. In **Figure 26** this is illustrated. In short:

- If in the Biofuels and efficiency scenario the breakthrough of advanced biofuels does not materialize, the developments could turn into Scenario 3 (Efficient fossil). However, in such a case, further efficiency improvements would need to be realized than in the biofuels and efficiency scenario. If these efficiency improvements do not occur, both scenarios will not reach the 60% objective. As fall-back option, this scenario could still introduce hydrogen in case the scenario's conditions are not met.
- In Scenarios 2 and 4, battery technology breakthroughs and hydrogen network developments are mutual fall-back options: If either of them does not materialize, more success in the other can compensate for that. However, if both of them are not successful, developments could turn into the Efficient fossil scenario. Furthermore, less than expected developments in renewable energy can be compensated by more strenuous introduction of clean fossil options with CCS, and possibly vice versa. As renewable energy is abundantly available in scenario 2, biofuels can also be a fall-back option here, provided biofuel technologies break through. Also more long-term and premature options like power-to-liquids and solar fuels could serve like this.
- Next to efficiency improvements, the Efficient fossil energy scenario also depends on significantly curbing mobility growth. This break in the historic relation between growth of economy and mobility is also pivotal for reaching the -60% objective: if this does not happen, the objective gets out of sight. Such curbing of mobility growth can be caused by stagnating economic growth, can be policy induced, or a combination of both.

Figure 26: Alternative scenarios in case the key conditions for each scenario are not met. Also depicted are fall-back technologies that might still be developed if the key condition is not met



The main uncertainties of the various scenarios energy routes are summarized in **Table 5**.

Table 5: Main uncertainties per energy carrier

Energy route	Main uncertainties
Biofuels	Availability and costs of sustainable biomass (including ILUC effects). Scaling up of production capacity of such types of biomass. Demand for biomass in other sectors (chemical industry, food, power sector, aviation, shipping). Breakthrough in innovative types of biomass such as algae. Break-through of (large-scale) advanced biofuel production technologies
Electric cars and vans	Costs and power-to-mass ratios of batteries. Breakthrough in battery technology needed for longer ranges (for large scale application on medium to long distances), e.g. lithium-silicon, lithium-sulfur, lithium-air batteries. Roll out and costs of charging infrastructure.
Electric Heavy duty vehicles	Breakthrough in battery technology needed for longer ranges (for large scale application on medium to long distances). Roll out and costs of (inductive) charging infrastructure and/or overhead catenary wires.
Hydrogen	Roll out and costs of hydrogen infrastructure External safety and public acceptance Vehicle costs in short to medium term
Methane (LNG/CNG)	External safety of LNG distribution and refuelling infrastructure Availability of sustainable biomass for bio-methane production

5.3 Robust outcomes of the scenarios

Essential robust outcomes of the scenarios are as follows.

Efficiency improvement: always useful, pivotal in some scenarios
In all scenarios, efficiency improvement of vehicles and (conventional) drivetrains makes the -60% GHG objective more within reach and less expensive. In the Efficient Fossil scenario, it is the most important option available, which needs to be pushed to its technical limits. In the Biofuels and efficiency scenario, it is also essential, as the potential of biofuels is not sufficient to meet energy demand without additional energy efficiency efforts. Obviously, vehicle efficiency improvements, e.g. in aerodynamics, will also reduce the necessary growth rates of battery and fuel cell electric vehicles in the New and All-renewable and Fossil Electric and Hydrogen scenarios, although we haven't looked at this in detail. All in all, efficiency improvement is a no-regret option to pursue.

Efficiency improvements alone will probably not get us there, new options are necessary
The Efficiency Fossil scenario indicates that maximum efforts on efficiency improvement in conventional internal combustion drivetrains will not by itself lead to a CO_2 reduction of 60%. For this scenario to reach the GHG target, substantial transport demand reductions will also be needed. So most probably, either one or more of the alternative options (biofuels, battery and fuel cell electric drivetrains, based on fossil or renewable resources) will need to be introduced in the transport sector in order to meet the climate objective. Given the assumptions that needed to be made in the three other scenarios (e.g. on fuel cell vehicle shares in 2050, and on biofuel growth rates), it is probable that one option alone will not suffice.

Transport will become more expensive in the coming decades, but the causes vary between the scenarios
All scenarios show a ramp-up of costs until 2030, which will probably set the scene for policy making as well. But the scenarios differ between each other in the cause of this. A common cause is the assumed energy price development towards 2030. In scenarios 2 and 4, this is strengthened by new technology introductions that pay themselves back on the long term.

Urban transport: Possible niche for zero-emission options
Conventional energy technology in transport has already experienced significant reductions of pollutant emissions and fuel consumption. However, it is uncertain whether this will be enough to meet air quality standards for urban areas, especially in the case of these standards being tightened in the future. The electrification of urban transport is an attractive and robust option for both greenhouse gas reductions, air quality improvement and noise reductions. Vehicles concepts that can be expected include small, full electric cars, plug-in hybrids, electric cars with range extenders and hydrogen fuel cell vehicles. A point of particular interest is the possibility for end users to recharge in densely populated areas.

Well-to-wheel scope is important because of increasing interactions with other parts of the energy economy

In three out of four scenarios, reaching the -60% CO_2 objective in IPPC-TTW terms results in less than 60% reduction on a WTW basis. This illustrates that future energy use in the transport sector will probably increase the pressure on other sectors. It will become increasingly important to evaluate developments in transport also in WTW terms, to overlook the integral impacts.

Developments in other countries will strongly influence the scope for the Netherlands
The Netherlands, with its open economy and lack of national automotive OEMs, will depend strongly on developments of other (EU and other) countries. Strategic choice made there on drivetrain will strongly determine the playing field for the Netherlands as well. And although the Dutch are better positioned in the field of biofuels (with strong agricultural and (petro)chemistry sectors), it will also strongly depend on factors abroad how this option will further develop. The review of other country strategies (see Appendix G) provide a mixed picture. In Germany, probably the most important country to look at, alternative drivetrains seem to obtain more attention today than biofuels, while in the USA, all options are pursued. As external developments do not show any conclusive trends, it will be important to monitor other countries' strategies in the coming decade.

Table 6: Fuel/vehicle combinations

	Passenger cars	Vans	Trucks	Buses	Two-wheelers	Special vehicles	Inland shipping	Railway	Mobile machinery
Petrol/diesel									
LNG/CNG									
Electric									
Hydrogen									
Biofuel									

No substantial share

Minor share in all scenarios (<5%)

Substantial but uncertain: medium to high share in some scenarios (up to at least 20%)

Robust element: medium to high share in some scenarios (up to at least 20%) and significant share of at least 5% in all scenarios

6

Conclusions

The main conclusions of this study are related to the essential features of the scenarios, robust elements in the set, key uncertainties, and some other conclusions.

Essential features of the scenarios:

- The scenario set shows that there are fundamentally different ways for coming to 60% CO_2 emission reduction in the transport sector by 2050. All scenarios rely partly on technological innovation, partly on societal transformations, but the balance between these two varies between them, and each scenario has its specific technological and societal challenges.
- The scenarios also differ from each other in the potential to reach emission reduction levels higher than 60%, by 2050 and beyond. The Efficient Fossil scenario hardly has any upward potential, where the other scenarios have, although dependent on uncertain conditions such as penetration rates for (battery and fuel cell) electric vehicles, and technologies and feedstock potential for advanced biofuels.
- The ambition from the Energy Agreement to limit transport emission to 25 Mton by 2030 appears to be hard to realize. The 15-20 PJ energy efficiency gain by 2020, also part of the Energy Agreement, is already part of the reference case for this study, and is therefore met by all scenarios. In general, the introduction of new fuels and vehicles starts having an effect only after 2020, as their roll-out substantiates. On the short term, actions may be needed to prepare for their introduction, but impacts in terms of efficiency gains and CO2 emission reductions will initially be limited. By 2030, the impacts of new fuels and vehicles becomes visible in the CO2 emissions, but the strongest effects are visible in the 2030-2050 period (along with increased market share).
- In three out of four scenarios, reaching the -60% CO_2 objective in IPPC-TTW terms results in less than 60% reduction on a WTW basis. This illustrates that future energy use in the transport sector will probably increase the pressure on other sectors. It will become increasingly important to evaluate developments in transport in WTW terms also, to overlook the integral impacts.
- In a 2050 perspective, cost per km does not vary greatly between the scenarios. This is partly inherent to our approach: in each scenario we assumed that a technology will only break through if it can reach cost levels comparable with reference system

costs with in this long-term horizon. However, all scenarios do show a cost hurdle on the short term, partly caused by the assumed energy costs for the coming decades, partly because new technologies in three of the four scenarios are expensive during first introduction and reduce cost by technological learning when growing towards a mainstream position in transport.

Robust outcomes of our analysis are:

- Energy efficiency improvement is a robust element that helps all scenarios reach the -60% target. Its importance varies over the scenarios, is essential in the Biofuels and Efficiency scenario and is pivotal in the Efficient Fossil scenario.
- Even in the 2050 timeframe, it is likely that petrol and diesel will still have a substantial share in the energy mix in all subsectors. This robust element is inherent to the condition that CO_2 emissions have to be reduced by 60% (compared to 1990). As CO_2 reduction options towards this level all come at a cost, most subsectors will tend to use as much as possible petrol and diesel (and CNG/LNG) as it remains a strong and convenient competitor.
- Urban areas is a logical niche for (battery) electric vehicles, given their technology characteristics and zero-emission profile. However, the latter is only a lasting if air quality standards are to be strengthened in the future.
- The role of natural gas for heavy transport is not a must in all scenarios in order to reach the -60% target, but might be pursued for other reasons, such as energy security and its precursor role for biogas.

Key uncertainties were identified for each factor supporting the -60% target over the various scenarios:

- The role of biofuels depends on breakthroughs in biofuel technologies, availability of biomass, and long-term success of innovative feedstock options and solar fuel technologies;
- The role of battery electric vehicles depends on battery technology breakthroughs improving their costs, capacity and performance, and on infrastructure development and end-user acceptance
- The role of fuel cell electric vehicles depends on end-user acceptance of hydrogen as a fuel, related hydrogen infrastructure development and fuel cell cost reductions by upscaling of the technology
- Efficiency improvements are partly conventional technology improvements, but for emission factors below 70 g/km, fundamental changes in vehicle concepts will be necessary. Also in freight transport and special vehicles, uncertainties about possible efficiency improvements are still significant.
- Transport volume reduction, essential in one of the scenarios, depends strongly on the role of mobility in our society as a whole. Decoupling economic growth and mobility growth will be needed for this, which has shown to be difficult in the past. However, new technologies, mobility concepts and social innovations might change this picture.

Finally, most important other conclusions and limitations of this study:

- The combination of a cost hurdle for the scenarios with new technologies and their potential for deeper CO_2 emission reductions clearly marks a risk for lock-in situations. If in the long run more substantial reductions are necessary, it is important to anticipate on new technologies and pick winners as soon as they've

emerged with sufficient certainty. Sticking to efficiency improvements and mobility reduction too long will probably increase costs of a late introduction of other options, and reduce opportunities for green growth.

- In general, the scenarios provide a useful basis for strategic thinking on transport. Initial steps would be to keep options open, identify indicators that help signaling toward which scenario the world is moving, closely monitor international developments, and reduce the package of options as soon as it is sufficiently certain that a specific scenario has become improbable.
- The analysis of the role and costs of infrastructure, particularly important for battery and hydrogen fuel cell electric driving, has remains relatively superficial. In further analyses, optimal and adaptive strategies for infrastructure roll-out deserve further attention.

The scenarios do not contain great submodal detail. For example, trucks and buses were not subdivided into e.g. urban, regional and (inter)national distance submodes. This keeps our conclusions about e.g. urban options relatively tentative. Particularly when searching for specific niches for specific technologies, a further subdivision can be helpful.

This scenario study finalises the first step of the process towards an integral Dutch vision on energy carriers for the transport sector. Based on this study, a starting document will be compiled which forms the basis input for the second step in the process. This will be the beginning of an intensive generation and exchange of ideas between the involved actors of the second phase. This scenario study focused on several possible images of the future from which robust elements, general preconditions and important key uncertainties related to these scenarios could be identified.

The next phase will focus on the required barriers and key uncertainties which come along with these future images. Specific combinations of fuel chains and user categories (urban passenger cars, long distance heavy duty trucks, etc) will be separately discussed. Based on these discussions, questions will be raised on how to eliminate specific barriers and how to deal with key uncertainties. The involved stakeholders in the process will jointly provide anwers to these questions. This will finally need to result in choices for no-regret options that anticipate on identified uncertainties. Important is to consider how *current* specific choices link to developments *in the long term* which might occur in the future and how choices of various fuel chains can strengthen each other.

In order to have successful alternative fuel policies and to reach sustainable targets, it is required to have a strong connection with the overall energy policy. For this reason, barriers and uncertainties in the overall energy sector will also be part of the discussions of the second phase of the development of the integral vision.

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Appendix A. Performance indicator calculation

Table 7 summarizes the methodology used in the model for calculating the various performance indicators. **Table 8** gives the impacts that were assessed qualitatively.

Table 7: Methodology for calculating performance indicators

Performance indicator	Calculation method
Final energy consumption per energy carrier, per mode of transport	For road modes: MJ per vkm * Number of vkm in Reference scenario * Share in vkm of energy carrier in scenario * Factor for changes in transport demand compared to reference scenario For non-road modes: MJ in reference scenario * Share in vkm of energy carrier in scenario * Ration in TTW energy efficiency of energy carrier compared to diesel * Factor for changes in transport demand compared to reference scenario
CO_2 emissions TTW per energy carrier, per mode of transport	Final energy consumption * TTW CO_2 emission factor per type of fuel (According to IPCC methodology TTW emission factor for biofuels = 0)
CO_2 emissions WTT per energy carrier, per mode of transport	Final energy consumption * WTT CO_2 emission factor per type of fuel
PM and NO_x emissions TTW and WTT per energy carrier, per mode of transport	For road modes: Transport volume in vkm * emission factor in gram per vkm For non–road modes: Energy use in PJ * emission factor in gram per PJ
Vehicle-related costs (TCO) per mode of transport (only for road transport) per energy carrier (in € per vkm)	Based on depreciation of purchase costs plus the annual vehicle costs
Vehicle-related taxes per mode of transport per energy carrier (only for road transport) (€ per vkm)	Based on depreciation of purchase taxes plus the annual vehicle taxes
Fuel-costs TCO per mode of transport per energy carrier (only for road transport) (in € per vkm)	energy efficiency (in MJ/km) * fuel costs (excl. tax)
Fuel-taxes per mode of transport per energy carrier (only for road transport) (in € per vkm)	energy efficiency (in MJ/km) * fuel tax
Social cost per mode of transport (only for road transport) and energy carrier (based on TCO excl. taxes and pollutant emissions)	TCO (excl. taxes) + sum-product of pollutant emissions and valuation of the emissions

Table 8: Methodology for assessment of qualitative impacts

Type of impact	Summary of the approach
Security of energy supply	This will be assessed by comparing the scenarios on: Total final energy use Fossil fuel use Number of countries for energy import Diversification: number of energy sources (and shares)
Green growth	This will be addressed in two ways: • By a comparison of macro-economic green growth indicators for the different scenarios • By qualitative indication of key green growth opportunities for each scenario.
Noise	This will be elaborated in a qualitative way. The argumentation will be as follows. The impact on noise is expected to be limited. Electric and fuel cell vehicles have hardly any engine noise and will therefore have some noise benefits. However, at driving speeds of 30 km/h and more, engine noise is just minor compared to noise from driving wind and tyres. Furthermore, heavy road vehicles and also rail transport are important sources of noise. So some noise reduction can be expected in urban areas when significant shares of electric and/or fuel cell vehicles enter the fleet, particularly when this also includes trucks and buses (see also the large EV study for DG Clima, 2011).
External safety	This will be semi-quantitively addressed by identifying key technologies or components that could lead to safety issues, identifying the type of issue (external safety or occupational safety), and the part(s) of the supply chain in which this occurs. This will be used for an indicative ranking of the scenarios.
Robustness	The robustness of the scenarios will be assessed by investigating to what extent there is potential for achieving higher GHG reduction.

Appendix B. The reference scenario

Starting points: 'Referentieraming 2012' and PBL transport projections until 2030
In order to be able to compare the influence of various fuel scenarios, a baseline scenario ('reference scenario') was defined first. This reference scenario illustrates the expected developments in the transport sector under business-as-usual conditions and current policies. Starting point of this scenario was the 'Referentieraming, actualisatie 2012' (Verdonk and Wetzels, 2012). We used the scenario appointed and intended policy ("vastgesteld en voorgenomen beleid") from this study and the underlying material. Projections of the developments in the transport sector for 2020 and 2030 in the 'Referentieraming' were delivered by PBL. Therefore, in this study the last update of available data of PBL was used (2012) as starting point. In this data, both road and non-road transport are distinguished. Road transport includes passenger cars and vans (both with distinction in fuel type and/or drive train), trucks and trailers, buses, special vehicles and motorbikes. Non road includes (passenger and national) inland water navigation, offshore fishing, rail transport and mobile machinery. This study excludes maritime and aviation in the calculations (as described in section 3.1).

Calculation method in the reference scenario
According to the method used in the data of PBL, two different definitions are used in this study: IPCC-values and Dutch-territory values (see also the Glossary).

Energy and CO_2-emissions are calculated according to the IPCC guidelines for national greenhouse gas inventories (IPCC, 2006). These 'IPCC-values' consider the amount of fuel which is fuelled on Dutch territory (and not per se *driven* on Dutch territory), but exclude bunker fuels for among others aviation and shipping. As the IPCC-values are commonly used for international targets, it is assumed that the 60%-target for CO_2-emissions will be calculated according the IPCC-values. Nevertheless, it is uncertain whether this assumption will remain valid, as international climate policy might develop in a direction towards well-to-wheel approaches.

Air pollution emissions (NO_x, PM_{10}, $PM_{2.5}$ and CH_4) are strongly linked to the location of emissions, so are based on the emissions resulting from kilometres driven on Dutch territory. Therefore, these 'Dutch territory values' are used for calculations of the air polluting emissions. In the data of PBL a fixed correction factor is used between IPCC- and Dutch territory-values, related to the fuel.

Extrapolation for 2050: main assumptions and uncertainties
In order to derive a reference scenario, the PBL-data for 2020 and 2030 are extrapolated to 2050. Such an extrapolation obviously carries a large uncertainty within itself. Projections in the transport sector are dependent on both internal and external factors, such as technology, economic, political and demographic developments. These developments are difficult to predict, but have a large influence on for example fleet development and composition. It is therefore that transport data for 2030 contains already a significant uncertainty (Hoen, pers. comm., 2013), which makes extrapolation

towards 2050 even more uncertain. Nevertheless, the reference scenario enables to identify the consequences of alternative fuel scenarios compared to this reference scenario under stated assumptions, which are described below.

Road-transport: extrapolation based on vehicle kilometers
Projections for 2050 for road transport are based on linear extrapolation of vehicle kilometers from 2030 towards 2050. For passenger cars, this linear extrapolation was dampened by multiplying it with a factor of 0.95 due to the flattening growth trend (KiM, 2013). For the other transport modalities a linear growth towards 2050 is assumed. It is furthermore assumed that the ratio between the various fuels for one transport modality in 2050 remains equal to the ratio in 2030. As the data of PBL includes already some electric transport, a small share of electric vehicles is already included in the reference scenario. However, as the share of fuels remains the same for 2050, the amount of electric transport remains limited.

Road transport: developments in energy- and CO_2-emission factors
As a second step the baseline CO_2-emission factors are defined towards 2050 and translated to energy factors via the existing conversion factors (g/MJ) for fuels. For passenger cars and vans the CO_2-emission factors are derived on the basis of the assumption that currently proposed policies regarding maximum CO_2-emission standards for new sold vehicles are set to the value of the maximum emissions standards for 2020. For passenger cars it is assumed that the limitation of 95 g/km for 2020 (or 2021), which already has some impact on 2020 emissions in the "Referentieraming", is fully integrated in the car fleet by 2040 2050. It is assumed that the difference between test- and real emissions of new cars is 30%, which means that the total emission factor for 2040 and 2050 for passenger cars will be ~124 g/km (TNO, 2013). The same calculation method is used for vans, which have a CO_2-emission standard for 2020 of 147 g/km. For the other transport modes the energy factor is set to the value of 2030 as there are currently no active policies to reduce emissions from these transport modes. Both total CO_2-emissions and energy use are calculated from the factors above.

Road transport: developments in other emission factors (NO_x, PM_{10}, etc)
The emission factors of NO_x, PM_{10}, $PM_{2.5}$ and CH_4 for 2050 are set equal to the value of 2030 for each of the transport modes. We assume that by 2030, EURO6 standards will be fully integrated in the vehicle fleet, and that no stricter standards will be set ('current policies' approach).

Non road transport
For non-road transport the data for 2050 are derived by linear extrapolation of the energy use trend between 2010 and until 2030, except for rail transport where the decreasing trend of energy use is flattened and 2040/50 values are set equal to the to the value of 2030. In addition, the emission factors in 2050 are set to the value of 2030 and no stricter standards are set.

Overall note
In this study no changes have been made in the data of the Referentieraming in the data until 2030. In some cases, new data might be currently available which would slightly change the reference path. For example, CNG buses were not included in the

Referentieraming, while there are already buses driving on natural gas. It would be inconsistent to change just some of the data of 2012 and since the goal of this study is to investigate and develop the alternative scenarios, the Referentieraming is strictly copied (and thus no CNG buses have been included in the reference scenario).

Appendix C. Key scenario inputs

This chapter presents the translation of the general scenario storylines to the input parameters that have been used for calculating the performance indicators. First, we discuss the scenario-dependent input data (4.1) and the fixed input data (4.2).

Scenario dependent input data

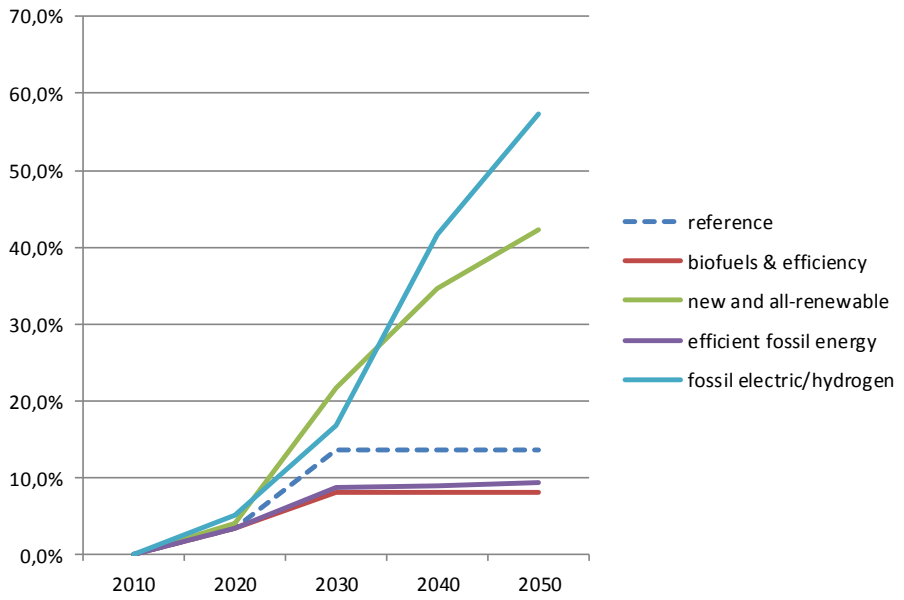
Several scenario dependent input data have been defined in order to be able to quantify the impacts of the four scenarios. Based on the qualitative assumptions of the story lines the following input data have been defined and varied across the scenarios:

- penetration rate of alternative energy carriers in the Dutch vehicle fleet (expressed in % of vkm per energy carrier)
- transport volume (vkm)
- energy efficiency (MJ/km)
- upstream (WTT) CO_2 emission factor per energy carrier (in g/MJ)
- biomass availability
- cost of energy carriers (including energy infrastructure costs) and vehicle-related costs
- taxes on fuel/energy and on vehicle registration/ownership.

Penetration rate of alternative energy carriers in the Dutch vehicle fleet
In chapter 3 we already provided the vkm shares of the different energy carriers per scenario for the year 2050. However, the shares of these energy carriers in the transport sector require penetration of alternative drive-trains in the vehicle fleet.
In the next section we will shortly explain the assumed growth rates of especially electric vehicles and vehicles running on hydrogen.

The penetration rates of electric vehicles in the fleet of passenger cars in the 'Biofuels and Efficiency' scenario and the 'Efficient fossil energy' scenario are lower compared to the reference scenario (see **Figure 27**). In the 'New and all-renewable' scenario the growth is based on the shares assumed in CE Delft (2011). The electrification of vans will follow the developments in passenger cars.

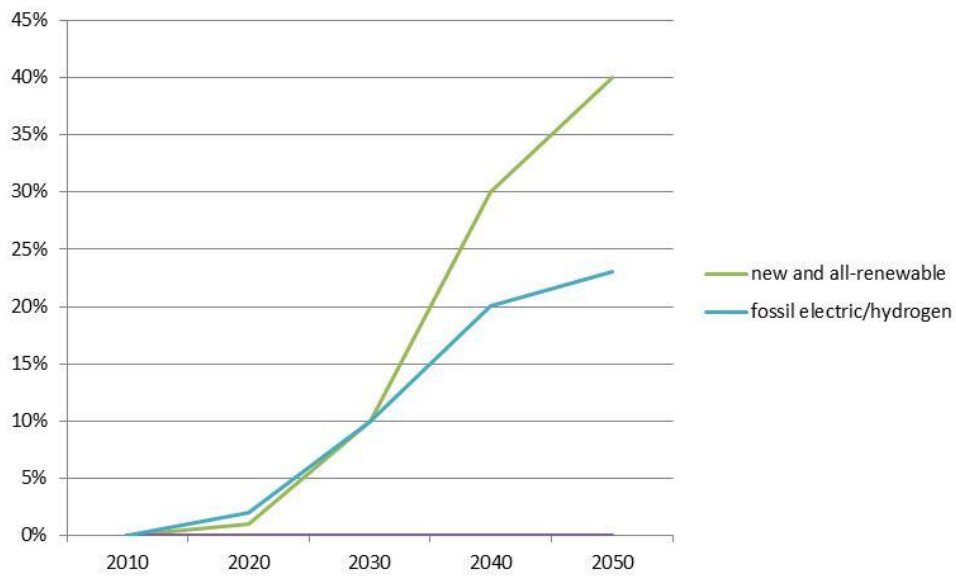
Figure 27: Development of electrification of passenger cars (in % of vkm)



Penetration rate of vehicles running on hydrogen

Hydrogen only enters the fuel mix in the New and All-renewable scenario (2) and the Fossil Electric/Hydrogen scenario (4). Given its potentially broader role in an all-renewable energy economy, the final share is highest in scenario 2.

Figure 28: Penetration rate of passenger cars running on hydrogen (% of vkm)



Transport volume

Energy use in the transport sector is strongly determined by transport volume. Due to the developments mentioned in the story line of each scenario, it is not likely that transport growth would be equal in all scenarios. However, if there are no strong arguments for significant deviations from the projection of the reference scenario, the transport growth rates have been chosen equal to the reference scenario.

Only in the 'Efficient fossil energy' scenario a deviation from the reference scenario has been assumed. In that scenario a significantly reduction of transport volume in 2050 will be required to meet the 60% reduction target. The reduction in demand growth compared to the reference scenario have been chosen by assuming:

- For cars, vans, trucks, special vehicles and non-road mobile machinery: a slightly lower growth in 2020 compared to the reference scenario and a constant transport demand from 2020 till 2050.
- The same volume as in the reference scenario for all the other modes, assuming that the net impact of modal shift towards these modes and increased load factors compared to the reference scenario will be zero. For buses the transport volume is assumed to remain constant over time, instead of the volume reduction assumed in the reference scenario.

The reduction in the transport growth will be the result of the modest economic growth and social innovations in this scenario such as a breakthrough in teleworking and other types of ICT applications curbing down transport growth. Moreover it will require policies for reducing transport growth rates, such as:

- transport pricing (e.g. introduction of a kilometre charge);
- lowering of speed limits;
- spatial and infrastructure policies reducing transport demand (growth).

The percentages in **Figure 29** and **Figure 30** represent relative transport growth in vehicle kilometres in 2050 compared to 2010 levels. Tables with the exact percentages per transport mode are included in **Table 9** and **Table 10**.

Figure 29: Relative growth in transport volume per transport mode in passenger transport in 2020-2050 for the reference scenario and 'Efficient fossil energy scenario' (3) (2010=100%)

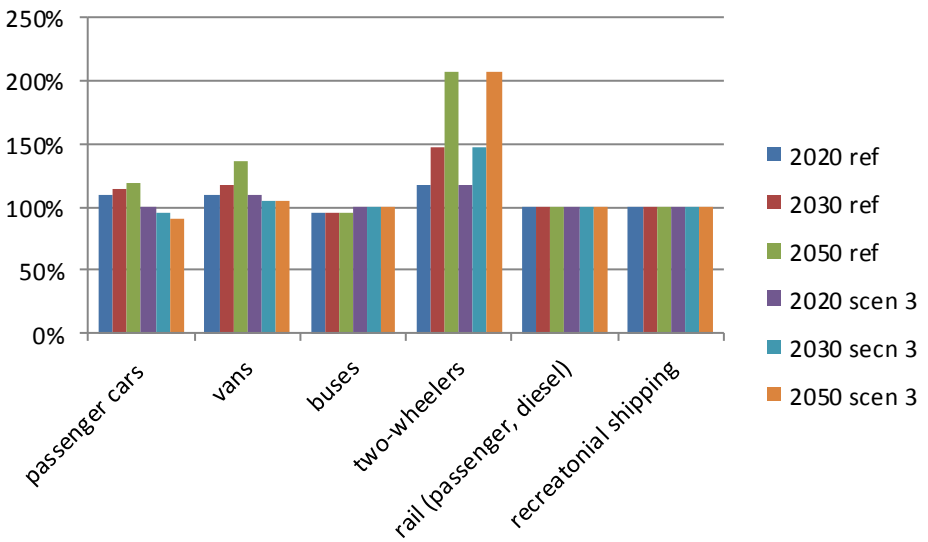


Figure 30: Relative growth in transport volume per transport mode in freight transport in 2020-2050 for the reference scenario and 'Efficient fossil energy scenario' (3) (2010=100%)

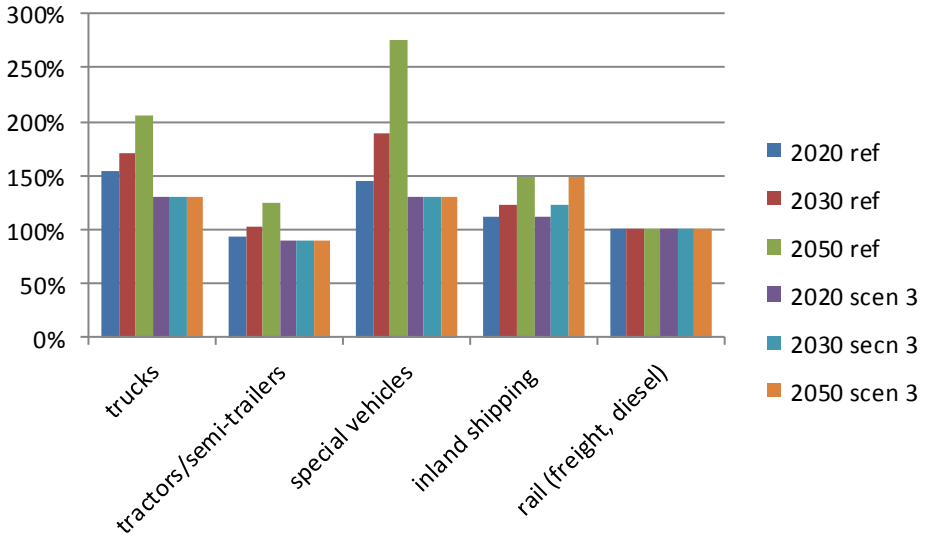


Table 9: Relative growth in transport volume 2010-2050 in the reference scenario

Passenger transport	2010	2020	2030	2050
passenger cars	100%	109%	115%	119%
vans	100%	109%	118%	136%
buses	100%	95%	95%	95%
rail (passenger, diesel)	100%	100%	100%	100%
special vehicles	100%	145%	189%	275%
two-wheelers	100%	118%	148%	207%
Freight transport	**2010**	**2020**	**2030**	**2050**
trucks	100%	154%	171%	206%
tractors/ semi-trailers	100%	93%	104%	125%
inland shipping (national, diesel)	100%	111%	124%	149%
rail (freight, diesel)	100%	100%	100%	100%
Other modes	**2010**	**2020**	**2030**	**2050**
recreational shipping	100%	100%	100%	100%
mobile machinery	100%	127%	147%	262%

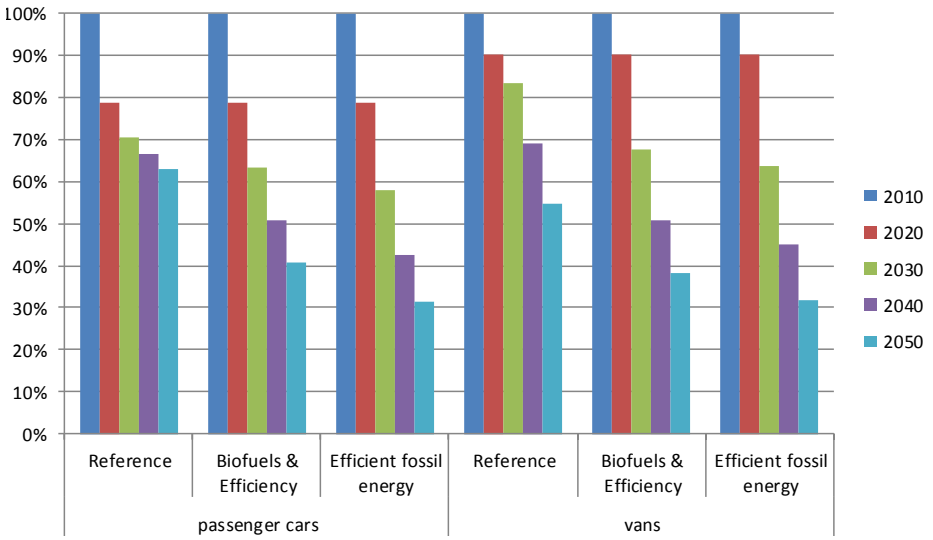
Table 10: Relative growth in transport volume 2010-2050 in the Efficient fossil energy scenario

Passenger transport	2010	2020	2030	2050
passenger cars	100%	100%	95%	90%
vans	100%	110%	105%	105%
buses	100%	100%	100%	100%
rail (passenger, diesel)	100%	100%	100%	100%
special vehicles	100%	130%	130%	130%
two-wheelers	100%	118%	148%	207%
Freight transport	**2010**	**2020**	**2030**	**2050**
trucks	100%	130%	130%	130%
tractors/ semi-trailers	100%	90%	90%	90%
inland shipping (national, diesel)	100%	111%	124%	149%
rail (freight, diesel)	100%	100%	100%	100%
Other transport modes	**2010**	**2020**	**2030**	**2050**
recreational shipping	100%	100%	100%	100%
mobile machinery	100%	120%	130%	130%

Energy efficiency improvements

Besides the introduction of alternative drive trains, CO_2 reduction could also be reached by energy efficiency improvements in conventional technologies. **Figure 31** shows the energy efficiency improvements that have been assumed in the Reference scenario, the 'Biofuels and efficiency' scenario and the Efficient fossil fuels scenario for passenger cars. For the 'New and all-renewable' scenario and the 'Fossil electric/hydrogen' scenario no additional efficiency improvements have been assumed compared to the reference scenario.

Figure 31: **Relative energy consumption for three scenarios for passenger cars and vans**



In the 'Efficient fossil energy' scenario the 60% GHG emission reduction will solely be reached by conventional technologies and therefore this scenario requires extremely high efficiency improvements to drastically reduce energy consumption per vkm (e.g. for passenger cars the fleet average real life CO_2-emissions in 2050 in this scenario are about 62 g/vkm; for vans these are 78 g/km; compared to 124 g/km and 191 g/km in the reference scenario). This shift to extremely fuel efficient vehicles will require:

- application of all types of energy saving technologies
- application of Intelligent Transport Systems (ITS)
- lower and more homogeneous driving speeds for closing the gap between real life and test cycle emissions
- significant downsizing.

Also in the 'Biofuels and efficiency' scenario very significant energy efficiency improvements are assumed. However, because biofuels also largely contribute to the decarbonisation of the transport sector, somewhat less extreme efficiency improvements have been assumed for that scenario (e.g. for passenger cars the fleet average CO_2 emissions in 2050 in this scenario are about 80 g/vkm; for vans these are 94 g/km).

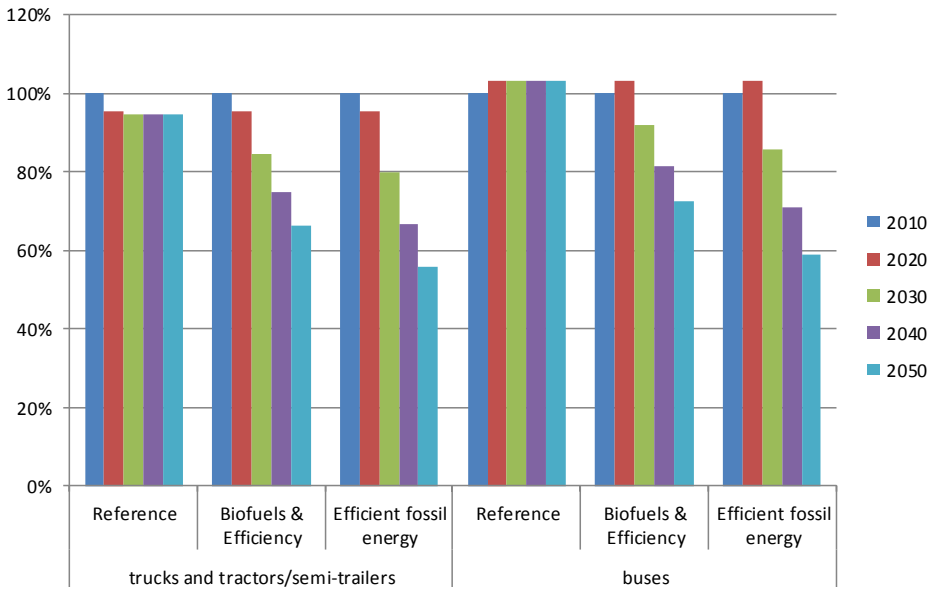
Table 11 summarises the fleet average real-world CO_2 emissions in the three scenarios. As can be seen the 'Efficient fossil energy' scenario requires the fleet average real-world CO_2 emissions to be half the average of the reference scenario in 2050.

Table 11: **Fleet average real life CO_2 emissions in gCO_2/vkm in 2050 for passengers and vans**

	Reference	Biofuels & Efficiency	Efficient fossil energy
passenger cars petrol	124	80	62
passenger car diesel	124	80	62
van diesel	191	94	78

The efficiency improvements assumed in the freight transport (trucks and tractors/semi-trailers) and buses are depicted in **Figure 32**. The three scenarios assume less drastic efficiency improvements in these transport modes.

Figure 32: Relative efficiency improvements for three scenarios for trucks/semi-trailers and buses



Well-to-tank CO_2 emissions

Although the IPCC definition of the 60%-target only takes into account tank-to-wheel CO_2 emissions, it is useful to see to what extent emissions would increase or decrease in other sectors, like the energy sector, as a result of a shift to other energy carriers in the transport sector. These WTW-emissions vary across the four scenarios, for example, WTW-emissions of fossil fuels increase in the reference scenario. The used WTT-factors for the various energy carriers in each scenario are given in **Table 12**. The basis for these factors was CONCAWE et al.(2013); for the trends in the different scenarios we used assumptions from CE Delft (2013).

Key assumptions are:

- In 2050, more energy-intensive methods are necessary to extract fossil resources than nowadays. In the 'Efficient Fossil Energy' scenario a lack of renewable energy results in attention for the whole fossil fuel chain and therefore lower WTW-emissions for fossil fuels are assumed.
- Biofuels are assumed to consist almost entirely of advanced biofuels from (agricultural and forestry) residues. Therefore, ILUC and carbon neutrality issues are assumed not to be relevant.
- The two scenarios depending largely on the use of electricity and hydrogen do not differ at the TTW-level, but show major differences in WTT-emissions. Since the electricity and hydrogen consumed in the 'New and all-renewable' scenario are all produced from renewable sources, the WTT-emissions are limited. Note, however, that energy use in other sectors is also decarbonised because of an overall climate change mitigation target. Therefore, centralised power and hydrogen production is less carbon intensive than it is today.

Table 12: WTT CO_2 emission factors per scenario

gCO2/MJ	Reference scenario		Biofuels and efficiency	New and all-renewable	Efficient fossil energy	Fossil electric/ hydrogen
	2010	2050	2050	2050	2050	2050
Gasoline	13.1	16.0	12.8	16.0	11.9	14.9
Diesel	15.3	17.9	14.3	17.9	13.2	16.6
LPG	8.0	9.3	7.4	9.3	6.9	8.6
CNG	13.0	15.1	12.1	15.1	11.2	14.0
LNG	19.4	22.5	18.0	22.5	16.7	20.9
Electricity	86.5	1.0	1.0	1.0	20.4	20.4
Hydrogen	111.0	2.0	2.0	2.0	24.0	24.0
Bio gasoline	70.0	17.5	13.1	13.1	17.5	17.5
Bio Diesel	87.5	35.0	26.3	26.3	35.0	35.0
CBG	18.5	7.4	5.6	5.6	7.4	7.4
LBG	25.9	10.4	7.8	7.8	10.4	10.4
BLPG	36.2	9.0	6.8	6.8	9.0	9.0

Biomass availability

The use of biomass in transport is limited by its availability. The table below shows how the biomass availability in 2050 has been estimated for the four scenarios. Other assumptions have been made for the first two scenarios compared to the last two: in the first two scenarios more renewable energy will be available.

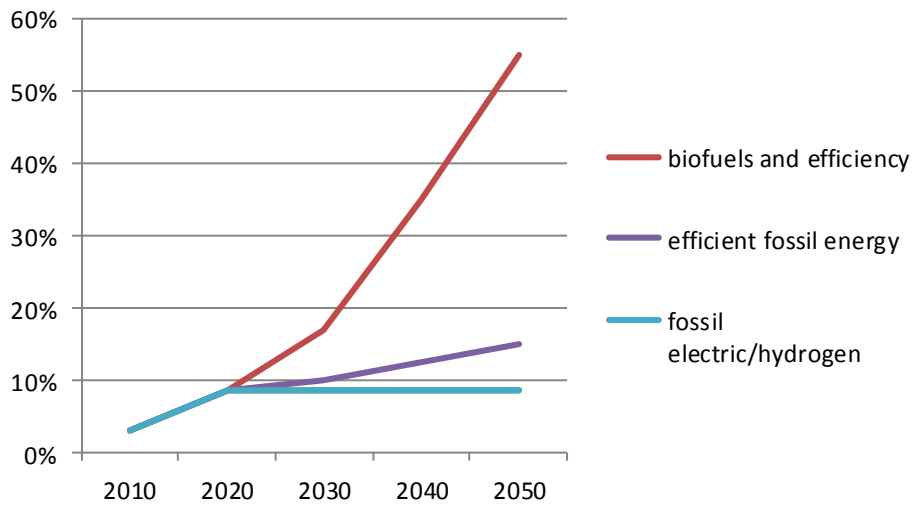
First of all, an estimation is made of the globally available amount of biomass. This was based on the IPPC Special Report on Renewable Energy (IPCC 2011). It has been assumed only 50% of the available biomass potential will be mobilised. Of this globally available amount of biomass the share available for the Netherlands has been determined using GBP (for the first two scenarios) and population share (for the last two scenarios). Not all biomass is assumed to be available for the transport sector: 60% is available for transport, 30% for materials and 10% for the energy and heat sector. 40% of the biomass available in transport will be used by maritime shipping and aviation, which makes that 180 PJ will be available in the 'Biofuels and efficiency' scenario and the 'New and all renewable' scenario. In the 'Efficient fossil energy' scenario and the 'Fossil electric/hydrogen' scenario the availability is limited to 24 PJ, which is close to the biofuel consumption predicted for 2020.

Table 13: Biomass availability and use in 2050 per scenario

	Biofuels and efficiency	New and all-renewable	Efficient fossil energy	Fossil electric/hydrogen
Globally available biomass	200 EJ	200 EJ	100 EJ	100 EJ
Mobilised potential	100 EJ	100 EJ	50 EJ	50 EJ
Biomass available for the Netherlands	850 PJ	850 PJ	100 PJ	100 PJ
Availability corrected for biomass required by other sectors	520 PJ	520 PJ	60 PJ	60 PJ
Availability corrected for biofuel demand maritime shipping and aviation	300 PJ	300 PJ	40 PJ	40 PJ
Corrected for conversion losses of biofuel production (1 MJ biomass = 0.6 MJ biofuel)	180 PJ	180 PJ	24 PJ	24 PJ
Biofuel consumption resulting from energy mix	174 PJ	10 PJ	21 PJ	8 PJ

Comparison of the biomass use and the availability shows that in all scenarios the share of biomass energy needed fits well within the amount of available biomass at least for the year 2050. However, to reach these quantities in 2050 certain shares of biofuels should also already be blended into the fossil fuel mix in 2020 and 2030. **Figure 33** shows which developments have been assumed for the years between 2010 and 2050. Biofuel consumption will increase equally in all scenarios until 2020 due to the targets of biofuel related policies, like the Renewable Energy Directive and the Fuel Quality Directive. After 2020 biofuel volumes will be stable in the Reference and Fossil electric/hydrogen scenario. In the 'Efficient Fossil Energy' scenario the biofuel consumption increases modestly, while in the 'Biofuels and Efficiency' scenario it increases rapidly.

Figure 33: Penetration rate of biofuels in fossil fuel consumption (% energy)



To what extent the growth of biofuel consumption in the 'Biofuels and Efficiency' scenario is realistic, can be found in **Figure 33**. Advanced biofuels are assumed not to have a major breakthrough until 2030. These assumptions are also in line with IEA-ETP assumptions (IEA, 2012).

Cost of energy carriers

Fuel prices at the pump were used, containing costs for feedstock, production, refining, distribution and commercial margins, excluding duties and taxes. They were calculated as follows.

- Future prices of commodities like oil, natural gas and electricity were taken from (Daniels et al., 2012), which are mostly based on the 2010 IEA ETP Blue Map Scenario. In this scenario, fossil energy prices go up until 2030 because of increasing scarcity, but go down again towards 2050 because of an increasing demand for fossil energy due to climate target. Oil consumption is roughly the same in all scenarios, therefore there was no solid ground for differentiation of gasoline, diesel and LPG costs. Natural gas consumption will mostly depend on demand outside the transport sector, therefore we did not differentiate costs of methane and LNG. For electricity costs, the Blue Map scenario uses a mix of renewables and fossil generation with CCS. We assumed that these costs are a reasonable assumption for all scenarios, both the cases in which power production is dominated by renewables (scenarios 1 and 2) and the cases in which fossil generation with CCS dominates (scenarios 2 and 4).
- These €(2000) prices were translated into € (2010) applying an annual inflation rate of 2%.
- For gasoline, diesel and LPG, commodity prices were multiplied by a factor of 1,89 to account for refining costs, distribution costs and commercial margins. This factor is based on ECN internal analyses of the ratio between commodity prices and prices at the pump.
- For electricity, distribution costs were added, taking € 1600/vehicle and grid investment costs for a loading point (Boer-Meulman et al., 2012), and assuming 20.000 km/year, 10 years vehicle lifetime and a 0% interest rate. This 0% interest

rate is relatively optimistic but the assumption that each vehicle needs a public loading point is relatively pessimistic. Electricity costs of renewables are today significantly higher than those of fossil options. However, we assume that in the scenarios in which renewables develop favourably (scenarios 1 and 2), these costs converge to fossil generation costs.

- For CNG and LNG, costs additions for distribution were taken from Verbeek et al. (2013). These costs were assumed to change with natural gas prices. For LNG, this distribution cost factor was assumed to reduce to 75% of its 2020 value by 2050.
- Costs for GTL at the pump were taken from Verbeek et al. (2012).

Prices of two fuels were made scenario-dependent:

- Hydrogen: For the New and all-renewable scenario and the fossil electricity and hydrogen scenario, hydrogen prices at the pump were directly obtained from Lebutsch and Weeda (2011) and McKinsey (2011). In the other scenarios, hydrogen does not play a role and no price assumptions were made. Although hydrogen comes from different sources in scenarios 2 and 4, and hydrogen may play a more ubiquitous role in the energy economy in scenario 2, we decided not to differentiate hydrogen costs between these two scenarios.
- Biofuels: In the Biofuels and efficiency scenario and the New and all-renewable scenario, biofuel prices were supposed to converge to liquid fossil fuel prices after refinery (see also IEA (2012). Biofuel prices were assumed 20% higher and fossil liquids in 2050, 60% higher in 2030, and 100% higher in 2020. In the other scenarios, biofuel prices were assumed to remain high, at the cost levels assumed in Daniels et al (2012). Distribution costs and margins were assumed to be equal (in absolute terms) to those of liquid fossil fuels.

Table 14: Costs per energy carrier (without VAT, without energy taxes) (in €/GJ), price level 2010

Energy carrier	2010	2030	2050
Gasoline	17.2	31.9	24.8
Diesel	17.2	31.9	24.8
LPG	19.3	35.9	27.9
Electricity	27.8	30.9	33.8
Hydrogen	55.0	41.7	37.5
CNG	21.8	17.0	17.0
LNG	29.4	20.9	19.5
Biofuels in reference and S3 and S4	51	51	51
Biofuels in S1 and S2			

Taxes on energy carriers

The taxes on energy carriers are given in **Table 15**. The only deviation from this set, is the tax on hydrogen in scenario 1 and 2 which was set equal to the tax on petrol from 2030 onwards.

Table 15: Taxes on energy carriers (without VAT) (in €/GJ), price level 2010

Energy carrier	Tax level
Petrol	20.2
Diesel	13.3
LPG	6.3
Electricity	30.9
H_2	0.0
CNG	4.3
LNG	6.6
GTL	14.2

Vehicle purchase prices

The vehicle purchase prices (excl. taxes) are based on current averages and estimates for 2020-2030 and 2050. Higher vehicle costs are assumed for electric and hydrogen vehicles, but the differences with conventional vehicles diminish over time, particularly in the scenario 2 and 4 with a technology breakthrough. In scenario 1 and 3, vehicle prices of conventionally fuelled cars are higher than in the other scenarios because of the energy efficiency improvements.

The vehicle purchase prices (excl. taxes) are depicted in **Table 16**. Higher vehicle costs are assumed for electric and hydrogen vehicles, but the differences with conventional vehicles diminish over time, particularly in the scenario 2 and 4 with a technology breakthrough. In scenario 1 and 3, vehicle prices are higher because of the energy efficiency improvements.

Table 16: Vehicle purchase prices in € per vehicle (excl. taxes), price level 2010

	2020	2030	2050
Car			
Gasoline	16795	16795	16795
Diesel	17568	17568	17568
LPG	17568	17568	17568
Electric (FEV or PHEV)	31588	28508	23568
LNG or CNG	19431	19431	19431
Van			
Diesel	19778	19778	19778
LPG	19778	19778	19778
Electric (FEV or PHEV)	33798	30718	25778
LNG or CNG	21528	21528	21528
Rigid truck			
Diesel	98337	98337	98337
LNG or CNG	128337	128337	128337
Tractor semi-trailer			
Diesel	144.743	144.743	144.743
Electric	215639	215639	215639
LNG or CNG	164743	164743	164743
Bus			
Diesel	270702	270702	270702
LPG	310702	310702	310702
Electric (FEV or PHEV)	350702	350702	350702
LNG or CNG	310702	310702	310702

Sources: Verbeek et al. (2013)

There are two deviations from this set. First, in scenario 2 and 4, lower prices of electric and fuel-cell (hydrogen) vehicles have been assumed, which are presented in **Table 17**. They are based on the assumption that in those two scenarios, by 2050 those vehicles will cost 10% more than a diesel vehicle and that the cost in 2030 will be decreased by 25% of the difference in vehicle costs between 2020 and 2050.

Table 17: Vehicle purchase prices of electric and hydrogen vehicles in 2050 in scenario 2 and 4 in € per vehicle (excl. taxes), price level 2010

	2020	**2030**	**2050**
Car -electric	29,925	24,239	19,325
Car-hydrogen	26,568	24,757	19,325
Van-electric	32,135	26,449	21,535
Van-hydrogen	28,778	26,967	21,535
Rigid truck - electric	168,337	153,295	108,171
Rigid-truck-hydrogen	248,337	213,295	108,171
Tractor semi-trailer - electric	215,639	201,534	159,217

Tractor semi-trailer – hydrogen	344,743	298,362	159,217
Bus-electric	350,702	337,470	297,772
Bus-hydrogen	420,702	389,970	297,772

Sources: Verbeek et al. (2013)

In the scenarios with additional energy efficiency improvements compared to the reference scenario, vehicle prices increase over time. These increases have been estimated based on cost curves from CE Delft and TNO (@@ref to be added). The additional cost in 2030 have been interpolated in the same way as the fuel efficiency improvement has been interpolated.

Table 18: Additional vehicle purchase prices for conventional vehicles in scenario 1 and 3 in € per vehicle (excl. taxes), price level 2010

Vehicle type	S1 - Biofuels and Efficiency	S3 - Efficient Fossil Fuels
Passenger car	€4,000	€7,000
Van	€4,000	€7,000
Truck (incl. tractor semi-trailer)	€20,000	€40,000
Bus	€16,000	€40,000

Vehicle taxes

In the reference scenario, scenario 1 and scenario 3, the vehicle purchase (registration) taxes (BPM) and annual vehicle taxes (MRB) are for all modes set at the level of 2014 (price level 2010). This means that full electric and hydrogen cars are exempted from purchase taxes, but not from annual taxes. Also for electric and hydrogen vans it is assumed that annual taxes will be charged from 2020 onwards.

In the scenarios with a high penetration of electric en hydrogen vehicles (scenario 2 and 4), it is assumed that from 2030 onwards the purchase tax of these vehicles will be equal to that of petrol cars/vans. The annual vehicle taxes in these scenarios are equal to those in the reference scenario.

For plug-in vehicles, the level of purchase taxes are assumed to be 50% of the conventional ones in all scenarios (because of the lower CO_2 values which are the basis for the purchase taxes). The annual taxes for these vehicles are assumed to be equal to those of conventional vehicles, in all scenarios.

Scenario independent input data

There are some fixed input parameters, which do not vary across the scenarios, but which are included in the model calculations. Because this input data influences the outcome of the model calculations each parameter is shortly described below.

Carbon content of energy carriers

The tank-to-wheel emissions per fuel are depicted in **Table 19**. These emissions are not likely to change over the years and therefore do not vary across the scenarios and years. According to the IPPC-definition, alternative energy carriers, like electricity, hydrogen and biofuels, do not result in any IPCC-TTW CO_2 emissions.

Table 19: IPCC-Tank-to-wheel CO_2 emissions per fuel type for all years (in gCO_2/MJ)

	IPCC-TTW (gCO2/MJ)		IPCC-TTW (gCO2/MJ)
Diesel	74.3	LNG	56.6
Gasoline	72.0	Electricity	0
LPG	66.7	Hydrogen	0
CNG	56.6	Biofuels	0

Tank-to-wheel and well-to-tank air polluting emissions

All emission factors related to air pollutants are fixed parameters. The tank-to-wheel emission factors per vehicle-fuel combination are taken from the Referentieraming. The well-to-tank emissions per fuel type are limited to the emission emitted in the Netherlands and only include emissions related to the fuel production. For the year 2050 the same development as for CO_2 emissions has been assumed.

Table 20: Well-to-tank air polluting emissions

	NO_x (g/MJ)		PM_{10} (g/MJ)	
Energy carrier	**2010**	**2050**	**2010**	**2050**
Gasoline	34.00	41.52	2.00	2.44
Diesel	34.00	39.62	2.00	2.33
LPG	34.00	39.50	2.00	2.32
CNG	34.00	39.49	2.00	2.32
LNG	34.00	39.49	2.00	2.32
Electricity	34.00	0.39	2.00	0.02
Hydrogen	34.00	0.61	2.00	0.04
Bio gasoline	34.00	8.50	2.00	0.50
Bio Diesel	34.00	13.60	2.00	0.80
CBG	34.00	13.60	2.00	0.00
LBG	34.00	13.60	2.00	0.00
BLPG	34.00	8.50	2.00	0.00

Valuation of emissions

The scenario outcomes of the model also include social costs as result of pollutant emissions. In **Table 21** the shadow prices used to valuate these social costs per

pollutant are presented. Both tank-to-wheel and well-to-tank emissions are included in the social cost calculation.

Table 21: Shadow prices used to valuate social costs of pollutant emissions 2010-2050 (source: Handboek Externe en infrastructuurkosten van Verkeer (not yet published))

Pollutant	Shadow price [in €/kg]
NO_x	10.56
PM2.5 (tailpipe emissions)	145.82
PM_{10} (brakes, tyres or refining and E-production)	65.51
CO_2	0.078

Costs

There are several other parameters, which are included in the cost calculations, but which are not varied across the scenarios. These parameters are:

- Annual vehicle costs, which are related to maintenance of vehicles
  For cars and vans, these costs have been included but not differentiated to energy technology. For the other vehicle types, these costs have been excluded.
- The charge level of the Eurovignette has been kept constant in all scenarios
- Vehicle lifetimes, average annual mileages have assumed to be constant in all scenarios (but are differentiated to vehicle type).
- A constant discount rate of 4% has been applied in all scenarios.

Appendix D. Safety assessment

Scenario 1 Biofuels and Efficiency: Solar-PV, (offshore) wind, biomass-to-energy

Relevant input and issues w.r.t. Safety:

- Solar and (offshore) wind will not present any external safety issues.
- Liquid biofuels are also not expected to introduce external safety issues. Their safety properties (like physical properties, explosive properties, dispersion behavior) do not -significantly- differ from fossil hydrocarbons. Especially the incidents with large effect areas, relevant for external safety, will be equal for bio-fuels and fossil fuels.
    - Attention has to be paid to possible 'new' safety aspects (more occupational safety, not external safety) for liquid biofuels as compared to fossil fuels: pathogenic compounds, corrosive (acidic) components, self- heating.
      <u>Pathogenic compounds</u>: biofuels (depending on type, production process, quality, storage time, …) have been known to sometimes contain Pathogenic compounds (e.g. "fungi") which may cause health problems for employees (occupational safety) as well as for clients using the fuel.
      <u>Corrosive ingredients</u>: some of the biofuels contain acidic components. This may require a higher quality steel for the tanks and related equipment to prevent corrosion or a more intensive inspection and maintenance program to early detect and correct corroded parts.
      <u>Decomposition / self heating:</u> before the biomass is transformed into a biofuel, large quantities of biomass can exhibit decomposition and self-heating, leading to fires. As long as this is recognized, solutions are available to prevent this. Since these large quantities will only be present at centralized production facilities for (liquid) biofuels, this is not seen as a widespread problem and might only affect external safety at these production locations, not for the rest of supply chain.
- Gaseous Biofuels like biomethane, -ethane and –propane will be used much more compared to the current situation, predominantly as pressurized biofuel. These fuels will be produced in large, centralized production facilities with a distribution network to provide fuel station with their supplies.
    - The pressurized biofuel has no special safety issues. Although some of the design specifications, standards and guidelines need further detailing or updating, most relevant standards and guidelines are present and the relevant knowledge and technology for updating is available. Combination of pressurized gas on a complete conventional fuel station has to be investigated due to possible domino effects.

- In case also liquefied biomethane might be used, it will introduce external safety issues like the safe design of the installations, the preferred fuel station locations and the way to supply these fuel stations. These external safety issues are the same as for fossil LNG and these issues are currently being addressed in the TKI-Gas JIP project on LNG safety and will most probably be solved before 2015.

Scenario 2 New and all renewable (diesel, hydrogen and electric)

Relevant input and issues w.r.t. Safety:

- Hydrogen will be the main issue for external safety in this scenario. Especially the 'design' of the overall small scale distribution network for hydrogen will determine the risks and the related safety distances.
    - In general it can be said that the safety distances around hydrogen fuel stations are likely to be less than for LPG and LNG but more than for gasoline and diesel.
    - The risk, safety distances and the areas exposed, will depend on the 'type' of the H_2 supply chain: e.g. H_2 (L) vs. H_2 (pressurized), supply vs local production, supply route and mode of transport (pipeline , truck, ship, ….);
    - The hydrogen supply chain in this scenario 2 will differ from the supply chain in scenario 4 because this scenario a large part of the hydrogen will be produced locally by electrolysis. In this case the transport of hydrogen will hardly be an issue. Also the locally stored amounts of hydrogen can be reduced since a more continuous production can be guaranteed as compared to (ir)regular delivery of a load from a hydrogen cargo truck.
    - Internal safety distances have to be determined for the various parts (storage vs. (un)loading location, production location etc). There is a lack of experience with relatively large quantities of Hydrogen (Liquid or pressurized) in publicly accessible areas and its operation by non-experts. This has to be arranged with robust technical and procedural safety barriers.
      The knowledge and expertise to do so is in principle available but has to be transferred to design criteria, practical guidelines, safety distances etc.
    - Optimal design of the various hydrogen installation parts w.r.t. operability, safety and costs has to be determined.
    - Possible domino effects of combined fuel stations with H_2, LNG, LPG, Gasoline, diesel etc.. Desirableness of hydrogen to be combined with other fuels, either within urban areas or outside has to be determined.
    - Dispersion behavior of (large) releases of liquid hydrogen is not well understood and good, validated modeling is missing
    - Safety issues in car-workshops, garages, car-parks due to venting.
    - Special attention for H_2 vehicles involved in accidents and for emergency response tactics.

- Electric vehicles have some 'small internal safety issues' (occupational safety + in case of accidents) but no external safety issues are foreseen.
    - Issues deal with behavior in fires, risk of shocks, behavior when immersed in water, ….. Knowledge about these risks seems to be available at the various parties but needs to be collected and translated into practical guidelines for maintenance and especially for emergency response services (currently in progress, under the auspices of Agentschap NL).

Scenario 3 Efficient fossil fuel (fossil, NG, partly electric and partly biofuels)

Relevant input and issues w.r.t. Safety:

- NG (as a fossil fuel) will be increasingly used compared to the current situation. Partly as pressurized NG and partly as LNG.
    - The LNG part will be associated with external safety issues like the safe design of the LNG installations, the preferred fuel station locations and the way to supply these fuel stations. These issues are currently being addressed in the TKI-Gas JIP project on LNG safety and will most probably be solved within the coming 1-2 years.
    - The pressurized NG has hardly any additional safety issues. Although some specific design specifications, standards and guidelines still need detailing or finalization. However all relevant knowledge and expertise to do is available.
- Electric, no significant safety issues (see also scenario 2)
- Biomethane as a biofuel:
    - In this scenario it is likely that there will be many local, small scale production facilities of biogas. This may results in local, occupational safety issues due to insufficient focus, knowledge and expertise of process equipment, proper operations, maintenance, incident preparation and all the related safety issues.
    - There may be a safety issue in combining all these small biogas flows –with varying qualities- into one central distribution network.

Scenario 4 Efficient fossil fuel (fossil, electric and hydrogen)

- Hydrogen will be the main issue in this scenario (see also scenario 2). Especially the 'design' of the overall small scale distribution network for hydrogen will determine the risks and the related safety distances, important for external safety.
    - The same issues as in scenario 2 will apply.
        - The difference with scenario 2 is however that in scenario 4 the hydrogen production will be more centralized, from fossil fuels. This results in relatively large installations for hydrogen production and a significant transport of hydrogen from these production to the fuel stations. In the first, safety is covered in the generic BRZO / BEVI legislation and regulations. Apart from local safety issues, no real problems are expected.

For the transport a safety issue cannot be excluded. The amount of transport, the routes and the specific risks of a single hydrogen transport are not yet clear. If the hydrogen transport volumes will fit within the safety ceilings for the 'basisnet weg' is hard to determine at this moment.

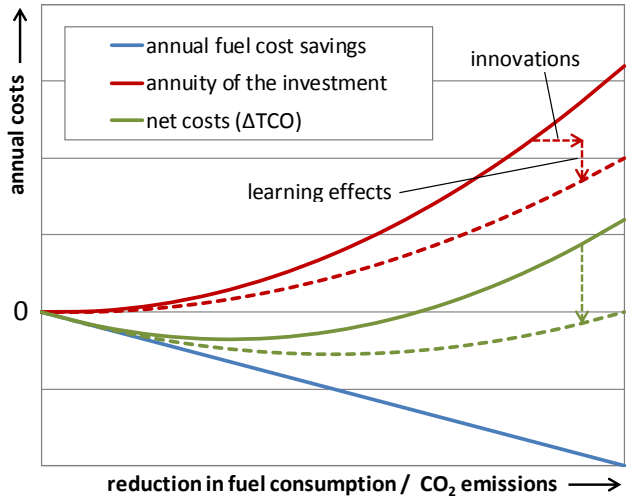
Appendix E. Green growth

Introduction

"Green growth" is an important concept in the motivation of the SER agreement on energy. As a consequence it should be an important guiding principle for the choices to be made in the vision for the Netherlands on the mix of energy carriers that will be best suited for meeting the targets with respect to sustainability and other criteria, taking account of boundary conditions for the Dutch situation.

The notion of green growth strongly relates to the "Porter hypothesis" which states that strict environmental policies provide incentives that lead to process optimisation and a more efficient use of production means. In the economic literature, however, this hypothesis is often claimed to lack empirical proof. Green growth has more recently gained popularity by a study commissioned in 2011 by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. In [Jaeger et al. 2011] economic modelling is used to show that measures that can be implemented to meet the European Commission's climate goals for 2020 lead to growth of both GDP and the number of jobs in Europe. Using a similar modelling approach Cambridge Econometrics and Ricardo-AEA have recently estimated that the proposed European CO_2 regulation for passenger cars and vans for 2015-2020 leads to economic growth and more jobs in Europe [CE 2013a & b]. The results of both studies, however, cannot straightforwardly be generalised to a notion that meeting longer term CO_2 reduction goals would not need to go at the expense of economic growth or could even generate additional growth. Many measures available for meeting targets in 2020 can be considered "low hanging fruit" and deliver high reductions (and associated energy cost savings) at relatively low investment costs. Payback periods are often shorter than the lifetime of the measures. Marginal abatement costs for reducing CO_2 emissions, however, have a tendency to increase non-linearly with increasing levels of CO_2 emission reduction, so that beyond a certain level of CO_2 reduction the net impact on costs (from a user and/or societal perspective) will be an increase compared to the reference situation. Below that point simultaneous reduction of costs and emissions is possible. This is illustrated in **Figure 34**. Obviously cost curves are not static and also develop over time. Costs of technologies generally decrease due to learning effects (economies of scale and innovations in product and production processes), while technological improvements and new innovations may increase the available CO_2 reduction potential. As a consequence the CO_2 reduction potential that is available at net negative or zero costs increases over time. This development, however, is very uncertain.

Figure 34: Illustration of how additional investment costs for reduction of CO_2 emissions and the associated reduction in fuel costs lead to net costs for CO_2 reduction which may be negative for lower levels of reduction. Over time the CO_2 reduction potential that is available at net negative or zero costs increases

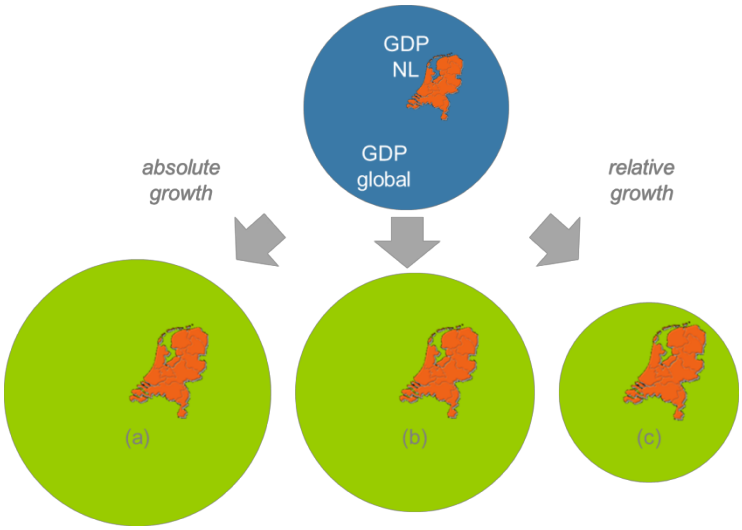


Recently also some studies have been published on green growth in the Netherlands ([PBL 2012], [PBL 2013], [CE Delft 2013], [CPB 2013]). These publications have a rather exploratory nature and pay limited or no attention to the transport sector. In [CE Delft 2013] a first monitoring effort is made of how developments in the field of electric transport in the Netherlands have affected certain green growth indicators. Compared to other assessed sectors the reported effects on these indicators are fairly small. [PBL 2013] identifies bio-based economy, sustainable built environment and the circular economy as the most promising sectors for green growth in the Netherlands. Biofuels could be considered an aspect of the first sector, although using biomass for fuel production is a relatively low value application of biomass. Sustainable transport can be considered an ingredient of a sustainable built environment but the study does not explicitly identify transport as a sector with green growth potential. In a comparison of sectors the production of transport means is considered in [PBL 2013] to score weak on level of specialisation as well as on export position. On green innovation, however, this sector is given an above average score. Both [PBL 2013] and [CE Delft 2013] offer some elements of a methodological framework that could be used to further explore green growth potentials associated with the energy mix for transport, but the proposed indicators do not directly relate to inputs or outputs that are used in this scenario study.

It should be noted, however, that the concept of green growth is not yet well defined. In a very wide and more or less macro-economic interpretation green growth is about the absolute decoupling of economic growth from environmental impacts and depletion of scarce resources [CPB 2012]. If GDP grows while at the same time the overall impacts on environment are reduced, this growth can be considered green. In a narrower, more micro-economic interpretation, green growth is about earning money with the greening up of economic activities. For both interpretations an important question is whether sustainable alternatives for existing techniques or activities generate added value in the sense that they make new products and services possible, improve the quality of existing products and services or reduce the costs of existing products and services. If that is the case then implementing these sustainable

alternatives will contribute to overall economic growth, in principle at a global level. The extent to which different parties (actors, countries, regions) profit from this growth obviously depends on how the value chain for these products and services is organised. This case is illustrated by example (a) in **Figure 35**.

Figure 35: Illustration of possible impacts on the Dutch economy of implementing vehicles running on alternative energy carriers

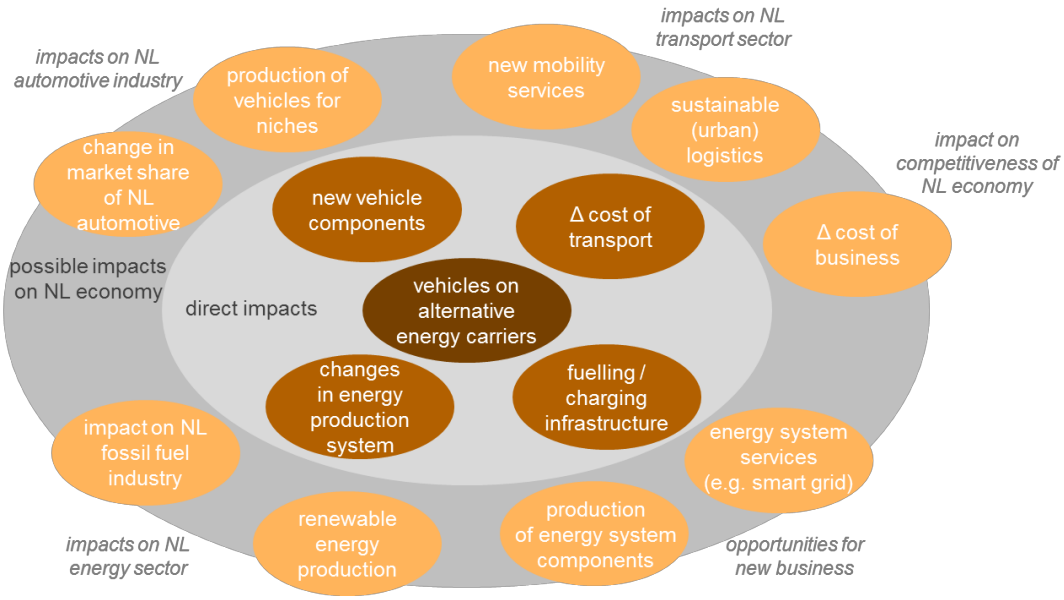


If sustainable alternatives do not lead to added value or reduced costs, then implementation of these alternatives makes existing economic activities more expensive or less efficient and therefore does go at the expense of overall economic growth. Economic growth at a regional / national level, however, is still possible in this case if a region / country has more than average success in selling sustainable products or services to other regions / countries which need these sustainable products or services to meet their environmental targets. This case is illustrated by examples (b) and (c) in **Figure 35**. If reaching long-term climate goals would lead to reduced economic growth at a global scale (case (b)) or even to economic decline (case (c)), then still the Dutch economy could grow if it is successful in exporting sustainable products and services. Choices made with respect to the energy mix for transport in the Netherlands determine the extent to which Dutch companies can develop new products and services, bring these to a level of technical and economic maturity on the Dutch market, and subsequently export these products and services outside of the Netherlands. Applied to the case of the future mix of energy carriers for the Dutch transport sector the above means that the green growth potential of various energy carriers at least depends on the extent to which their introduction:

- contributes to improvement of relevant environmental indicators, including greenhouse gas emissions, air quality and noise, assessed at a TTW, WTW or complete life-cycle level;
- reduces or increases the costs of transport, taking account of changes in the costs of vehicles as well as of the transport and energy infrastructure;
- offers opportunities for Dutch companies to develop new products and services and/or improve their international competitiveness.

The net effect on the Dutch economy of changes in the mix of energy carriers for transport is determined by a complex set of direct and indirect impacts as illustrated in **Figure 36**.

Figure 36: Illustration of possible impacts on the Dutch economy of implementing vehicles running on alternative energy carriers



A detailed assessment of the mechanisms through which a future energy mix for transport may contribute to economic growth in the Netherlands, let alone a quantification of the net effects, is beyond the scope of the scenario exercise. This is not only due to a lack of suitable assessment tools available, but mostly caused by the fact that the scenario exercise does not generate information at the level of detail and certainty that would be required to carry out such an assessment.
For that reason the green growth potential of the four scenarios developed in this report will be assessed in a more indicative way. A very preliminary attempt at a quantitative comparison of the scenarios can be based on results from the modelling tool with respect to CO_2 emissions and costs. A qualitative assessment is made by identifying how the energy carriers and associated technologies featured in the four scenarios might potentially generate opportunities for the Dutch industry and knowledge infrastructure to develop new products and services and strengthen their international competitive position. In this study potentially interesting technologies for the Netherlands are identified based on expert judgement. It is recommended to carry out a more detailed assessment of which companies and knowledge institutes have the knowledge and competences that would allow these potential green growth opportunities to be further developed and exploited.

Appendix F. Transport mode TCOs

Figure 37: TCO for passenger cars in million €/year

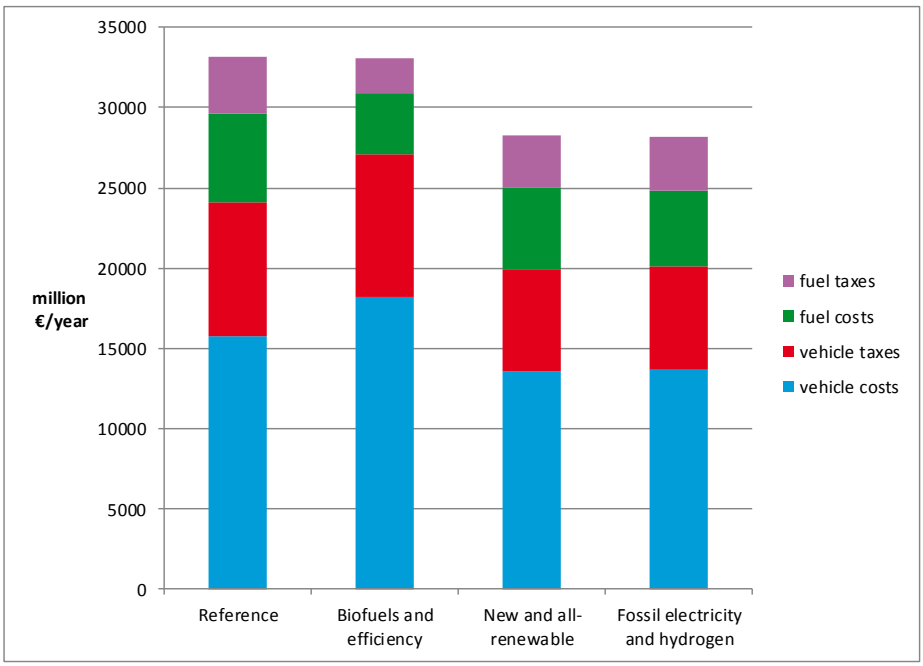


Figure 38: **TCO for vans in million €/year**

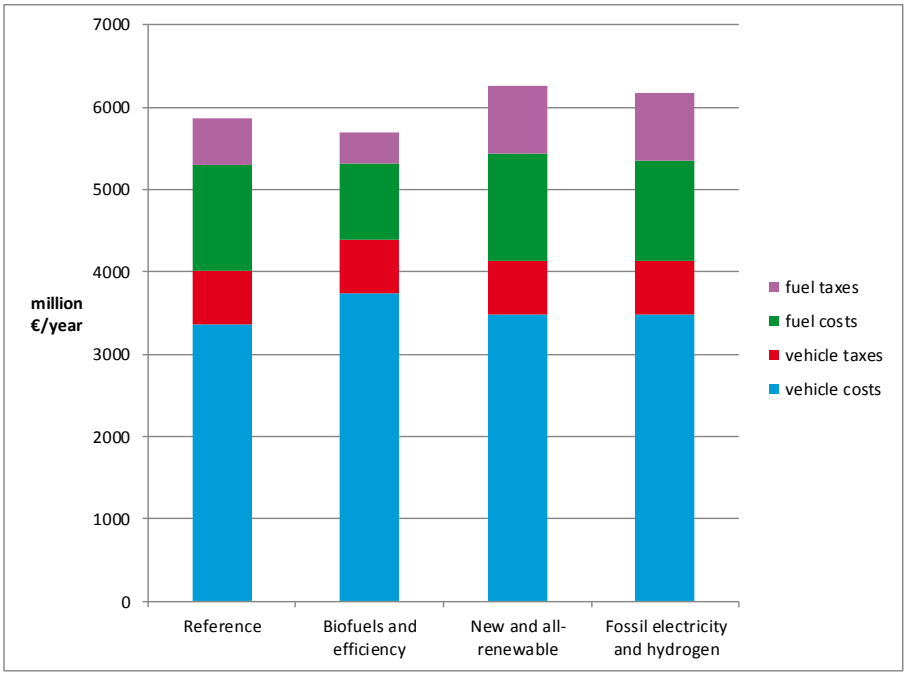


Figure 39: **TCO for trucks in million €/year**

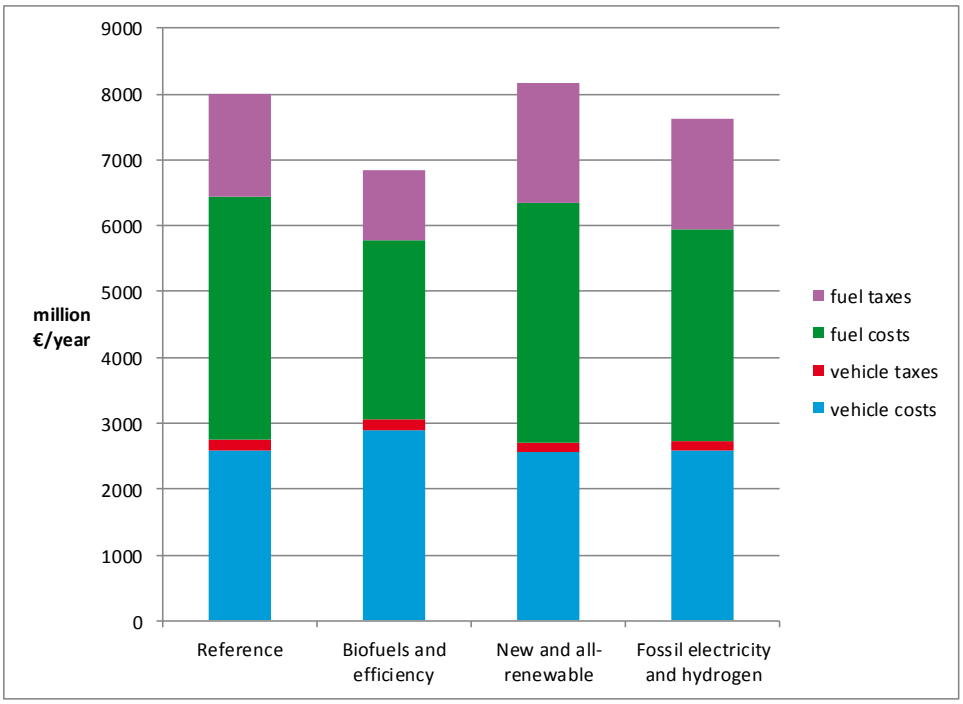
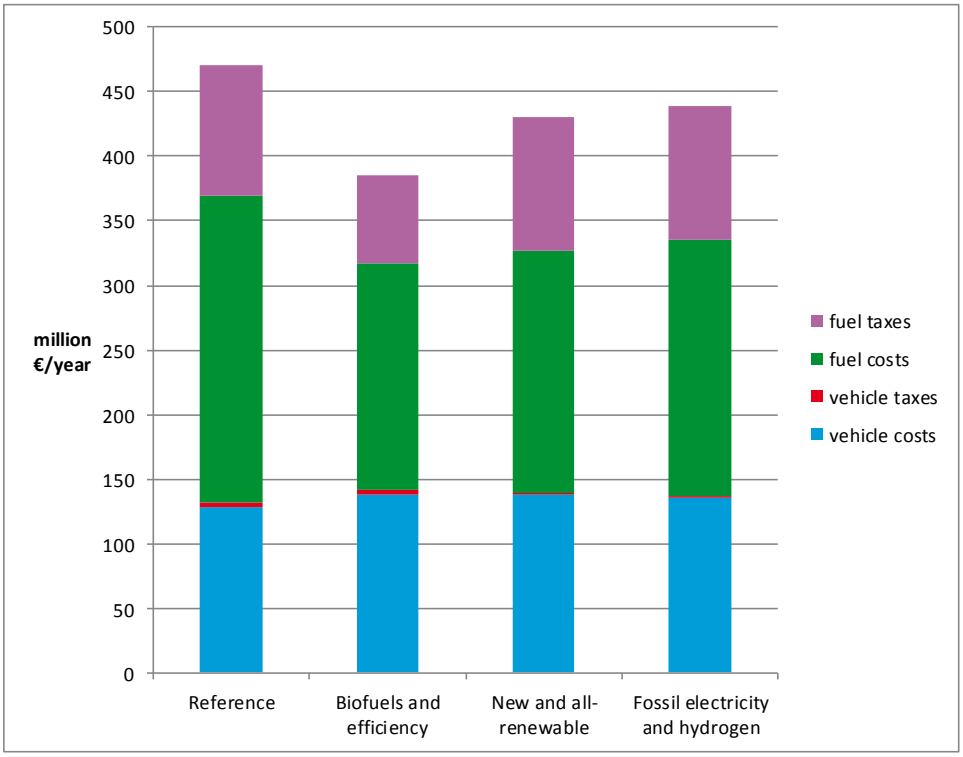


Figure 40: **TCO for buses in million €/year**



Appendix G. Comparison with strategies of other countries

National strategies and developments on energy and transport fuels cannot be isolated from the international context. Energy trends worldwide, the energy strategy of neighboring countries and development of new transport solution will directly influence the energy and fuels situation in the Netherlands. For this reason, this paragraph will give a brief overview of the vision and strategies of leading countries worldwide and of neighboring countries in Europe, whenever available. The most important aspects of these visions and strategies in relation to the Dutch situation on energy and transport will be identified and incorporated in the scenario definition and analyses of the scenario impact.

In 2013, a mobility and fuels strategy of the *German government* was released by the Federal Ministry of Transport, Building and Urban development [REF]. The main focus is on a strategic understanding between government, industry and academia on the medium and long term prospects for fossil fuels and fuels based on renewable sources of energy and on promising drivetrain technologies and supply infrastructures. Besides the close link with the German economy, this strategy is especially interesting from the Dutch perspective, because of the German decision to move away from nuclear and fossil based energy sources in relation to the important position of the automotive industry. For that reason, the strategy emphasizes the condition for the automotive and petroleum industry, enabling them to change to more environmentally friendly forms of transport, whilst allowing them to maintain and increase their competitiveness in global markets. Particularly mentioned here are the areas of electromobility, hydrogen technology, LNG for shipping and alternative fuels for aviation. The German government will organize the transition to sustainable mobility so that the competitiveness of the German economy is preserved and strengthened. The German government does not use sector-specific targets for the reduction of greenhouse gas emissions: at least 80% in 2050 compared to 1990, for all sectors. Renewable energy should account for 60% of gross final energy consumption by 2050 across all sectors. According to the strategy, the greatest potential for CO_2 savings are probably to be found in passenger car and rail transport by the increased use of electricity and hydrogen using battery and fuel cell technology. For commercial vehicles, the further development of conventional vehicles is emphasized. For the longer term, options are recognized to take over more revolutionary technologies developed for passenger cars through electrification. The extension of the fuel base for trucks from diesel to gas should be systematically addressed as a new pillar. Dual fuel (diesel/gas) vehicles are specifically mentioned as a means to diversify the energy supply. For shipping, the combustion engine will remain dominant and particular attention has to be paid on a

further reduction of emission. Especially mentioned here is the role of LNG in shipping, including inland shipping. No profound changes in the energy sources for transport are expected until at least 2020. In view of the significant share of renewable energy in the German energy system, gas and renewable methane as a storage medium are becoming more important. Furthermore, it is recognized that the raw material base for biomethane is broader than for other biogenic fuels. The use of biomass for energy or fuels should primarily be dictated by the potential for future climate protection efficiency and the availability of other alternatives for climate protection. A state determined allocation of biofuels to particular modes of transport is not regarded as a viable solution at this moment. Looking at the strategies of the important German passenger car industry, significant differences can be observed. All manufacturers invest in electric vehicle technology, but BMW puts electric mobility central in their sustainable future mobility vision. In contrast, Daimler together with Air Liquide, Linde, OMV, Shell and Total announced an action plan to expand the hydrogen refueling stations to 400 by the year 2023. The objective is to offer a hydrogen refueling station at least every 90 km of motorway between densely populated areas. The link with renewable energy storage and buffering in combination with the use of CO_2 for the production of renewable fuels compatible with conventional powertrains (power-to-gas, power-to-fuel) is one of the focus points of Audi.

The *United States* are steadily moving from an energy importer towards meeting all of its energy needs from domestic resources by 2035. The U.S. Department of Energy sponsored a multi-agency project to identify underexplored strategies for abating greenhouse gases and reducing petroleum dependence related to transportation. In one of the studies in this project, it was examined how expansion of the low-carbon transportation fuel infrastructure could contribute to deep reduction in petroleum use and greenhouse gas emissions across the U.S. transportation sector [REF]. For this, three low-carbon scenarios were developed: Portfolio (successful deployment of a variety of advanced vehicle and fuel technologies), Combustion (market dominance by more efficient end-use technologies that are fueled by advanced biofuels and natural gas and Electrification (market dominance by electric-drive vehicles in the light-duty vehicle sector, fueled by low-carbon electricity and hydrogen). Clear similarities with the scenario's for the Dutch situation can be observed. The basis of the scenario build-up are transport demand reductions and efficiency improvements. Demand reductions account for 10% of the total greenhouse gas reduction target of 80% by 2050 (compared to 2005), efficiency improvements for approx. 55%. The scenarios are distinct from each other with respect to the use of low carbon fuels, accounting for 35%. In the scenarios, conventional gasoline is nearly completely displaced and the use of conventional diesel is reduced dramatically. Each scenario involves significant volumes of infrastructure-compatible biofuels for the diesel, jet and gasoline fuel markets. The scenarios show variation in the use of electricity, hydrogen and natural gas. One of the overall conclusions of the Transportation Energy Futures [REF] is that vehicle efficiency improvements are essential to balance increases in travel and freight demand. Furthermore, advanced vehicles have the potential to dominate the US light-duty vehicle market by 2050, such as FCV, BEV, PHEV. However, (uncertain) non-cost barriers must be overcome to reach this domination. Advanced biofuels can displace significant volumes of petroleum in future fuel markets, ranging from 10% for bunker fuels up to 55% for jet fuels in 2050. The overall conclusion is that deep reduction in

transportation energy use are technically possible by 2050, as are deep reduction in transportation greenhouse gas emissions.

The strategy of *Japan* related to energy use by the transportation sector is closely related to the national energy perspective. The vulnerability of the power generation system due to the nuclear crisis, the potential strategy to move away from nuclear energy and the need to import primary energy sources (e.g. LNG) have impact on the future transport strategy. Japanese passenger car OEM's focus on electrification of their products. Besides hybrid and battery-electric technology, Japanese (and Korean) OEM's play a significant role in the development of fuel-cell technology.

China sees the biggest absolute increase in power generation from renewable sources, more than the increase in the EU, US and Japan combined (IEA, 2013). Furthermore, China now uses as much coal as the rest of the world combined. Both trends are closely linked to the strategy to improve the air quality in the big cities by the electrification of transport, illustrated by the fact that the major battery manufacturers are located in China. Especially mentioned here is the strategy to use methanol as a clean transportation fuel, to be produced from feedstock such as natural gas, biomass and especially coal, as China owns approx. 5% of the global coal reserves.

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