PBL Netherlands Environmental Assessment Agency

The worldwide context of **China's Green Transition** to 2050

Policy Study

The worldwide context of China's Green Transition to 2050

The worldwide context of China's Green Transition to 2050

In collaboration with Utrecht University

PBL Netherlands Environmental Assessment Agency

Utrecht University

CCICED

This report was compiled in support of the China Council for International Collaboration on Environment and Development (CCICED). It does not necessarily reflect the views of the CCICED.

The worldwide context of China's Green Transition to 2050

The Hague, 2017
PBL publication number: 2982
Revised second print

Corresponding author
jan.bakkes@pbl.nl

Authors
Jan Bakkes (PBL), Harmen Sytze de Boer, Oreane Y. Edelenbosch[a] and Detlef P. van Vuuren (Utrecht University and PBL)
Contributor: Stefan van der Esch (PBL)

[a] Current affiliation: Politecnico di Milano; oreane.edelenbosch@polimi.it

Supervisors
Jacqueline Timmerhuis and Pieter Boot

Acknowledgements
The analytical work for this report was supported by the Ministry of Infrastructure and the Environment. The International Support Office of the China Council for International Collaboration on Environment and Development (CCICED) facilitated our interaction with the other members of the Task Force on China's Green Transition Outlook to 2050. Our colleagues of the Development Research Centre of the State Council of China made their projections and comments available at an early stage. PIB (Partners in Business) of Clean Coal China kindly shared their insights (contact: zhang@ecn.nl). All these forms of support and input are gratefully acknowledged.

Comments and suggestions on drafts of this report were received from Pieter Boot, Michel den Elzen and Jonathan Doelman, all of PBL, and from Knut Alfsen, International Chief Advisor's Group to CCICED, and are greatly appreciated.

Graphics
PBL Beeldredactie

Layout
Xerox/OBT, The Hague

Production coordination
PBL Publishers

Chinese translations: Peishen WANG
PIB Clean Coal contact information: Dr. Y. Zhang, Consultant Technology Transfer, Business Developer, Energy research Centre of the Netherlands (ECN); PO Box 1, NL - 1755 ZG Petten, The Netherlands; Adjunct Professor, Shanghai Jiao Tong University; T: +31 (0) 224564045; F: +31 (0) 224568214; M (NL): +31 (0)610147741; M (CN): +86 15021957567; E-mail : zhang@ecn.nl 张烨 博士；科学研究员,商务拓展专员；荷兰能源研究中心 , ECN; 太阳能; PO Box 1, 1755 ZG Petten, The Netherlands; 电话：+31 (0) 224 - 56 40 45; 传真：+31 (0) 224 - 56 82 14; 手机 (NL): +31 (0)6 10147741 手机 (CN): +86 15021957567 E-mail : zhang@ecn.nl

PBL Netherlands Environmental Assessment Agency is the national institute for strategic policy analysis in the fields of the environment, nature and spatial planning. We contribute to improving the quality of political and administrative decision-making by conducting outlook studies, analyses and evaluations in which an integrated approach is considered paramount. Policy relevance is the prime concern in all of our studies. We conduct solicited and unsolicited research that is both independent and scientifically sound.

Contents

MAIN FINDINGS

Summary and reflections

Box 1: Questions posed by the CCICED Task Force on China's Green Transition to 2050 in relation to its worldwide context

Q1. **How necessary**, from an environmental resources point of view, is a green transition of China's economy?

Q2. Assuming a green transition of China's economy between now and 2050, what would be **its contribution to achieving global targets** of sustainable development?

Q3. Would the transition as envisaged **be sufficient** to remain within planetary boundaries?

Q4. What type of worldwide or regional potential **constraints and synergies** can be identified? Consider, for example, dynamics elsewhere in Asia or China's increasing presence worldwide.

Q5. What are important **issues for follow-up work**?

I Introduction

This report supports China's Green Transition Outlook to 2050 [CCICED – in prep] and aims to kick-start an assessment of the worldwide context of China's green transition. The current section of our report summarises our findings and reflects on them in the light of additional material.

The assessment was developed in parallel to the main work on the subject, which is being carried out by a task force of the China Council for International Collaboration on Environment and Development (CCICED). The central claim of the task force is that a new economic development model is emerging in China, requiring significant policy changes. The CCICED report views these emerging developments through an economic 'lens', mindful of connections in terms of environment, resources and China's social development. It considers six complex areas of change: manufacturing, agriculture, services, urbanisation, rural development, and resources and the environment, and focuses on the question what should be achieved by the pivot year of 2030 and how.

The CCICED Task Force addresses five policy agenda items, namely establishing the new norm, promotion policies for green industries, incentive mechanisms and regional pilot projects, building the digital green economy, and building an inclusive society and resilient economy, including groups and areas that are impacted by the green transition.

Focus

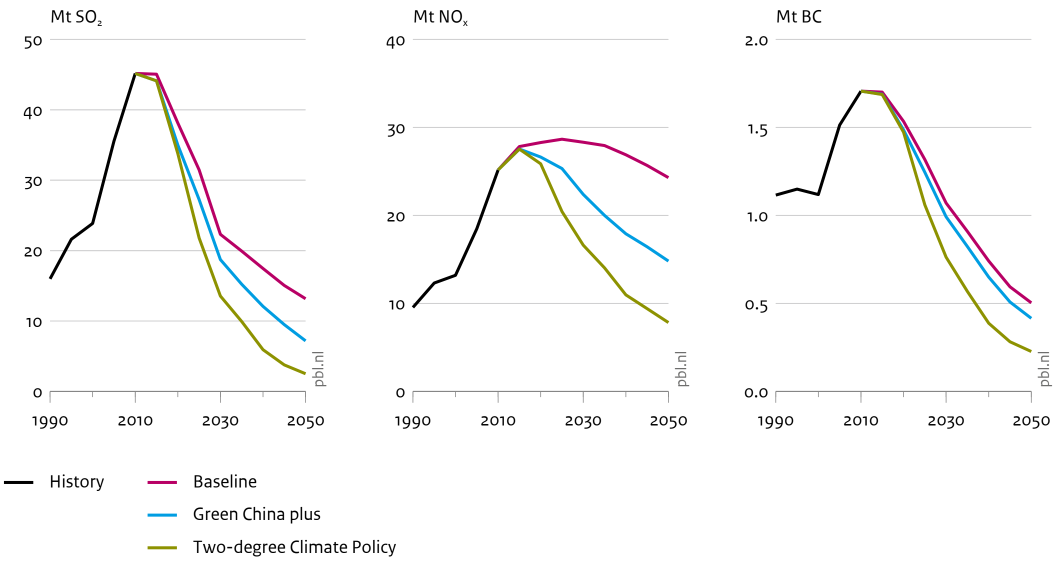
Our assessment of the worldwide context addresses five general questions posed by the CCICED Task Force (see Box 1). For our model-based analysis of issues relating to energy, climate and air pollution, these are operationalized as follows:

- How do the domestic projections developed by the Chinese partners in the CCICED Task Force **compare to recent projections by international teams**?
- Assuming a green transition of China's economy between now and 2050, what would be **its contribution to achieving global climate policy targets**?
- On climate change mitigation, would the result of the transition as envisaged be sufficient?

In addition, with regard to **land resource** issues, the results from a comparable scenario study for the Global Land Outlook were selected in as far as they relate to the questions posed by the CCICED Task Force.

Taking a global perspective also enabled us to highlight what seemed to be a number of **key conditions** that Chinese policy would have to meet in order for its envisaged transition to be successful.

Figure 1
Air polluting emissions in China region



Source: PBL

Finally, we listed important **topics that warrant more in-depth analysis**.

Method

This report draws on:

- the interim report of the CCICED Task Force on China's Green Transition Outlook (CCICED, 2016);
- model-based scenario analysis, carried out specifically for this project at Utrecht University on the basis of the Shared Socio-economic Pathways (SSPs);
- additional relevant PBL work containing worldwide analyses, in particular the scenario analysis for the first Global Land Outlook (United Nations Convention to Combat Desertification, 2017; Van der Esch et al., 2017).

The current report is **no more than a kick-start** for the assessment of the worldwide context of China's green transition, and reflects the limited time and budget. For example, water issues have not been addressed at all and no second opinion from Chinese knowledge organisations was obtained.

Robustness and limitations of our model-based findings

We did not explicitly test the robustness of our conclusions. However, we are confident that they appropriately provide a first impression of the worldwide context of China's green transition as depicted by the CCICED Task Force. Limitations apply, of course; most importantly:

- This report is only the result of a preliminary (kick-start) project, not a full assessment. For example, fresh water availability was not considered and no peer review by Chinese knowledge organisations was carried out.
- Our assessment focuses on China's role in a worldwide context. It therefore models the China region as a whole, disregarding its internal heterogeneity in terms of environment, pressure factors and opportunities.

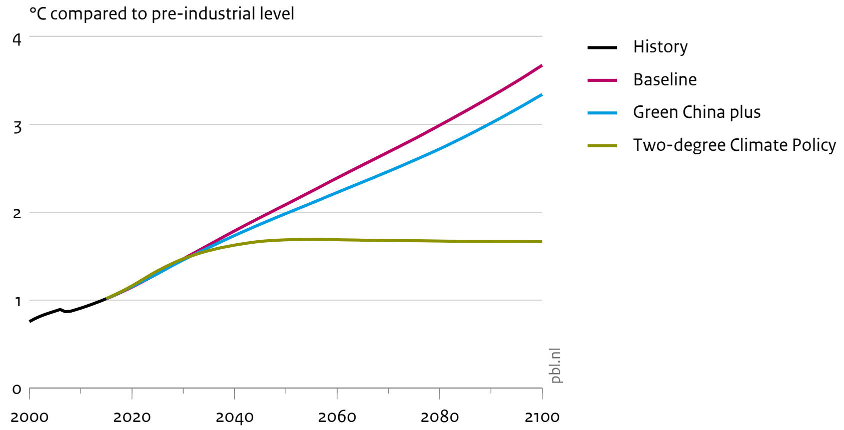
II Summary of results of the model-based analysis

Our main analytical results are as follows. Their numbering (Q1, Q2, etc.) refers to the questions posed by the CCICED Task Force (see Box 1).

In response to Q1 and Q4: **China's Green Transition Pathway reduces the increase in emissions of important air pollutants towards 2030 and decreases them further towards 2050.** Sulphur dioxide (SO_2), nitrogen oxides (NO_x) and black carbon (BC) are major contributors to urban air pollution. Under baseline conditions, reductions in emissions of sulphur dioxide and black carbon are expected towards 2050.

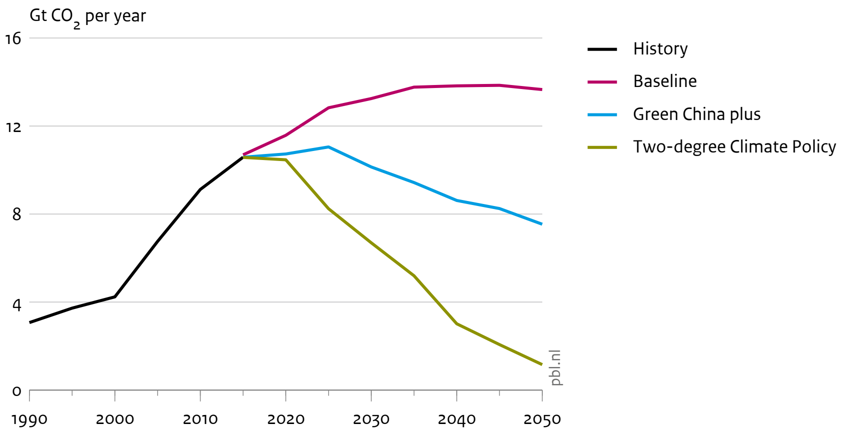
The introduction of China's Green Transition Pathway can further reduce these emissions by 45% (SO_2), 39% (NO_x)

Figure 2
Change in global mean temperature



Source: PBL

Figure 3
Carbon dioxide emissions in China region



Source: PBL

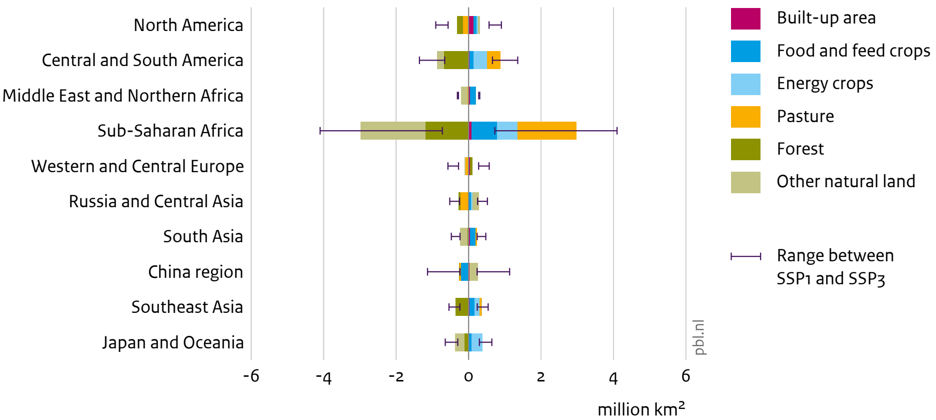
and 17% (BC) compared to baseline projections by 2050 (see Figure 1). Figures 1, 2 and 3 show results of worldwide scenarios. Of these, Green China plus comprises China's Green Transition Pathway. A full description of how China's green transition has been incorporated is provided in Section 2.1, with further details in Appendix 2.

Further reductions are achieved if additional climate policy is introduced to achieve a 2 °C climate target. More precisely, these ancillary results of additional climate policy would improve emission reductions to 81% (SO_2), 68% (NO_x) and 55% (BC), compared to baseline projections by 2050.

In response to Q2: **A green transition would help achieve environmental goals in China and globally**, assuming that current and planned policies elsewhere will be implemented, as well. This can be illustrated by comparing baseline and policy projections from our scenario analysis regarding climate change (see Figure 2).

Elements of China's green transition that influence demand for land may not bring huge changes by 2050. They are nevertheless significant because there is not much more suitable land available in China. Such elements of the green transition include agricultural productivity, the proportion of meat in the human diet, bioenergy production and, locally, urbanisation.

Figure 4
Land-use change per region, under SSP2, 2010 – 2050



Source: PBL

In response to Q3: **International current and planned global policies and China's Green Transition Pathway are insufficient to achieve a 2 °C climate target.** The implementation of China's Green Transition Pathway reduces China's share in global emissions of carbon dioxide and in energy use. It features less emissions of carbon dioxide than currently foreseen in most international baseline scenarios. However, it is not sufficient to get on the emission pathway of a cost-optimal implementation that keeps the global average temperature increase well below 2 °C relative to pre-industrial levels, as agreed in the Paris Agreement.

Therefore, additional mitigation efforts will be required to further reduce greenhouse gas emissions and to achieve a 2 °C warming target. Roughly speaking, compared to current and planned global policies and China's Green Transition Pathway, a doubling of carbon dioxide mitigation is required until 2050 in order to achieve a 2 °C warming target (see Figure 3).

III Reflections

In response to Q4: **Opportunities for China's green transition to contribute in a significant way** to the worldwide management of land resources appear in the findings of the scenario exercise. Projected land-use changes in sub-Saharan Africa towards 2050 dwarf those in other world regions (see Figure 4). China's large investments in the region represent leverage in helping African agriculture and agricultural land management to cope with their challenges – assuming China and Chinese investors do indeed have good land management practices to export over the coming decades.

In terms of **constraints and synergies** of China's green transition to 2050, three issues are obvious from our global vantage point.
- First, the current dynamic period in China's development **provides a finite opportunity** for transition. In particular, infrastructure investments are likely to remain, in the long term. This applies, for example, to the power distribution grid, urban planning and education systems. The amount of time required to get these systems in order and up to scale is significant.
- Second, a remarkable **risk in the region appears** when the scenario outcomes for the Global Land Outlook are viewed together (UNCCD, 2017; Van der Esch, 2017, pp. 86–87). While China is assessed as a region with relatively few land-related challenges up to 2050, neighbouring South Asia ranks as facing the most difficult challenges (South Asia comprises India, Pakistan and Bangladesh).
- Third, **global and regional collaboration remain as important as ever**, especially with China in a new, more active role. For example, as an element of green transition, China's economy will abandon its role as the world's cheap mass production house. All other things being equal, other Asian economies will take over that role. Regional collaboration can help prevent, or mitigate, a potential continuation of the associated burden to the global environment. Or, considering climate change, it is obvious that only worldwide implementation of 2 °C climate policies would be sufficient to keep global climate change well below 2 °C.

Some **key conditions are apparent** for China's green transition to succeed. Our assessment of the worldwide context enables us to appreciate, by comparing it with internationally coordinated scenarios, the necessary scale and speed of the changes foreseen during China's green transition. The quantification of internationally coordinated scenarios is based on observed rates of change and interrelations in economies worldwide.

Key conditions include the following:
- Successful policies to steer the **supply side of China's production** away from its previous path and towards a development that is more like that of South Korea and Japan.
- Successful and innovative policies to steer the development of the increasingly important **service sector** in China, including its new business models, towards a development that is truly green in terms of energy use, waste and transport.
- Successful and timely policies guiding how **urban development and mobility** in the next decades will be organised, in particular in spatial terms.
- Fully instrumenting policies aimed at capping and eventually phasing out **fossil fuel** use well before 2050.
- A firm strategy and budget to avoid **the interim tool of 'clean coal'** locking China into a path of continued coal use at a time when this will be incompatible with agreed international goals. Any application of coal and derived fuels should be accompanied by carbon capture and storage (CCS).

Over and above such technical conditions, **social policies are obviously crucial** for the transition to succeed. See, for example, the *Study on China's Environmental Protection and Social Development. Executive Report of CCICED Task Force, November 2013* (CCICED, 2013). Such policies will be needed to ease the pain of transition for China's manufacturing industry, as will targeted policies for education. This is beyond the scope of the current report. A somewhat fuller discussion can be found in the executive report of the current task force, to be published in December 2017 (CCICED, in prep).

Further work

In response to Q5: Our work, kick-starting an assessment of the worldwide context of China's green transition, leads to a number of suggestions for important further work, as follows.

With a domestic focus on China's transition

A fuller version of the current scenario analysis, addressing a wider set of environment and resource issues. We recommend the following:
- Address, in particular, the implications of the transition and its envisaged new business models in terms of fresh water availability and use, air pollution exposure, landscape, agricultural nutrients and pesticides, and waste. Of course, this would be in addition to energy/climate issues and land-use changes.
- Be region-specific, possibly with a view to the regional pilot projects proposed in the task force report. Conditions for China's green transition as identified now can then be interpreted in more concrete terms.
- Involve Chinese expertise and/or review by Chinese knowledge organisations, in addition to any work by international organisations.

This would lay the basis for specific assessment tools to be subsequently deployed in order to help guide the transition. For example, this could include proper backcasting; that is, reasoning back from the 2050 vision and identifying the must-have accomplishments for 2030. Or, in the style of strategic environmental assessments, such assessment tools could include a framework of region-specific targets, enabling periodic monitoring and revision.

From an international perspective on China's transition

This could possibly be carried out in tandem with domestically focused follow-up work: short papers scrutinising each of the comments made here on regional risks and opportunities, such as:
- the prospect of multiple land/agriculture/water-related risks in the South Asia region, foreboding increasing pressure on environmental and socio-political systems outside, but neighbouring on, China (UNCCD, 2017; Van der Esch, 2017, pp. 86–87);
- Chinese opportunities to scale up green practices in sub-Saharan Africa during its fast changes in the coming decades.

中文稿摘要小结

限于时间和预算，目前的报告仅仅是中国绿色转型国际背景的初步探讨。例如，本报告没有论及水的问题，也未及征询其它中方智库机构的意见。

针对情景分析，我们比较了一个中间的基线情景和两个政策情景。其中一个政策情景包括了世界范围内现行和计划中的政策以及国合会课题组描述的中国绿色转型路径。我们称之为"绿色中国Plus"。另一个政策情景假定了实现2oC气候目标所采取的经济有效的行动，我们称之为"2oC气候政策"。

我们的分析结论如下：

中国绿色转型路径会在2030年前降低重要空气污染物排放的增长，之后到2050年间进一步减少排放总量。引入实现2oC目标的额外气候政策将实现进一步的减排。与基线情景相比，至2050年这些额外的气候政策将带来连带的污染减排效益，即二氧化硫减少81%，氮氧化物减少68%，黑炭减少55%。

绿色转型将有助于实现中国乃至全球的环境目标。但是，中国的绿色转型，加之国际上当前的和计划中的全球政策还不足以实现2oC气候温控目标。在基准情景以及"中国绿色Plus"情景中，气候温度水平一直在升高，即使是2050年之后亦是如此。因此，还需要采取额外的努力才能保证2oC目标的实现。粗略估计，与目前的中国绿色转型以及国际上当前的和计划中的全球政策相比，到2050年我们还需要两倍的努力才能实现2oC温控目标。

与此相对照，"2oC气候政策"将使全球气温与工业化之前相比上升接近2oC或者更少。在这种情况下，二氧化碳的排放轨迹与到2100年实现2oC目标的相比，概率达到66%。

在全球土地供应和土地退化问题上，中国2050绿色转型将面临一个日益充满挑战的世界。相对于周围的世界，到2050年中国预计的土地利用总体变化不会太大。但是，中国绿色转型中那些影响土地需求的要素十分重要，因为中国没有过多的土地适于耕作。这些要素包括农业生产力、肉类在饮食结构中的比例、生物能源生产，以及地方层面的城镇化。

此外，针对国合会中国2050绿色转型课题组提出的问题，我们提出一下一些思路：

就中国2050年绿色转型的制约因素和协同作用而言，从全球的高度来看，四个问题是显而易见的。

- 目前中国发展的动态时期为转型提供了有限的时机。重要的是，大规模转变重要的系统需要很长时间，而这些系统通常会存续数十年，即使在瞬息万变的中国。 例如配电网，城市布局和教育系统。
- 当"全球土地展望"的情景成果被一并看待时，结果显示出了一个显著的地区风险。虽然到2050年中国面对的与土地相关的风险相对较小，但是邻近的南亚地区却面临着重重困难。
- 全球和区域合作仍然是一如既往的重要，尤其是中国在全球日益活跃的角色。例如，作为绿色转型的一个重要部分，中国将摆脱世界大宗廉价产品工厂的角色。在所有其它条件相同的情况下，亚洲其它国家将承接这一角色。区域合作将有助于预防或减缓这种承接所带来的延续的全球环境负担。
- 情景分析显示中国绿色转型将会对世界范围内土地资源管理做出巨大贡献。中国在撒哈拉以南非洲地区的大量投资将有助于非洲农业和农用土地管理应对挑战——假设中国和中国投资者在未来几十年内确实能够输出良好的土地管理实践。

在我们的分析过程中，中国绿色转型取得成功的关键条件是显而易见的。这些条件可以概括如下：

- 成功的供给侧改革政策使发展摆脱过去的路径，走上一条更类似韩国和日本的道路；
- 成功的创新政策推动中国日益重要的服务业（包括新型生业模式）在能源使用、废物管理和运输方面走上一条真正绿色的发展道路。
- 指导未来几十年城市发展和人口流动的成功和及时的政策，特别是在空间布局方面。
- 全面实施旨在限制并在2050年以前逐步淘汰化石燃料的政策。
- 一个明确的战略和相应的预算，以避免"清洁煤炭"这个临时工具将中国锁定在继续使用煤炭的道路上。任何煤炭以及其衍生燃料的应用都应该附带上CCS。
- 除了上述技术条件之外，社会政策无疑是转型成功的关键。中国需要这样的政策来缓解制造业转型的痛苦，同时也需要有针对性的教育政策。这一点不在本报告的讨论之列。

最后，我们的报告建议针对目前的情景开展全面详尽的分析。建议：

- 分析绿色转型在水资源获取和利用、空气污染暴露、农业营养物和农药、废物管理等方面的影响，尤其是服务业转型及可预见的新型商业模式的影响。当然，能源、气候问题以及土地利用方面的影响分析也是必须的。
- 针对具体地区，可能的话在课题组报告中建议开展地方示范。这样可以针对目前识别的中国绿色转型条件进行具体阐释。
- 除了国际机构的参与，也吸纳中国的专家和智库组织参与研究或评审。

FULL RESULTS

ONE

Introduction

China is at an important crossroads. Over the past decades, China has been on an economically successful development trajectory spurred mostly by the growth of export-oriented, energy-intensive manufacturing industries. The limits of continuing such a strategy have now become visible. First of all, China's economy is very resource-intensive. China is currently the world's largest consumer of several resources, including energy (22% of the global primary energy supply in 2015; IEA, 2017), and many of these resources need to be imported. Second, the development pathway has led to serious environmental degradation, such as urban air pollution. Moreover, China is now the largest emitter worldwide of the greenhouse gas carbon dioxide, and therefore an important contributor to human-induced global warming (Olivier, Janssens-Maenhout, Muntean, and Peters, 2016). In turn, global warming can also be a serious threat to the further development of China, increasing drought and flood risks and threatening agricultural yields. Given this situation, questions have been raised regarding the viability of the historical development pathway and a major reorientation is expected in future years.

The Chinese government has realised that a new, more sustainable development pathway is needed. The recently released 13th five-year Energy Sector Plan (National Energy Administration, 2017) and five-year Environmental Protection Plan (State Council Information Office, 2017) contain ambitious energy and climate targets. From an economic point of view, China has entered a new stage, which is referred to by President Xi Jinping as the *new normal* (Green and Stern, 2015). With strategic urban and industrial policy plans and an increasing importance attached to the service sector, innovation and high tech development, this projected pathway associates with a more sustainable development to drive the country's economy (IEA, 2016a). Along that same line, China has gradually taken up more responsibility in international climate policy (ERI, 2016; IEA, 2016a).

Within the framework of the China Council for International Collaboration on Environment and Development, Chinese and international experts are looking at the possible impacts of a reorientation of development. This report contributes to this work by exploring the possible impacts of China's projected new trajectory in a global context. The reason for this is that environmental issues such as climate change are not bounded by national borders and are clearly global problems. An important question, therefore, is what a more sustainable development pathway for China implies for the world. And, vice versa, what do possible developments in the broader global system related to available resources such as energy and land imply for China?

In our model-based analysis of energy and climate, the following specific questions are addressed:

- How do the projections of China's Green Transition Pathway compare to the China development projections conventionally assumed in international model-based studies?
- How does China's Green Transition Pathway contribute to environmental issues, such as air pollution and climate change?
- To what extent does China's Green Transition Pathway enable China to achieve its climate targets?

The methodology is elaborated on in Chapter 2. Most importantly, this chapter introduces the scenarios that this report refers to. The results of our analysis are the subject of Chapters 3 and 4. First, in Chapter 3, China's Green Transition Pathway is compared to the baseline results of global model-based scenario exercises. This puts the ambitions of China's Green Transition Pathway in perspective, as well as highlighting key uncertainties. Then, in Chapter 4, China's Green Transition Pathway is analysed using the global integrated assessment framework IMAGE, focusing on its global implications. Chapter 5 addresses the uncertainty and robustness of our model-based analyses and Chapter 6 concludes with a discussion.

TWO

Methodology

Computational models, including macro-economic models and integrated assessment models (IAM), are tools that are widely used to develop long-term scenarios for the analysis of global environmental issues and sustainability challenges. Such models can provide insight into the interactions between human activity and natural systems over the coming decades. While originally these models focused mostly on climate change, more recently other environmental impacts such as air and water quality, water scarcity, the depletion of non-renewable resources and the overexploitation of renewable resources have also been addressed.

In this report, we use the integrated assessment model IMAGE (Integrated Model to Assess the Global Environment; Stehfest et al., 2014) to explore development patterns in China in relation to the rest of the world. The horizon year of the analysis is 2050. We compare the IMAGE results with projections developed by the Development Research Centre (DRC) of the State Council to ensure compliance with China's Green Transition Pathway (Chapter 4). We also compare China's Green Transition Pathway with the results of global scenarios (Chapter 3).

2.1 Scenario description

Several scenarios are presented in this study. They are used to answer the questions raised in Chapter 1. In all cases, a comparison is made with the scenario developed by DCR, referred to as China's Green Transition Pathway (CGTP). Table 2.1 presents an overview of the scenarios used in this study.

Comparison of international projections and China's Green Transition Pathway (Chapter 3)

In order to obtain a better understanding of China's Green Transition Pathway, it is compared with a broad range of international projections on key drivers, energy system indicators and emissions. As well as China's Green Transition Pathway, for which the Chinese domestic developments have been quantified by DRC (see Appendix 1 for more information), the three Shared Socio-economic Pathway (SSP) scenarios quantified by the IMAGE model are included, along with IEA's World Energy Outlook (WEO) scenarios.

SSP1, SSP2 and SSP3 are three of the Shared Socio-economic Pathways (SSPs) developed for multiple IAMs to improve the interdisciplinary analysis and assessment of climate change, its impacts, and the options societies have for mitigation and adaptation (O'Neill et al., 2017; van Vuuren et al., 2017). SSP2 is a middle-of-the-road scenario, while SSP1 is a pathway leading towards more global sustainable development. In contrast, SSP3 projects a fragmented world. Excerpts of the narratives of SSP 1, 2 and 3 can be found in the next section.

Because of the central role of energy projections in this study, the most recent baseline projection of the International Energy Agency (IEA) has also been included in this comparison. IEA's Current Policies scenario assumes no changes in policies, whereas the IEA New Policies scenario takes into account broad policy commitments and planned policies (IEA, 2016b).

China's development trajectory in a global context (Chapter 4)

Three global IMAGE scenarios have been analysed. Comparing the different scenarios enables us to evaluate the impact of China's green transition.

Table 2.1
Overview of scenarios included in this study

Chapter	Scenario	Origin	Description
Comparison of international projections and China’s Green Transition Pathway (Chapter 3)	SSP1 baseline	IMAGE	Pathways oriented towards a more sustainable development
	SSP2 baseline	IMAGE	Middle-of-the-road scenario
	SSP3 baseline	IMAGE	Fragmented world scenario
	WEO Current Policies	IEA World Energy Outlook 2016	Reference projections with no new policies
	WEO New Policies	IEA World Energy Outlook 2016	Reference projections with planned policies
	CGTP	DRC	China’s Green Transition Pathway
China’s development trajectory in a global context (Chapter 4)	SSP2 baseline	International research community + IMAGE	Middle-of-the-road scenario
	Green China plus	IMAGE, this report	China region: China’s Green Transition Pathway representation, expected economic development and demographic development as projected by the DRC + Worldwide: current and planned policies on climate change mitigation
	Two-degree Climate Policy	IMAGE, this report	Green China plus scenario assumptions *and* worldwide low-cost policies from 2020 onwards to ensure that the global mean temperature increase remains less than 2 °C relative to pre-industrial temperatures

The middle-of-the-road baseline scenario SSP2 forms the basis for all these scenarios. This baseline scenario features no new environment or resource policies but does account for autonomous developments based on current trends, for example in resource efficiency.

The two policy scenarios include assumptions based on China’s Green Transition Pathway. These scenarios depict policy-rich developments over the next decades while the economy becomes much more a service economy; that is, less focused on manufacturing and cheap exports, while urbanisation continues at an unprecedented pace and scale and the total population levels off by 2025. For more background on China’s Green Transition Pathway, see Appendix 1.

- The Green China plus scenario comprises in relation to China the energy transition pathway as described in China’s Green Transition Pathway. At the global scale, energy policies have been included based on Roelfsema et al. (submitted). Both currently implemented and planned climate policies in all countries are accounted for in this context; climate policies can vary from policy targets formulated in national policy documents (e.g. National Communication, strategy documents) to specified policy instruments (e.g. ETS, renewable portfolio standard). Emission reduction targets are enforced model-wise for some regions by applying a regional carbon tax.
- In the Two-degree Climate Policy scenario, worldwide additional climate policy is assumed in addition to the policies included in the Green China plus scenario through the introduction of a global carbon price. The carbon price is chosen so that global emissions of greenhouse gases are moderated sufficiently for anthropogenic radiative forcing levels to remain at 2.6 W/m^2 while minimising the total discounted climate policy costs induced by this carbon tax. This radiative forcing level corresponds to (a 66% probability of) keeping the increase in global mean temperature below 2°C relative to pre-industrial levels (Clarke et al., 2014; Krey et al., 2014). In the model, the carbon price induces a broad global shift to technologies with much lower greenhouse gas emissions and to the more efficient use of energy.

TWO

2.2 The global Shared Socio-economic Pathways SSP1, 2 and 3

The Shared Socioeconomic Pathways (SSPs) define five trajectories that human society could follow over the next century. They have been designed in the context of climate change research to show the range of worldwide challenges and opportunities. Over and above their original purpose, the SSPs constitute a widely used starting point for exploring other issues of worldwide significance in development and the environment. The SSPs consist of storylines and quantification, which is provided by six integrated assessment models, including the IMAGE model used in this research.

Among the SSPs, **SSP2 is regarded as a baseline scenario**. It follows median assumptions, as the middle-of-the-road pathway. Median projections do not necessarily imply an extrapolation of current trends, but can also result in a gradual deviation from past trends (O'Neill et al., 2017). An example is global total population, for which the SSP2 scenario sees stabilisation at around nine billion people by 2050. In SSP2, technology development is assumed to continue without breakthroughs, and agricultural systems continue to evolve steadily in line with FAO expectations.

O'Neill et al. write on SSP2: … '*Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Most economies are politically stable. Globally connected markets function imperfectly. Global and national institutions work toward but make slow progress in achieving sustainable development goals, including improved living conditions and access to education, safe water, and health care. …. Education investments are not high enough to accelerate the transition to low fertility rates on low-income countries and to rapidly slow population growth. This growth, along with income inequality that persists or improves only slowly, continuing social stratification, and limited social cohesion, maintain challenges to reducing vulnerability to societal and environmental changes and constrain significant advances in sustainable development*'. (O'Neill et al., 2017, p.173)

SSP2 population (KC and Lutz, 2017) and economic (Dellink, Chateau, Lanzi, and Magné, 2017) projections are input to the IMAGE model. The structural change in the economy is roughly equal to the continuation of current trends, and assumes a very gradual convergence among the world's economies in their annual rates of productivity increase, as elaborated for the OECD Environmental Outlook to 2050 (OECD, 2012).

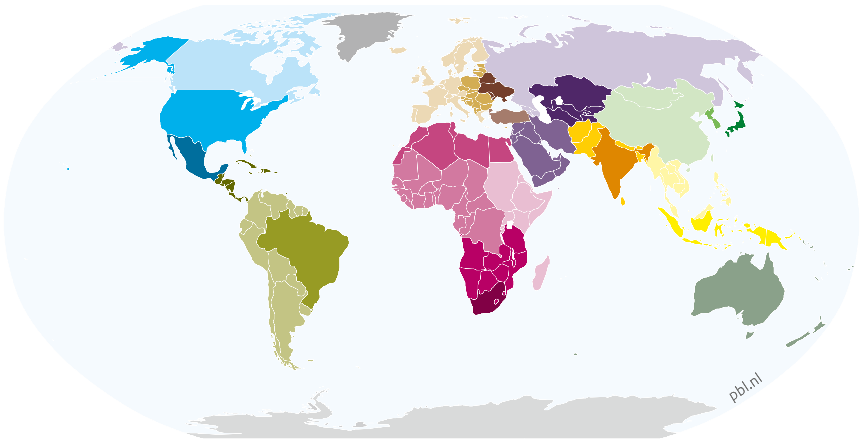
By contrast, **the SSP1 scenario depicts a more sustainable development path**, in accordance with its motto *Taking the green road*. In this relatively inclusive world, countries collaborate for a greener future. Technology development and policy incentives lead to a reduction in energy use and the increased attractiveness of renewable energy technologies. The scenario is characterised by small population growth and large economic growth. On balance, all developments lead to climate change mitigation being less of a challenge.

O'Neill et al. write on SSP1: '*…Increasing evidence of and accounting for the social, cultural and economic costs of environmental degradation and inequality drive this shift. Management of the global commons slowly improves, facilitated by increasingly effective and persistent cooperation and collaboration of local, national and international organizations and institutions, the private sector, and civil society. Educational and health investments accelerate the demographic transition, leading to a relatively low population. … Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Investment in environmental technology and changes in tax structures lead to improved resource efficiency, reducing overall energy and resource use and improving environmental conditions over the longer term.*' (O'Neill et al., 2017, p.172)

At the other end of the spectrum, in term of climate change mitigation effort and many other challenges, lies **the SSP3 scenario, depicting a rocky road**. In this case, there is much rivalry between regions, leading to less sustainable technology development and to environmental concerns being treated as a low priority. In currently industrialised countries, the population does not increase much but in developing countries population increases are large. In the SSP3 scenario, the world remains very dependent on fossil fuels and similar resources.

O'Neill et al. write on SSP3: '*…Policies shift over time to become increasingly oriented toward national and regional security issues, including barriers to trade, particularly in the energy resource and agricultural markets. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development, and in several regions move toward more authoritarian forms of government with highly regulated economies. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time, especially in developing countries. … Growing resource intensity and fossil fuel dependency along with difficulty in achieving international cooperation and slow technological change imply high challenges to mitigation. The limited progress on human development, slow income growth, and lack of effective institutions, especially those that can act*

Figure 2.1
The 26 world regions in IMAGE 3.0



- Canada
- United States
- Mexico
- Central America
- Brazil
- Rest of South America
- Western Europe
- Central Europe
- Ukraine region
- Turkey
- Northern Africa
- Western Africa
- Eastern Africa
- South Africa
- Rest of Southern Africa
- Russia region
- Central Asia
- Middle East
- Southeast Asia
- Indonesia region
- India
- Rest of South Asia
- China region
- Korea region
- Japan
- Oceania
- Greenland
- Antarctica

Source: PBL 2014

The China region in the IMAGE model comprises mainland China, Hong Kong, Macau and Taiwan, as well as Mongolia (Stehfest et al., 2014).

across regions, implies high challenges to adaptation for many groups in all regions.... SSP3, with its theme of international fragmentation and a world characterized by regional rivalry can already be seen in some of the current regional rivalries and conflicts, but contrasts with globalization trends in other areas.' (O'Neill et al., 2017, p. 173)

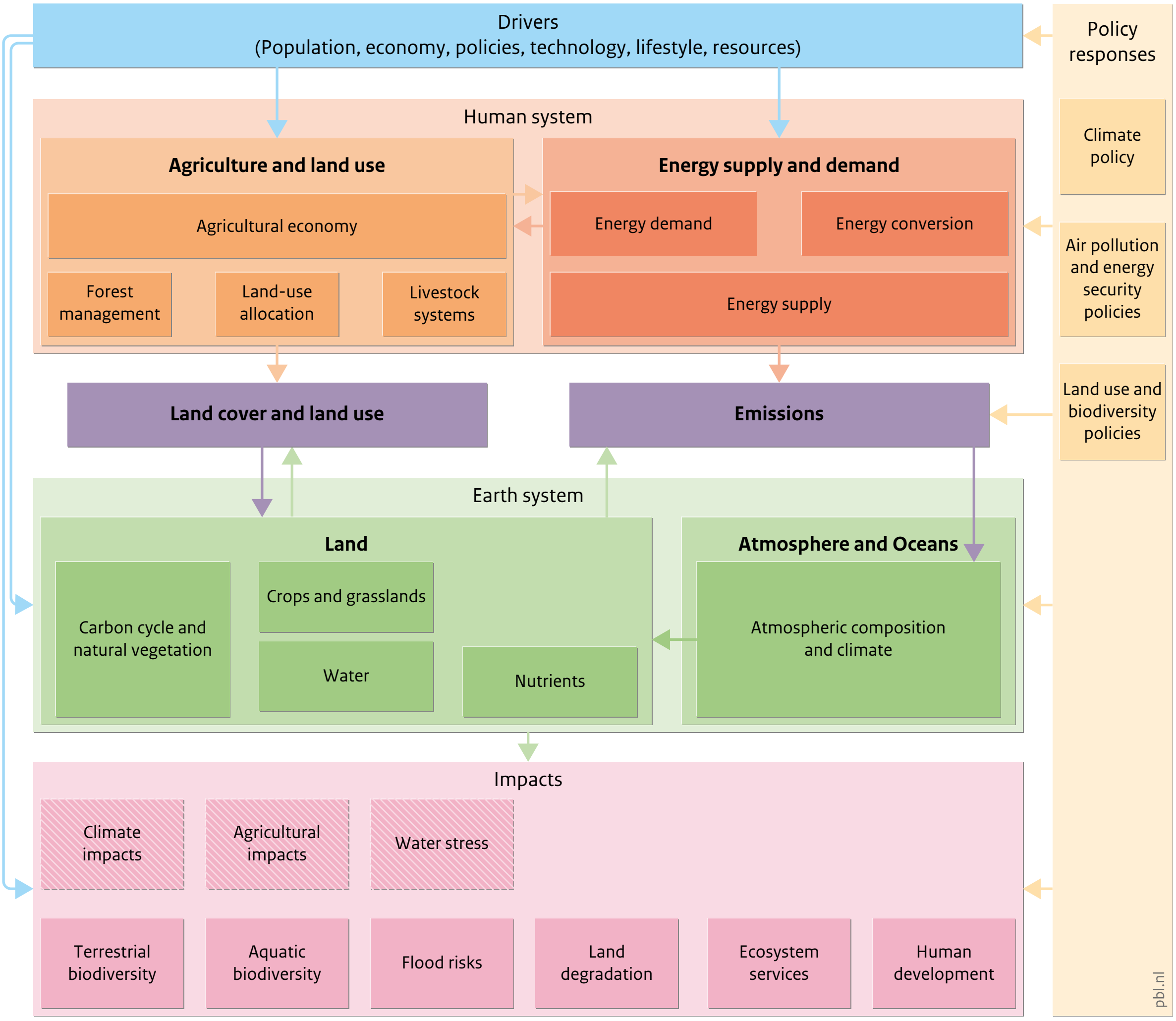
An overview table presenting how the storylines have been translated for quantitative modelling with IMAGE can be found in Van Vuuren et al. (2017).

2.3 Model description

The IMAGE framework (Stehfest et al., 2014) has been designed to analyse large-scale and long-term interactions between human development and the natural environment and to identify response strategies to global environmental change based on the assessment of options for mitigation and adaption. It is a simulation model, which means that changes in model variables are calculated on the basis of the information from the previous time step. The IMAGE framework is structured so that it broadly reflects the causality chain of key global sustainability issues. It comprises two main systems: 1) the human system, featuring the long-term development of socio-economic activities relevant for sustainable development; and 2) the earth system, featuring changes in natural systems such as the carbon and hydrological cycles.

The two systems are linked through emissions, land-use changes, climate feedbacks and potential human policy responses. The model simulates most of the socio-economic parameters for 26 regions (see Figure 2.1) and most of the environmental parameters, depending on the variable, on the basis of a geographical grid of 0.5° longitude by 0.5° latitude. Some earth system variables are however presented at a spatial resolution of 5 by 5 minutes. At the equator, these resolutions equal approximately 50x50 km and 10x10 km, respectively. IMAGE regions are defined so that biophysical developments (e.g. water availability) and socio-economic developments (e.g. trade flows) can be modelled and can be calibrated historically using very long time series, even for economic units that no longer exist (e.g. the former USSR). The exact composition of the IMAGE regions and their relation to national historic data series can be found here: http://themasites.pbl.nl/models/image/index.php/Region_classification_map.

Figure 2.2
IMAGE 3.0 framework



Source: PBL 2014

The IMAGE framework has a modular structure (Stehfest et al., 2014).

The IMAGE framework has a modular structure, with some components linked directly to the model code of IMAGE. Other components are connected through soft links, meaning that modules run independently and information between them is exchanged using data files.

The human system of the IMAGE framework comprises detailed representations of the energy system and the agricultural system. Important inputs relate to the future development of direct and indirect drivers of global environmental change: exogenous assumptions on population, economic development, lifestyle, policies and technology change. These assumptions feed into the food and agriculture system model MAGNET and the energy system model TIMER (Woltjer et al., 2014).

TIMER is a system dynamics energy system simulation model. In the energy system model, future energy systems are described in terms of changes in energy demand, energy conversion and supply, driven by key dynamics of economic activity, development, technology change and resource depletion. MAGNET is a computable general equilibrium (CGE) model that provides information in the IMAGE framework on the agricultural economy (Woltjer et al., 2014). It is connected via a soft link to the core model of IMAGE.

In IMAGE, the main interaction with the earth system is through changes in energy, food and biofuel production that induce land-use changes and emissions of CO_2 and other greenhouse gases (see Figure 2.2). A key component of the earth system in IMAGE 3.0 is the LPJmL model (Bondeau et al., 2007), details of which can be found in Müller et al. (2016). LPJmL covers the terrestrial carbon cycle and vegetation dynamics in IMAGE 3.0. It estimates productivity at the grid cell level for natural and cultivated ecosystems on the basis of plant and crop functional types. A set of allocation rules in IMAGE determines land cover based on regional production levels and the output of LPJmL.

A worldwide hydrology model is also included in the LPJmL model. Due to this linked hydrology model, IMAGE captures future changes in irrigated areas, water availability, agricultural water demand and water stress. LPJmL calculates water demand for irrigated agriculture based on evapotranspiration requirements for the crop types grown on irrigated land. Water demand for other sectors (households, manufacturing, electricity and livestock) is determined based on population, economic growth, industrial value added and electricity production as projected with IMAGE-TIMER.

To capture climate change impacts, the results of calculations of emissions of greenhouse gases and air pollutants are used in IMAGE to estimate changes in concentrations of greenhouse gases, ozone precursors and substances involved in aerosol formation on a global scale. Climate change is calculated as the global mean temperature change. Using a slightly adapted version of the MAGICC 6.0 climate model (Meinshausen, Wigley, and Raper, 2011), changes in temperature and precipitation in each grid cell are derived from the global mean temperature using a pattern-scaling approach. MAGICC 6.0 accounts for several feedback mechanisms between climate change and dynamics in the energy, land and vegetation systems.

THREE

Comparison of international projections and China's Green Transition Pathway

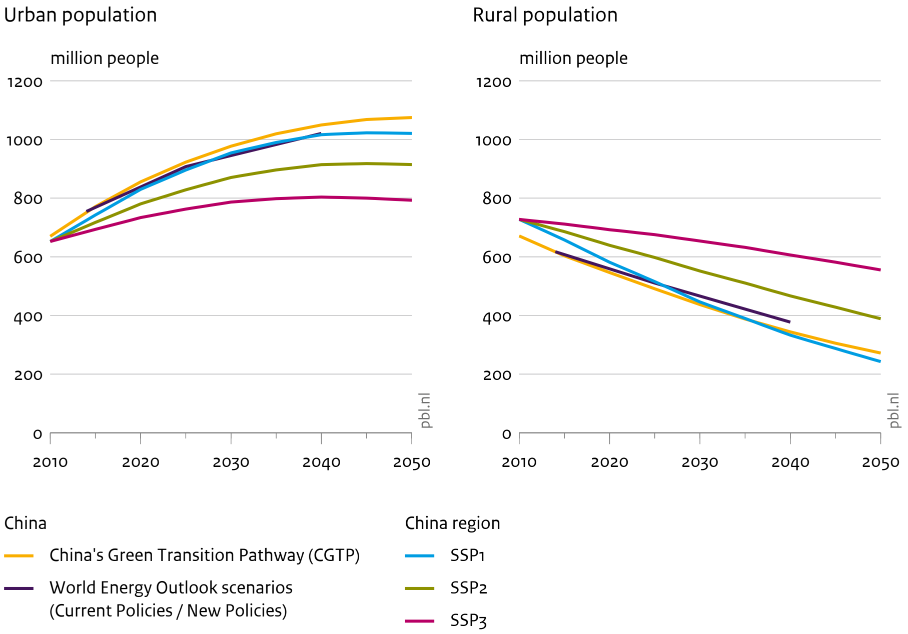
For a better understanding of China's Green Transition Pathway, it is compared with a broad range of international projections described in Chapter 2. The comparison focuses on three topics: key socio-economic drivers, energy system indicators and carbon dioxide emissions. China's Green Transition Pathway is compared with the IMAGE model Shared Socio-economic Pathway baselines SSP1, SSP2 and SSP3, as described in Appendix 1. It should be noted that the China region as modelled in IMAGE comprises mainland China, Hong Kong, Macau and Taiwan, as well as Mongolia. In addition, China's Green Transition Pathway is compared to the IEA's Current Policy and New Policy WEO scenarios (for which only 2020 and 2040 data was available).

3.1 Key drivers

Economic and population growth typically result in an increased pressure on resources and the environment due to growing demand. This section evaluates how these drivers of demand develop according to China's Green Transition Pathway (CGTP), compared to authoritative international projections.

In all scenarios, the urban population continues to grow compared with the rural population (Figure 3.1). China's Green Transition Pathway features extensive urbanisation, comparable to the trend in the sustainable development SSP1 scenario and the two IEA WEO scenarios. Whether the net environmental impact will be positive or negative will depend on how urban development and mobility will be organised and how lifestyles and consumption trends in this increasingly urban, and ageing, society will develop.

Figure 3.1
Population in China



Source: PBL; DRC; IEA

By 2050, China's Green Transition Pathway features 160 million more urban dwellers than the SSP2 baseline.

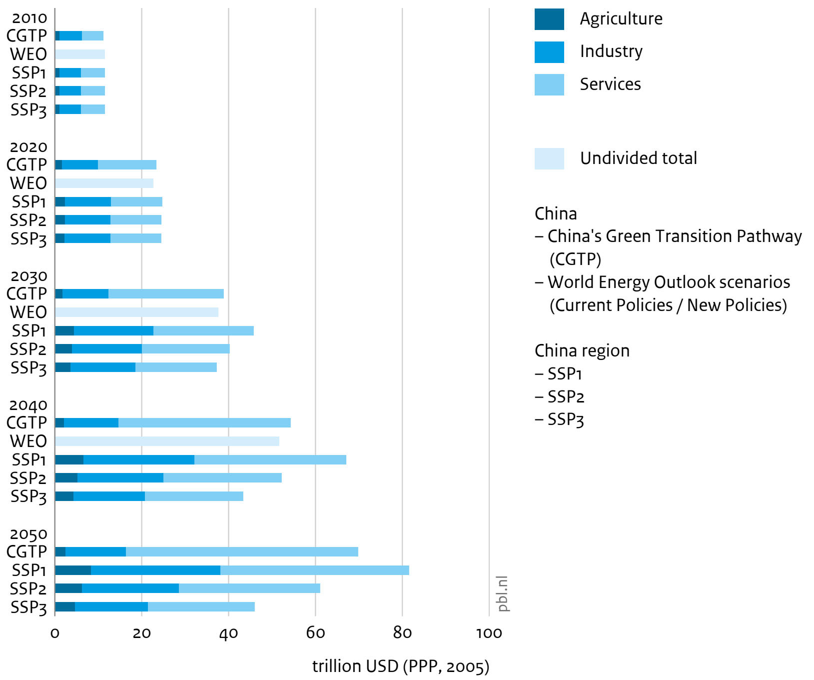
Figure 3.2 shows the sectoral GDP assumptions. For CGTP and IEA's WEO projections, only GDP growth rates were available. These have been applied to the IMAGE SSP GDP projection from historic values onwards. Sectoral GDP data was unavailable for IEA's WEO projections. Figure 3.2 shows that the economy continues to grow in all scenarios, although CGTP sees the economy growing faster towards 2050 than is assumed in most SSPs.

The most striking feature of China's Green Transition Pathway is the growth in the share of the service sector, which is larger than assumed in the SSPs. Whereas the service sector currently makes up approximately half of China's GDP, this grows to more than 75% in the CGTP.

As a result, industrial and agricultural shares in GDP decrease. Although the share of the industrial sector in the Chinese economy decreases in the CGTP, its absolute size does increase, although to a much lesser extent than in the SSPs.

CGTP appears potentially much greener than any of the international scenarios because its GDP growth comes from the service sector. Whether this greenness will in fact materialise is however dependent upon policy. For example, in an online economy it is dependent on transport (including the notorious last mile delivery), inner city development and the use of natural resources.

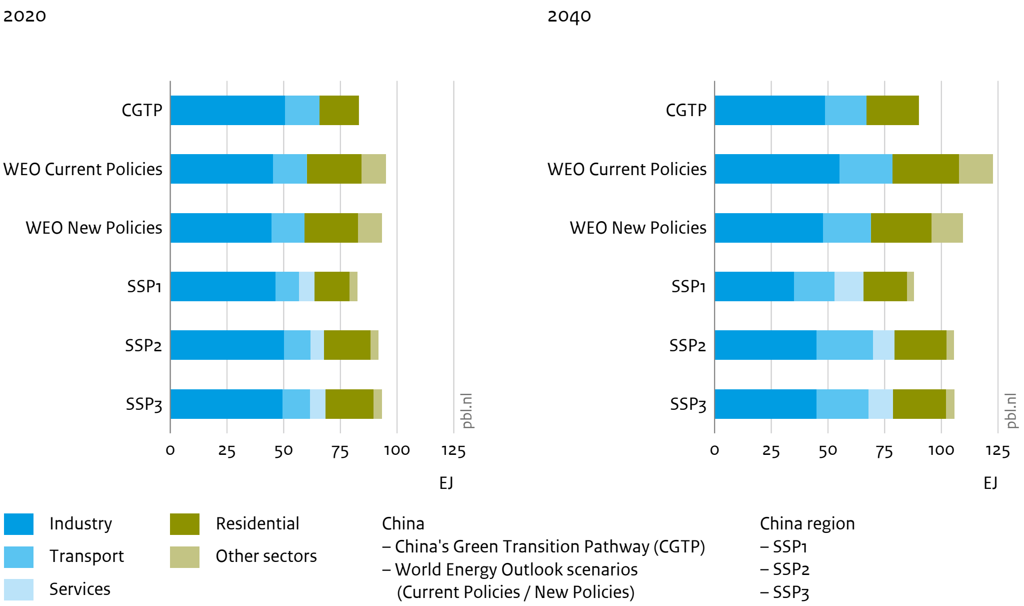
Figure 3.2
Gross Domestic Product (GDP) of China



Source: PBL; DRC; IEA

China's Green Transition Pathway sees strong growth in China's service sector; much more so than in the SSP2 baseline.

Figure 3.3
Final energy demand in China

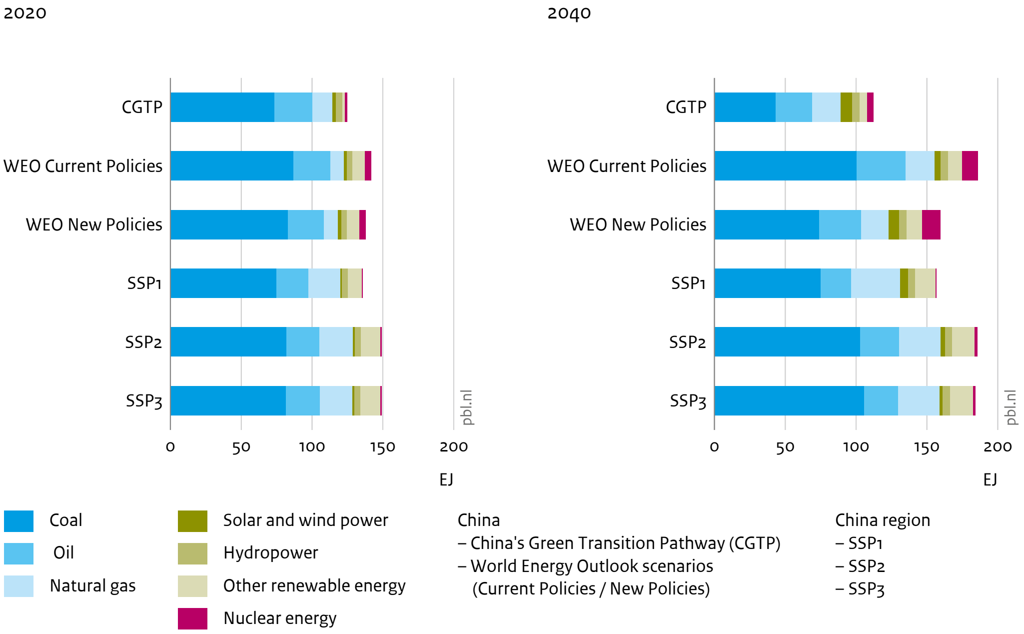


Source: PBL; DRC; IEA

China's Green Transition Pathway final energy demand[1] is roughly in line with international scenarios. Here, a certain degree of uncertainty applies, as DRC data on the services sector are missing.

Figure 3.4

Primary energy supply in China



Source: PBL; DRC; IEA

China's Green Transition Outlook shows a decrease in the primary energy supply.

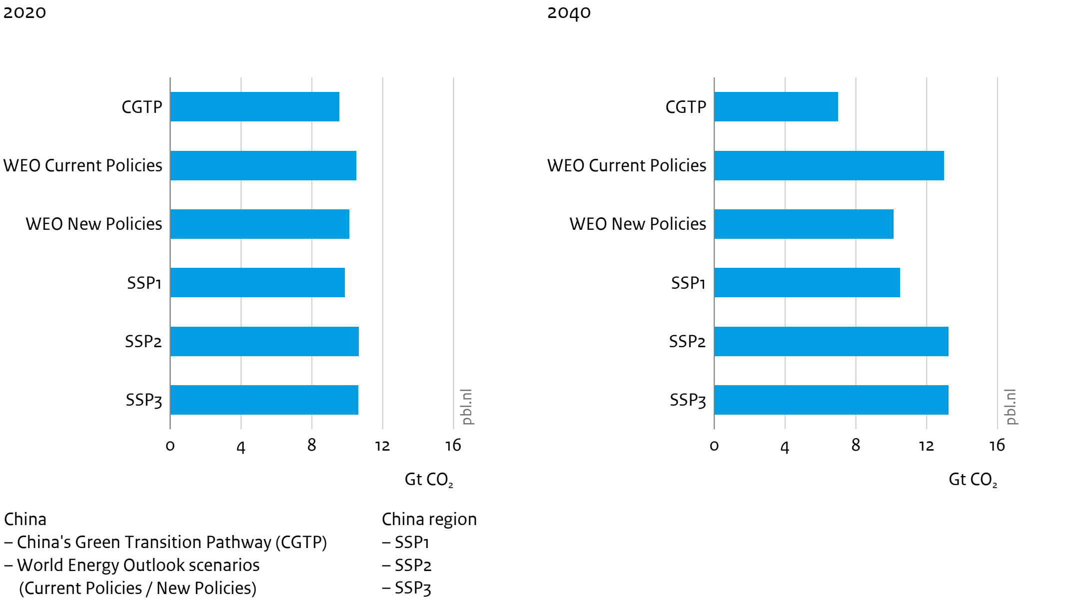
3.2 Energy

Chinese energy consumption is projected to increase slightly in all scenarios included in the comparison over the coming decades, mainly due to growing energy use in the transport sector (see Figure 3.3). China's Green Transition Pathway shows a similar trend. Industrial energy consumption in this scenario is slightly larger than in the international scenarios, except for the IEA Current Policy scenario. This larger energy consumption by industry is unexpected since China's Green Transition Pathway sees less growth in the industrial sector (see previous section). Energy use in the transport sector is comparable to the SSP1 projections in which green growth is associated with the increased use of energy efficient modes such as public transport and cycling (Van Vuuren et al., 2017).

The primary energy supply takes a notably different path in China's Green Transition Pathway compared to the projections by the international scenarios (Figure 3.4). In 2020, the differences are not that obvious. However, according to China's Green Transition Pathway, the primary energy supply in 2040 is much less and a large share of it is supplied by low-carbon energy production technologies. Ambitious energy policy targets are adhered to by the Green Transition Pathway, including capping the total primary energy supply and limiting the share of fossil fuels.

For this figure, primary energy source conversion factors for nuclear energy, hydropower, and solar and wind power are set to one. As a result, the contribution of renewable energy looks rather limited, compared to its share in final energy supply.

Figure 3.5
Carbon dioxide emissions from energy and industry in China



Source: PBL; DRC; IEA

The reduced increase in energy demand and increase in share of renewable energy in China's Green Transition Pathway result in lower carbon dioxide emissions.

3.3 Carbon dioxide emissions

The effect of less carbon-intensive energy production on emissions can clearly be seen in Figure 3.5. This figure shows the projected energy and industry-related CO_2 emissions. The same emission factors have been applied for fossil fuel use for all scenarios. In China's Green Transition Pathway, carbon dioxide emissions are 53% to 69% of the CO_2 emissions projected for 2040 in the international scenarios.

FOUR

China's development trajectory in a global context

How does China's Green Transition Pathway, as outlined by the DRC, affect the global environment? And, in return, how do developments in the global environment impact China's projected futures? To better understand these interactions, three scenarios are compared within the IMAGE model framework. Unlike the comparison scenarios used in the previous chapter, these are all tailor-made for the current study. For a brief description, see Section 2.1 and the table included therein. The three scenarios provide a general illustration of Chinese energy systems over the coming decades, building on China's Green Transition Pathway. First, energy system effects are discussed. Then, we look at the effects on global climate change as well as emissions of macro air pollutants. Finally, land-use changes are considered.

4.1 Energy

Differences in policies and drivers have a large effect on the energy demand per sector (Figure 4.1a). In the baseline scenario, almost all major demand sectors show growth in energy demand towards 2050 (except for the industrial sector, where demand increases towards 2030 then decreases in 2050 back to 2010 levels). The baseline scenario shows particularly high relative growth in the transport and service sectors compared to 2010 levels.

China's Green Transition Pathway assumptions result in a large decrease in the industrial sector's energy demand compared to the baseline scenario (a difference of more than 25% in 2050). The figures in this chapter show results of worldwide scenarios. Of these, Green China plus comprises China's Green transition Pathway. A full description of how China's Green Transition has been incorporated is provided in Section 2.1, with details in Appendix 2. Demand in the transport sector also decreases (a difference of more than 15% compared to the baseline scenario in 2050). The energy demand for the residential sector shows no large difference, which is remarkable given the enormous urbanisation going on in these decades. On the other hand, demand for the service sector increases by almost 33% compared to the baseline scenario in 2050.

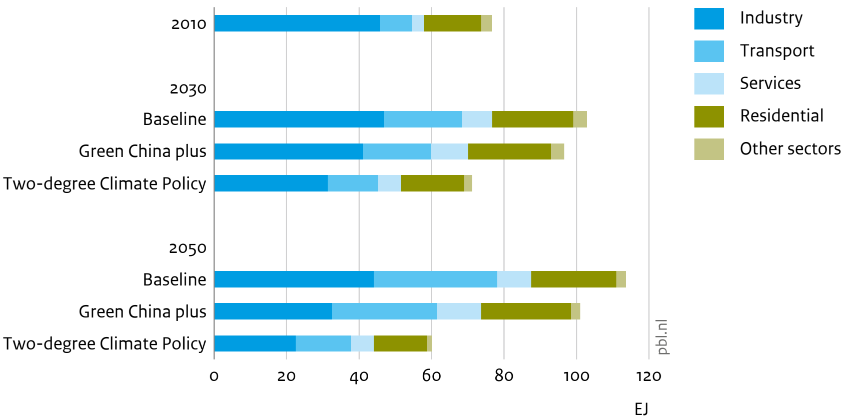
Table 4.1
Carbon tax applied in the Two-degree Climate Policy scenario

	USD/tCO_2
2015	0
2025	99
2050	569
2075	853
2100	998

A greater reduction in energy use is required to achieve a 2 °C climate target, but the various policy strategies in the Green China plus scenario do bring Chinese energy use closer to a 2 °C pathway. In order to achieve the required additional reduction, a global carbon tax is applied in the model (Table 4.1).

Figure 4.1b shows the contribution of China's final energy demand to the global final energy demand both in absolute terms and per capita. In all scenarios, China continues to be the region with the largest final energy demand, although the share slightly decreases for the Green China plus and the Two-degree Climate Policy

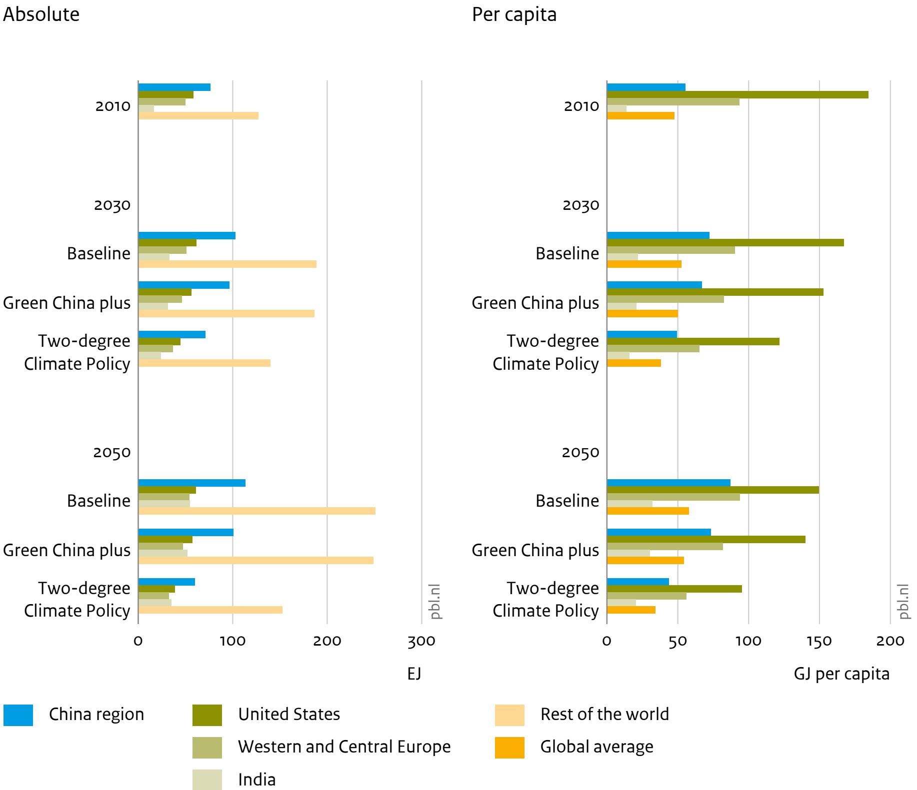
Figure 4.1a
Final energy demand in China region



Source: PBL

The global Two-degree Climate Policy scenario shows a particular decrease in China's energy use for the transport sector.

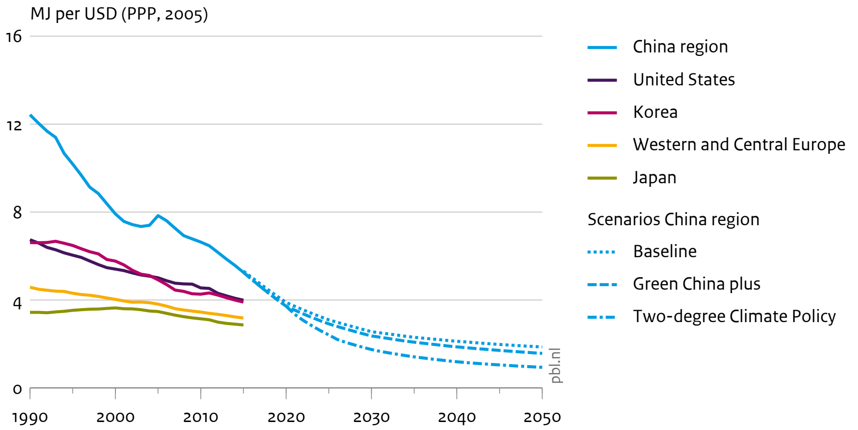
Figure 4.1b
Final energy demand per region



Source: PBL

By 2050, the final energy demand in the Rest of the World will be large in any scenario. China's per-capita final energy use remains roughly half that of the USA and more than that of India in all scenarios throughout the scenario period.

Figure 4.2
Energy use per GDP



Source: IEA; PBL

China's economy is expected to become much less energy-intensive, even under baseline conditions. Green China plus slightly improves on this.

scenarios (from 21.2% to 19.9% and 18.8%, respectively). China's per-capita final energy demand moves towards European values in 2050, although such developments in China depend highly on the climate ambitions.

The baseline scenario and the Green China plus scenario allow for some increase in per-capita final energy demand compared to 2010, but the Two-degree Climate Policy scenario requires a decrease.

A key element of the new path laid out by the Chinese leadership is a break with current economic trends by moving away from energy-intensive industries and attaching increasing importance to the service sector. As a result, China's energy intensity (energy use per GDP) is expected to follow a path similar to that of economies such as Japan and South Korea. The projected energy intensity of the Green China plus scenario, which follows developments as assumed in China's Green Transition Pathway, would indeed continue to decrease to a level even lower than Korea[1] and Japan currently (Figure 4.2). However, strong energy intensity improvements are already assumed in the baseline scenario. The scenario that pursues a 2 °C goal implies an even greater decrease in energy intensity.

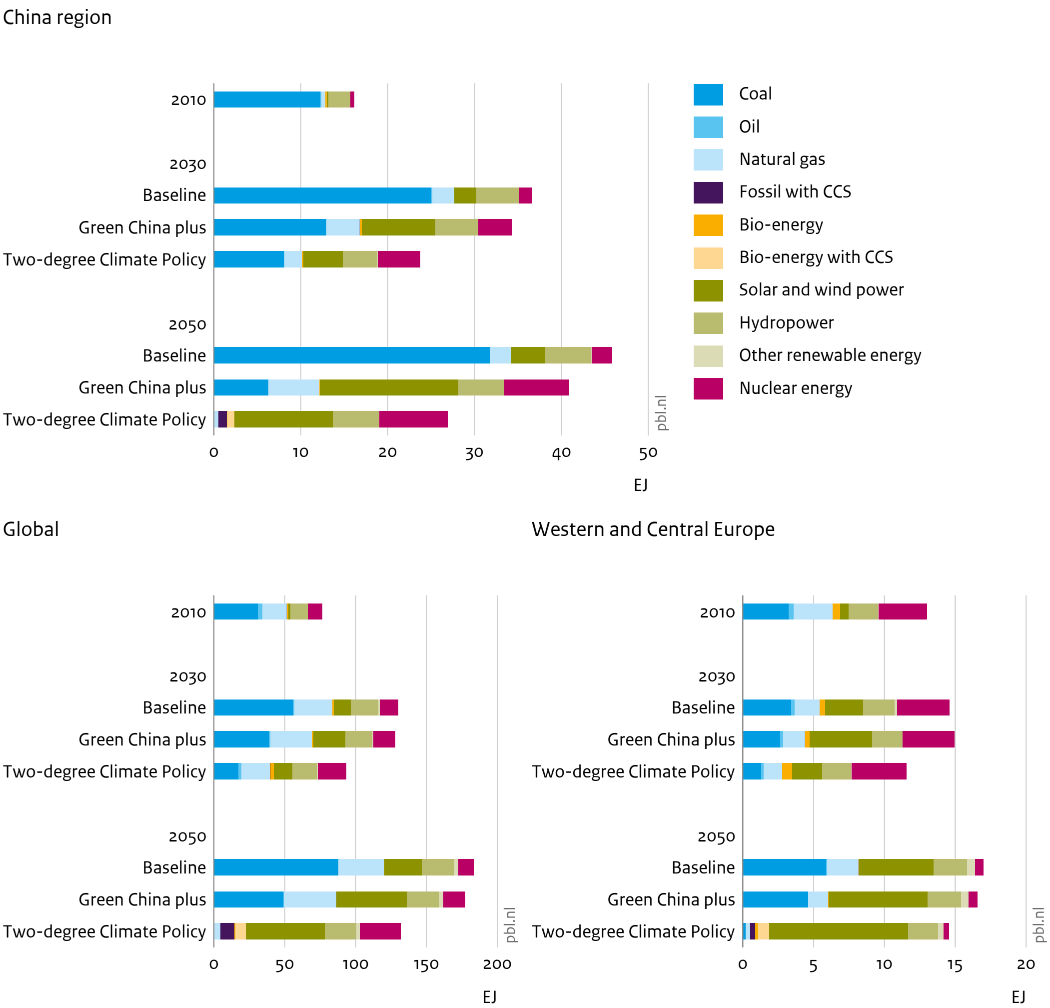
A large transformation in the power sector can be identified in the Green China plus scenario (Figure 4.3), as the dominant role of coal in the baseline scenario is replaced with low-carbon technologies towards 2050. The Two-degree Climate Policy scenario shows an even larger shift away from coal and all other fossil fuels, as almost all non-CCS fossil fuel consumption has disappeared by 2050.

Comparing China's electricity sector projections to developments in Europe and global developments, a few differences stand out. First, China's Green Transition Pathway policy included in the non-baseline scenarios is relatively successful in reducing the share of fossil fuels in the electricity mix. The difference is especially large when it comes to China's baseline projections on coal use. Introducing further climate policy in the Two-degree Climate Policy scenario removes almost all coal use in all regions in 2050. In this scenario, nuclear energy, and solar and wind power outcompete CCS, based on costs in China.

Secondly, due to assumptions on the relatively low Chinese capital costs for nuclear power plants compared to those in Europe, China's nuclear energy share in the Two-degree Climate Policy scenario becomes relatively large. In Europe, nuclear energy capital costs are considerably higher, contributing to a larger solar and wind share. Given the merit order dispatch of power technologies, the larger share of solar and wind, in turn, results in fewer full load hours available for nuclear energy, increasing the capital costs of nuclear energy per kWh of produced electricity even more. This is also true for fossil CCS technologies in Europe. Biomass CCS is competitive, but restricted due to limited biomass availability.

Effects of China's Green Transition Pathway can also be identified in the total primary energy supply (see

Figure 4.3
Electricity generation



Source: PBL

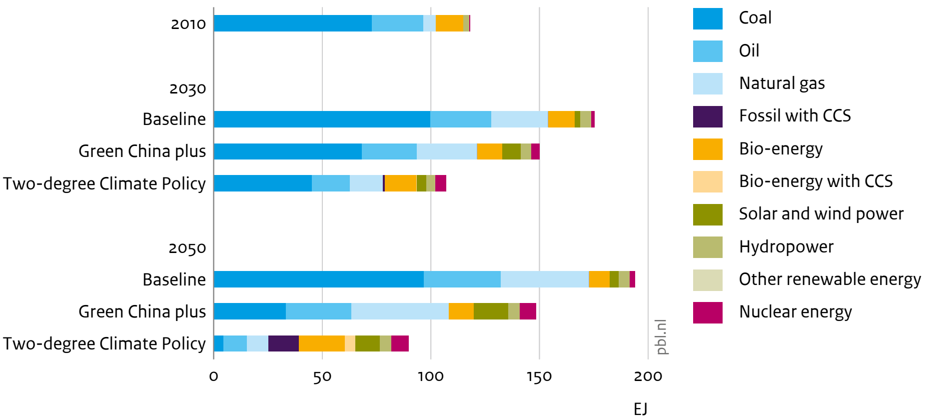
The role of coal in electricity production shrinks in all scenarios except in the baseline scenario .

Figure 4.4a). The reduction in sectoral energy demand in the Green China plus scenario compared to the baseline scenario results in less demand for primary energy carriers. The Green China plus scenario deviates from the baseline scenario when it comes to the share of coal and carbon low technologies. Coal consumption in the Green China plus scenario shrinks by about 65% compared to the baseline scenario in 2050. This shrinkage is largely replaced with low-carbon sources, such as solar, wind and nuclear energy. The introduction of climate policy results in the use of CCS technologies, especially towards 2050. CCS is mostly applied outside the electricity sector.

For Figure 4.4, primary energy source conversion factors for nuclear energy, hydropower, and, solar and wind power are set to one. As a result, the contribution of renewable energy looks rather limited, compared to its share in final energy supply.

Figure 4.4b shows the shares of China, India, Europe and the United States in the global primary energy supply, as well as the per-capita primary energy supply for these regions. Towards 2050, China's share in the global primary energy supply is expected to stay constant in the baseline projection. When introducing energy and climate policy, the global primary energy supply decreases in both the Green China plus and the Two-degree Climate Policy scenarios, by about 10% and 44%, respectively, compared to the baseline scenario in 2050. The figure shows that, also globally, a relatively large reduction in

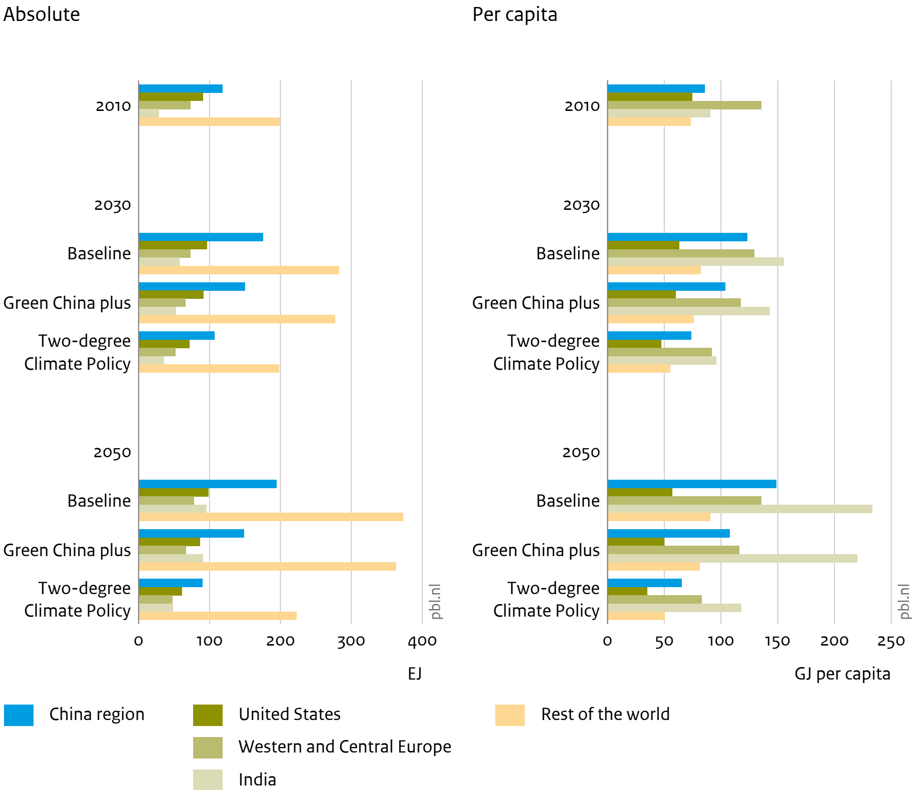
Figure 4.4a
Primary energy supply in China region



Source: PBL

Achieving a 2 °C target requires large additional reductions in non-CCS fossil fuel use compared to the Green China plus scenario.

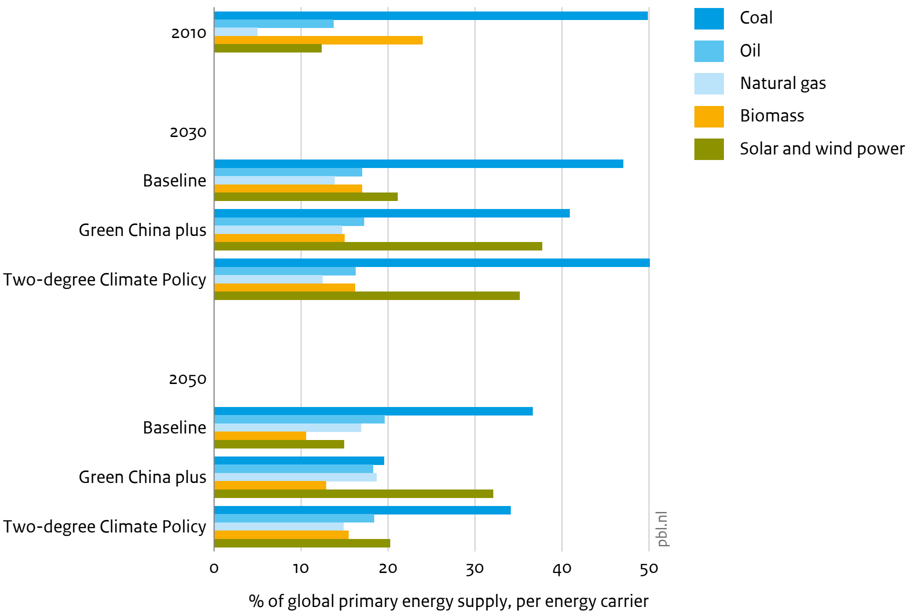
Figure 4.4b
Primary energy supply per region



Source: PBL

The Green China plus scenario sees the primary energy supply in China decrease relatively strongly. The Two-degree Climate Policy scenario features a large reduction in per-capita energy use in the United States.

Figure 4.5
Share of China region in the global primary energy supply



Source: PBL

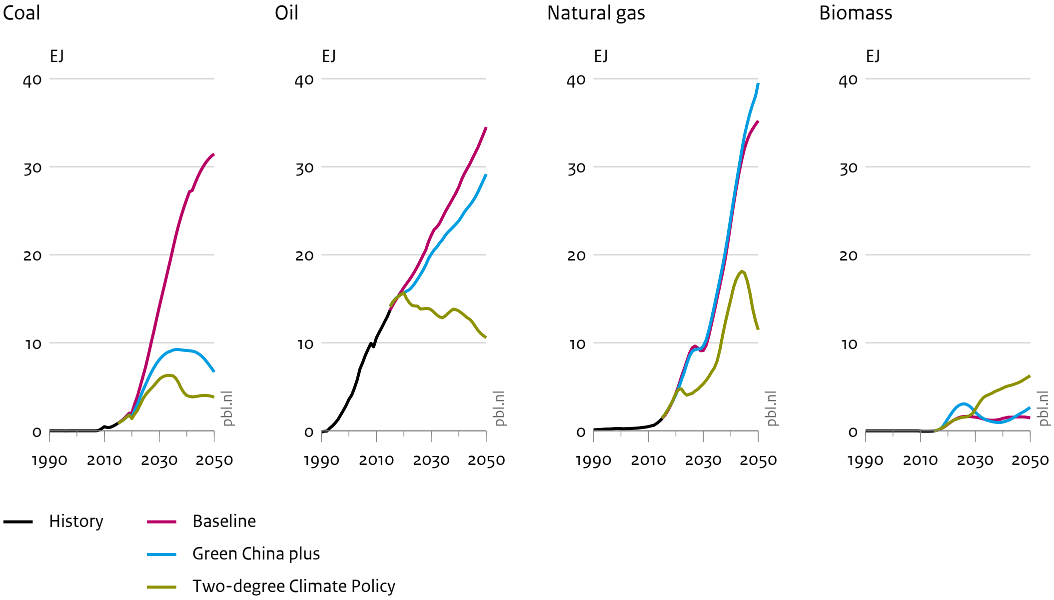
China's share in global coal use remains large, albeit of a much smaller world total.

the global primary energy supply is still required to achieve a 2 °C climate target compared to the Green China plus scenario.

In the policy scenarios, China's share of the total primary energy supply decreases to about 19%. Policy also reduces the Chinese per-capita primary energy supply compared to the baseline scenario. Only in the Two-degree Climate Policy scenario does the per-capita primary energy supply decrease compared to 2010. In all scenarios, Chinese projections move towards European per-capita primary energy supply levels. This is partly because Europe follows a different trend: for Europe, a decrease in per-capita primary energy supply is expected in all scenarios. This is also the case for the United States, while for India an increase is expected in all scenarios.

Figure 4.5 shows the share of the Chinese primary energy supply in the global total for the different scenarios. In the baseline scenario, the dominance of China in the global coal market is already expected to decrease towards 2050, due to continued demand in Western countries such as the United States and increasing demand in emerging markets such as India. In the Green China plus scenario, the dominant role of coal is replaced with a large Chinese share of the total produced solar and wind power. This share decreases when climate policy is introduced in the Two-degree Climate Policy scenario, as this assumes that more countries use solar and wind in their decarbonisation efforts. In this scenario, the Chinese share of coal consumption looks relativity large, but it should be noted that, in absolute terms, the coal consumption is small in all regions.

Figure 4.6
Net import of fossil fuel and biomass in China region



Source: PBL

Natural gas features as a transition fuel in the Two-degree Climate Policy scenario.

The reduced use of fossil fuels after climate policy is introduced is also reflected in the net import of energy carriers into China (Figure 4.6; net import is defined as import minus export; it should be noted that the IMAGE China region comprises, inter alia, Mongolia). However, the Two-degree Climate Policy scenario implies an increased import of biomass. The decreased coal imports between 2030 and 2040 and the decreased natural gas imports between 2040 and 2050 are caused by the impact of the carbon tax on electricity sector dynamics. The Green China plus scenario entails a decrease in coal imports due to a decrease in coal use in the electricity sector. The impact on the import and export of other energy carriers is much smaller as less stringent policy measures for these carriers are included in the scenario.

4.2 Climate change

In the baseline scenario, Chinese carbon dioxide emissions peak between 2040 and 2050 (Figure 4.7a). China's Green Transition Pathway moves the peak forward to around 2020. These developments are contingent upon policies; we do not know what these will be, other than what is described in general terms. Although China's Green Transition Pathway in the Green China plus scenario already results in a substantial reduction in carbon dioxide emissions, emissions have to be reduced considerably more in order to limit global average warming to 2 °C.

The assumed relative effectiveness of China's Green Transition Pathway compared to other international current and planned policy can be observed when looking at China's share in absolute and per-capital global carbon dioxide emissions (Figure 4.7b). China's share in global emissions was 25.4% in 2010. By 2050, this share remains almost the same, at 24.4%, in the baseline scenario, but of a much larger total. The Green China plus scenario sees China's share decrease to 17.5%. In the Two-degree Climate Policy scenario, China's share of global carbon dioxide emissions shrinks to 15.8% by 2050, of a much smaller total.

The relative effectiveness of Chinese policies assumed in China's Green Transition Pathway compared to international current and planned policies can also be seen by focusing on Chinese per-capita carbon dioxide emissions. By 2050, these emissions have decreased by almost 50% in the Green China plus scenario compared to the baseline scenario. The world average per-capita reduction is substantially smaller (almost 25%). The Two-degree Climate Policy scenario requires a much larger decrease in per-capita emissions, using hitherto unused mitigation options, in all regions. In fact, the global average per-capita reduction in emissions in the Two-degree Climate Policy scenario would be about 87% by 2050, compared to the baseline scenario.

Box 2: Clean coal

Coal currently plays a dominant role in China's energy supply due to its low cost and regional availability. However, coal use has its downsides. These range from health and safety risks in coal mines to local environmental degradation in the form of air, water and soil pollution and greenhouse gas emissions, that cause global warming.

Some experts believe that clean coal has an important role to play in reducing the impact of coal use. Clean coal technologies refer to a group of technologies that aim to mitigate the impacts of coal production, transformation and use. Examples are post-combustion flue gas treatment, the pre-combustion treatment of coal in integrated gasification combined cycle plants or the application of carbon capture and storage (PIB Clean Coal, 2017).

It is important to be aware that the introduction of clean coal technologies, despite creating environmental benefits, does not per definition create net environmental benefits and can also result in paradoxical effects.

An important example of the latter is the conversion of coal to produce synthetic natural gas. The resulting gas is mostly methane, which can be conveniently transported by pipelines to be used as fuel for power generation elsewhere. The coal conversion would be located away from population centres. Even so, from the point of view of China's green transition towards 2050, this example brings to light strategic difficulties surrounding clean coal, as follows.

On the positive side, replacing coal with synthetic natural gas as the fuel in power generation plants close to population centres would allegedly deliver:

(i) a major contribution to the current war on pollution, in particular the reduced exposure of urban inhabitants to air pollution, especially if this switch is applied to all coal-fired units and combined with equivalent policies on transport; and

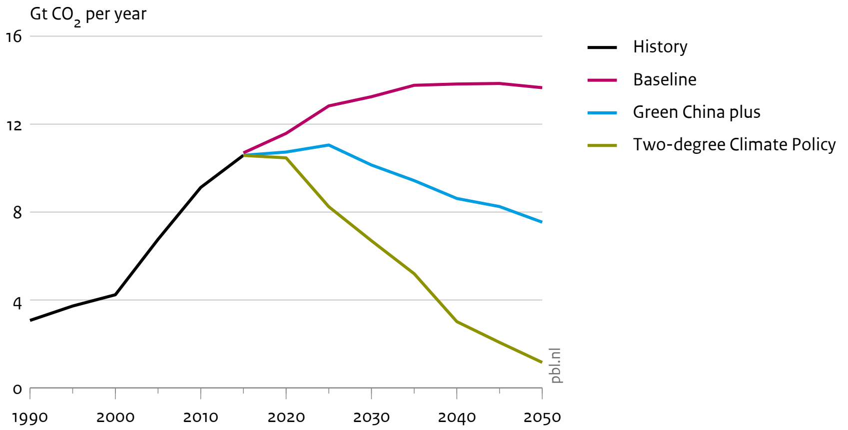
(ii) possibilities for smaller and more flexible units of power generation that are better suited to the complexities of electricity provision in the coming decades.

However, there are some important challenges that must be addressed or avoided. The initial conversion step from coal to synthetic natural gas releases a significant amount of carbon dioxide. This is in addition to, and is a similar quantity to, the 'normal' carbon dioxide released when the gas is used for power generation.

In order to reduce the impact of clean coal on climate change, both steps, coal conversion as well as gas burning, would have to be carried out with carbon capture and storage (CCS). Applying CCS at both steps would be relatively expensive, requiring suitable locations and needing to be done centrally in large installations in order to limit costs.

On balance, clean coal and synthetic natural gas for power generation should be seen as transient technologies, bridging from old to new during China's transition if deemed necessary, but having no place thereafter. Moreover, it seems China is in a unique position to address its air quality issues and greenhouse gas emissions at the same time. This is in contrast to the situation in OECD countries, who typically did this in two consecutive steps, decades apart. Linking the two agendas would send an important signal to other BRICS countries, given China's unenviable reputation on air quality.

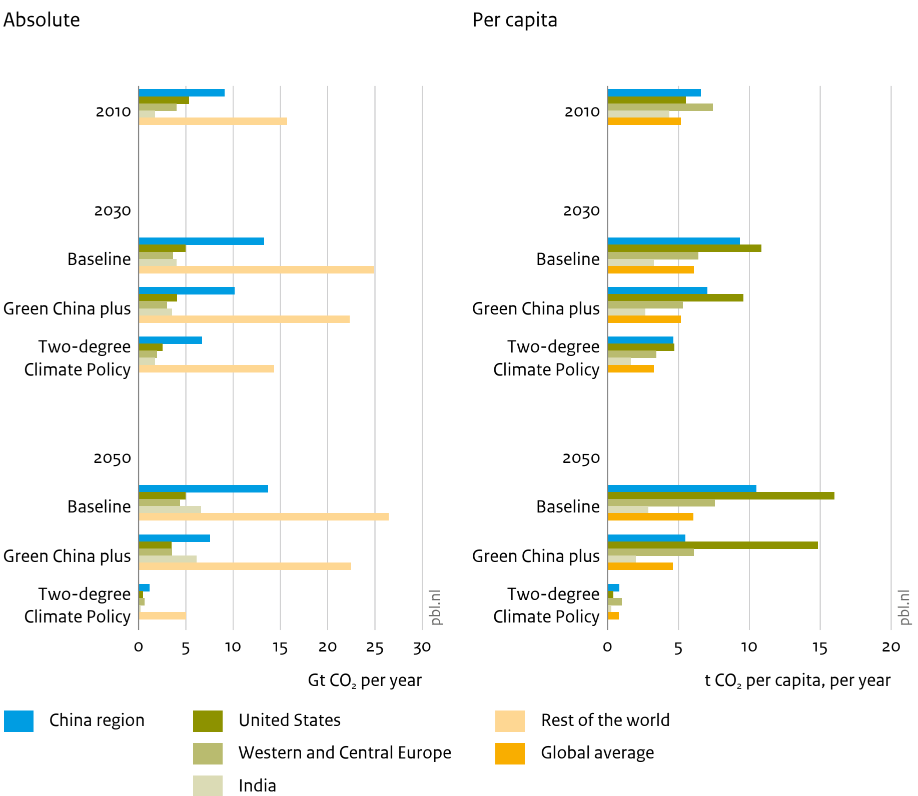
Figure 4.7a
Carbon dioxide emissions in China region



Source: PBL

By 2050, Green China plus almost halves China's carbon dioxide emissions compared to the baseline scenario. However, this is only half of what is needed for climate stabilisation at an average warming of 2 °C.

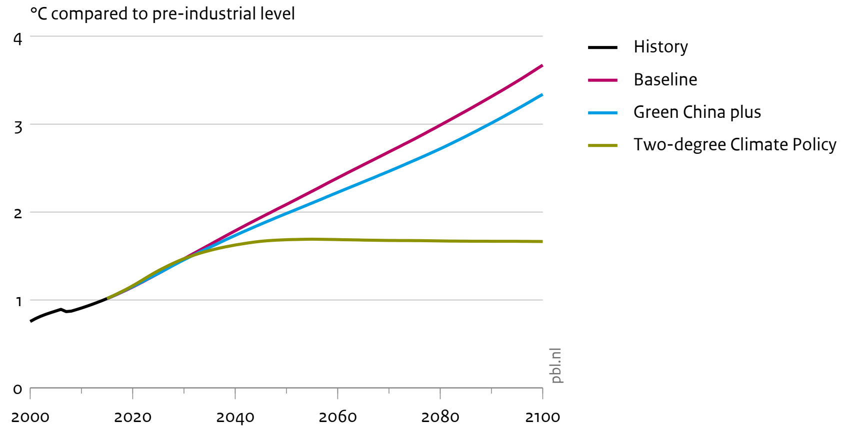
Figure 4.7b
Carbon dioxide emissions per region



Source: PBL

China's emission reduction in the Green China plus scenario in 2050 is relatively large compared to other regions. In per-capita terms, the United States remains the world's largest carbon dioxide emitting region, except in the Two-degree Climate Policy scenario.

Figure 4.8
Change in global mean temperature



Source: PBL

The Green China plus scenario results in some mitigation of the global temperature increase, but not enough to achieve the 2 °C target.

Figure 4.8 shows the global mean temperature change compared to pre-industrial temperatures for the three scenarios up to 2100. Until 2030, the different scenarios follow the same trajectory. Towards 2100, the Two-degree Climate Policy scenario moves towards the temperature goal, with a 66% probability of keeping the increase in global mean temperature below 2°C relative to pre-industrial levels. The temperature levels in the baseline and Green China plus scenarios continue to increase after 2050. It should be noted that the Green China plus scenario focuses on the pre-2050 period and therefore, assumedly, not all of the policy intensity is continued beyond the 2050 scenario horizon.
The calculations underlying Figure 4.8 account for all the main heat-trapping gases, not just carbon dioxide.

4.3 Air pollution

China faces serious issues regarding urban air pollution. Almost all Chinese cities currently exceed the WHO guideline on ozone and aerosols on a regular basis (Zhang and Crooks, 2012). Figure 4.9 presents the projected emissions of some key air pollutants. Sulphur dioxide (SO_2) emissions are responsible for the formation of aerosols, especially in the winter.

Even in the baseline scenario projections, Chinese sulphur dioxide emissions show a large decrease. This is due to a decrease in expected emissions factors, independent of climate policy, as a result of increased pollution controls such as a limit on the sulphur content of liquid fuels and the desulphurisation of flue gases (Rao et al., 2017).

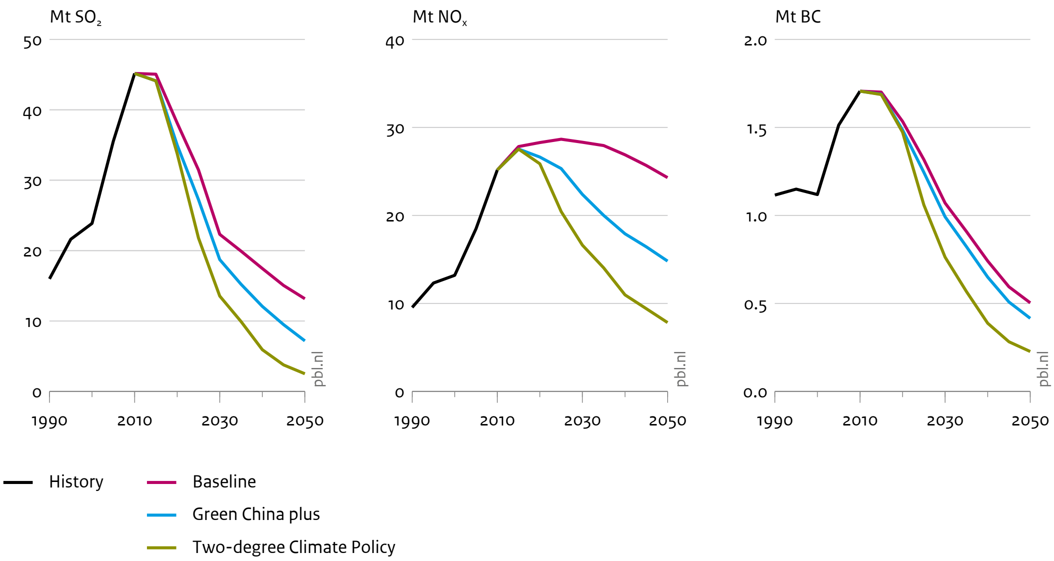
Additional measures in the Green China plus and Two-degree Climate Policy scenarios result in a substantial further decrease of 45% and 81%, respectively, compared to the baseline scenario in 2050. A large part of this decrease is caused by less coal being used in these scenarios.

Nitrogen oxides[2] (NO_x), in combination with volatile organic compounds, are an important contributor to tropospheric ozone formation, causing smog. Chinese emissions of nitrogen oxides are projected to only slightly decrease in the baseline scenario as they are more difficult to mitigate than emissions of or black carbon (Rao et al., 2017).

By the same token, the decrease in nitrogen oxides emissions in the policy scenarios relative to the baseline scenario is much larger than that of the other pollutants. The decrease in nitrogen oxides emissions compared to the baseline scenario is 39% and 68% for the Green China plus and Two-degree Climate Policy scenarios, respectively.

Emissions of black carbon (BC) are another major contributor to particulate matter in the atmosphere. Black carbon emissions follow a similar trajectory to the sulphur dioxide emissions in the various scenarios.
The decrease in black carbon emissions compared to the baseline scenario by 2050 is 17% and 55% for the Green China plus and Two-degree Climate Policy scenarios, respectively. The relative emission decrease is smaller for black carbon than for sulphur dioxide because black carbon emissions are less dependent on coal use in the electricity sector and more dependent on coal and biofuel

Figure 4.9
Air polluting emissions in China region



Source: PBL

Macro air pollutants show a large decline in emissions under baseline conditions.

use in the residential sector and diesel use in other sectors.

For China as a whole, macro air pollutants decrease to their 1990 levels by 2030. This, however, would not necessarily mean that the health impacts of air pollution are taken away. Emissons would still be large in China. Moreover, population exposure would not exactly follow trends in national total emissions as presented here. In addition, the Chinese population of 2030 will be older than that of the 1990s, and therefore more vulnerable health-wise. Furthermore, a larger part of the Chinese population will live in urban agglomerations by 2030. Possibly, China's green transition policies on urban design and regional development will have resulted in modest-sized, well-ventilated cities. An absence of such specific spatial planning will mean that these agglomerations become of an unwieldy size, exposing their inhabitants to greater levels of background air pollution in addition to the effects of increasingly frequent heatwaves that will come with climate change.

4.4 Land use

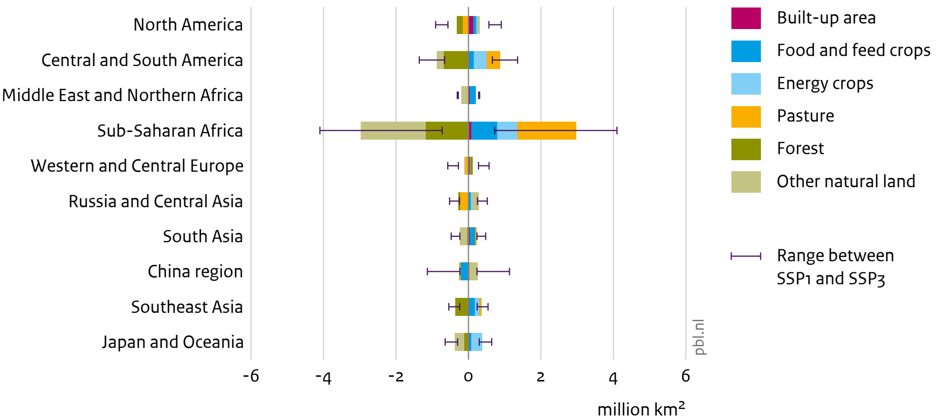
As an example of other environment implications of China's Green Transition to 2050 (other than energy, climate and air quality), this report presents findings on the availability and condition of land resources.

Our findings are based on the recently published *Global Land Outlook* (United Nations Convention to Combat Desertification, 2017). We focus on changes up to 2050, based on the scenario analysis contributed by PBL (Van der Esch et al., 2017). This was carried out using IMAGE and is based on the Shared Socio-economic Pathways, including SSP2 (Popp et al., 2017). It is therefore comparable with the scenario analysis reported here for energy, climate and air pollution. The Global Land Outlook understands land resources to include soil, water, and biodiversity. The model-based projections in this report are in terms of land-use changes.

Necessity of change

Figure 4.10 is illustrative when it comes to the necessity of China's green transition from a worldwide perspective on land resources. Under the conditions of the SSP2 scenario, **no** large net changes in agricultural area are projected for the China region towards 2050 and the least productive areas may face abandonment, although this would depend on domestic agricultural support policies. This lack of change is the result of a projected stability or even small decline in domestic demand for crops and livestock products, combined with expected improvements in agricultural productivity per hectare (Figures 4.11 and 4.12). China does not have much of a margin in terms of remaining unused suitable land.

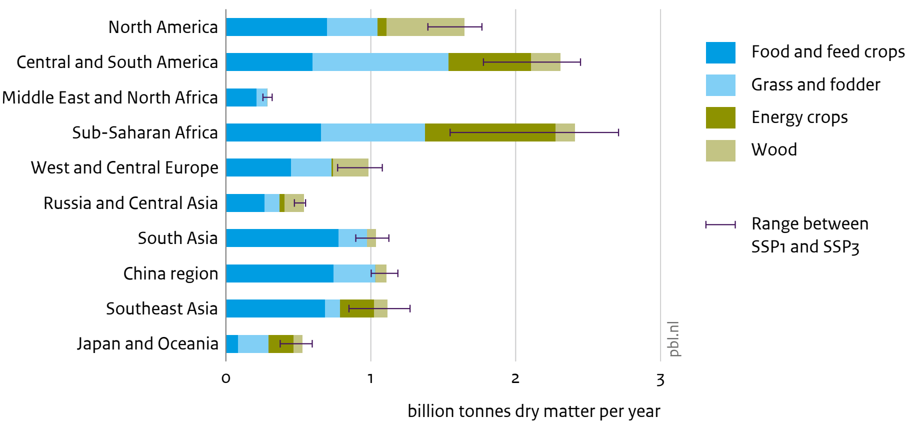
Figure 4.10
Land-use change per region, under SSP2, 2010 – 2050



Source: PBL

For the China region, a different scenario than the SSP2 Baseline scenario can mean a relatively large difference in land-use change.

Figure 4.11
Agricultural production per region, under SSP2, 2050

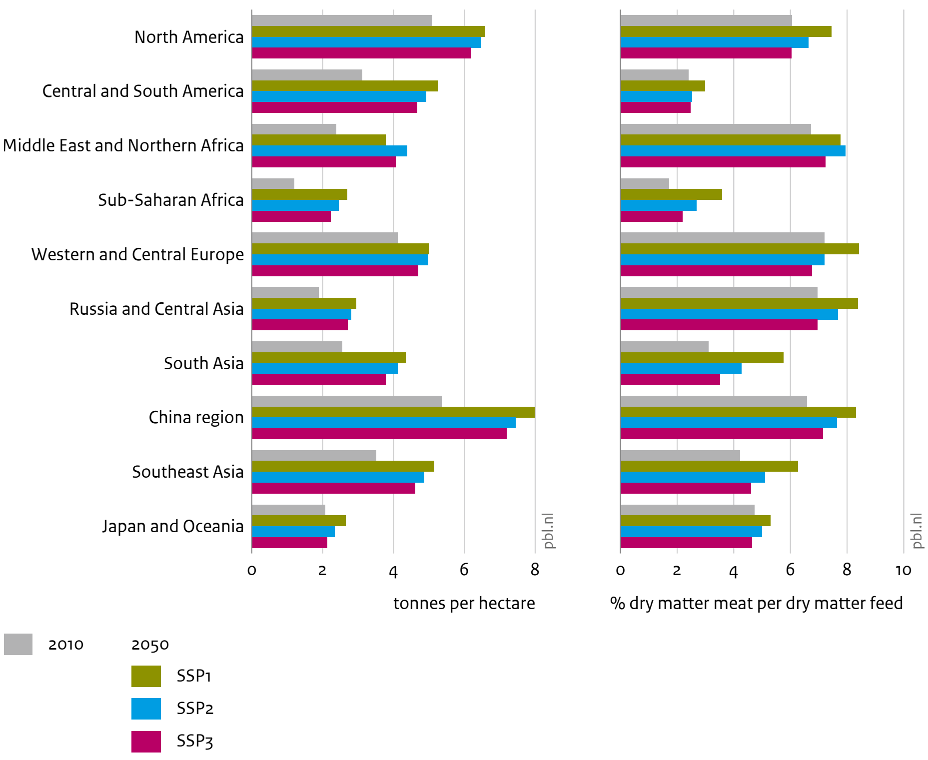


Source: PBL

If demand for land products were to increase strongly beyond SSP2 projections, additional agricultural production would have to come from making marginal lands much more productive, or from imports. This is apparent in Figure 4.13.

On the whole, the Global Land Outlook categorises China as a region facing challenges that are relatively small, compared to the land-related challenges faced by a number of other regions. However, bearing in mind that China has almost no margin when it comes to remaining land suitable for agriculture, it is significant that **other pathways than our SSP2 baseline would bring relatively large differences** in China's projected demand for agricultural land: either much less or much more (Figure 4.10). Therefore, elements of China's green transition that influence land demand may not bring huge changes by 2050 but are nevertheless significant in terms of ensuring that upward pressure on land demand is managed, given that there is not much more suitable land available. Such elements include agricultural productivity, the proportion of meat in the human diet, bioenergy production and, locally, urbanisation (on the latter, see Bren d'Amour et al., 2017).

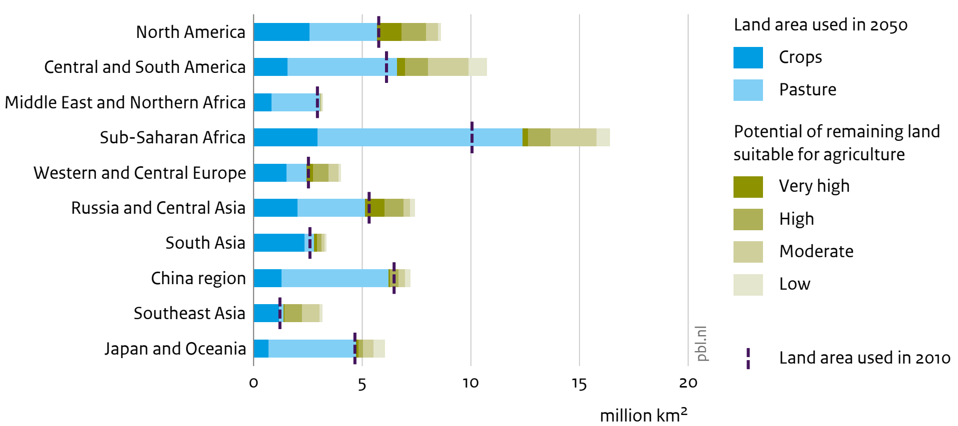
Figure 4.12
Crop yield and livestock efficiency per region



Source: PBL

Under the conditions of the baseline scenario, agricultural production in the China region is projected to be comparatively stable.

Figure 4.13
Agricultural land use and remaining suitable land per region, under SSP2

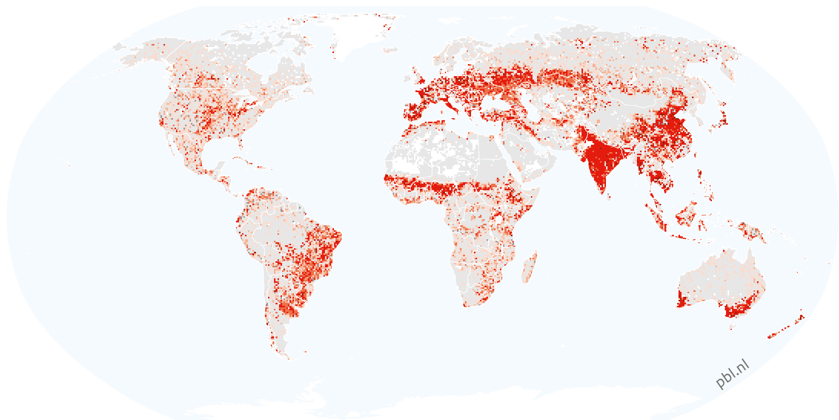


Source: PBL

Not much more suitable land will be available for agriculture in the China region, over the period up to 2050.

Figure 4.14

Change in soil organic carbon, compared to natural situation, 2010



Percentage loss

- 50 and more
- 30 – 50
- 20 – 30
- 10 – 20
- 2 – 10
- 2% loss – 2% growth
- More than 2% growth
- No data

Source: Stoorvogel et al. 2017; Schut et al. 2015; PBL

The China region is among the world regions in which a relatively high amount of soil organic carbon has been lost.

China is one of the world regions in which a large proportion of soil organic carbon (i.e. natural soil productivity) has been lost. This translates into challenges for agricultural production, water availability, and water regulation and quality in river systems, as well as carbon storage potential (see Figure 4.14). China is also a country with large differences in net primary productivity potentials (Figure 4.15), and land management appears to have negatively affected net primary productivity consistently over the past 30 years on at least 7% of China's land area. Soil organic carbon and net primary productivity are key indicators under the UNCCD.

Climate change is projected to affect agricultural production in different ways, depending on the location. At the global level, yields are projected to be about 10% lower on average than they would have been without climate change (van Meijl et al., 2017). For China, the challenge is the way in which climate change is projected to affect the location of agricultural production and associated land use, given the spatial distribution of agricultural production in eastern China.

China's contribution

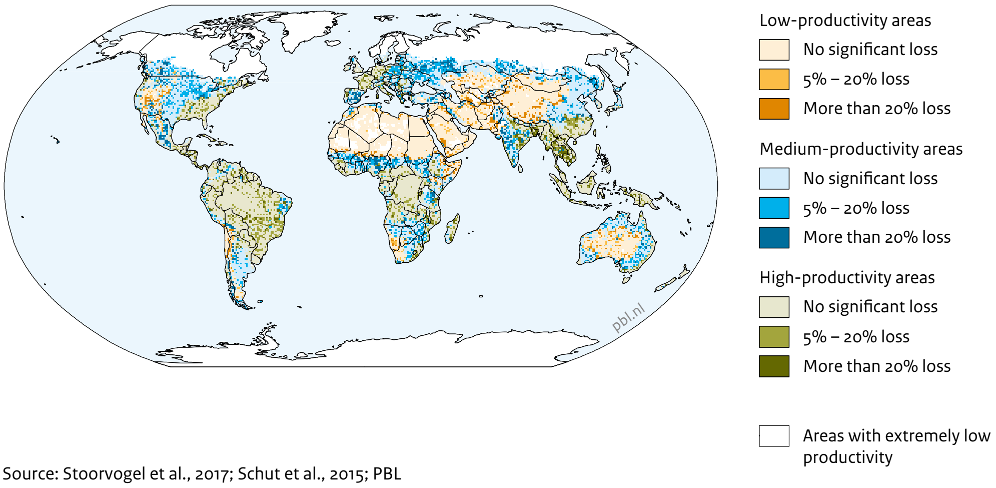
The largest potential contribution of China's green transition to managing global land resources and the global food system is arguably to **keep its own agricultural system stable** in a world that otherwise will be facing very challenging decades on this theme. As noted before, diet and agricultural productivity are the key balancing factors. By illustration, China's net imports of food by 2050 under the conditions of the SSP2 Baseline scenario are projected to be relatively modest, while different scenarios feature much larger imports (Figure 4.16).

Opportunities for China's green transition to contribute in a significant way to the worldwide management of land resources appear in two findings of the scenario exercise. First, projected land-use changes in sub-Saharan Africa towards 2050 dwarf those in other world regions. China's large investments in the region represent leverage in making African agriculture and agricultural land management cope with its challenges – assuming China and Chinese investors do indeed have good land management practices to export over the coming decades.

Second, the potential for reforestation and the discontinuation of agricultural land use in the least productive areas appears relatively large in China in the worldwide projections. This may signal a need to develop a more robust assessment of this dynamic, including potential ways of adapting abandoned agricultural areas for other uses and exploiting the potential for refore-station. Important factors that will determine land dynamics in the coming decades include advances in agricultural efficiency, demand for agricultural products, reforestation for carbon sequestration, bioenergy

Figure 4.15
Net primary production

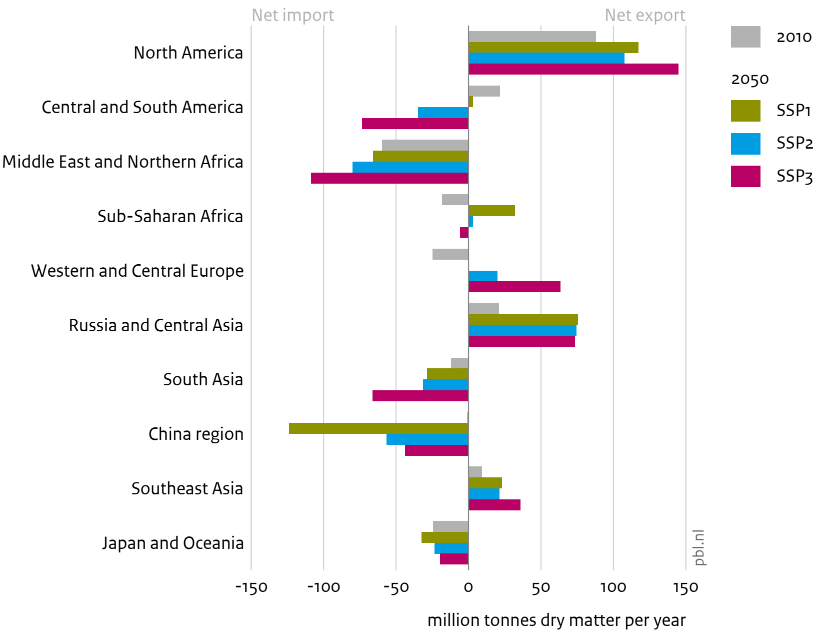
2010 compared to natural conditions



Source: Stoorvogel et al., 2017; Schut et al., 2015; PBL

Nearly a quarter of the global land area shows a productivity that is less than it would have been under undisturbed conditions.

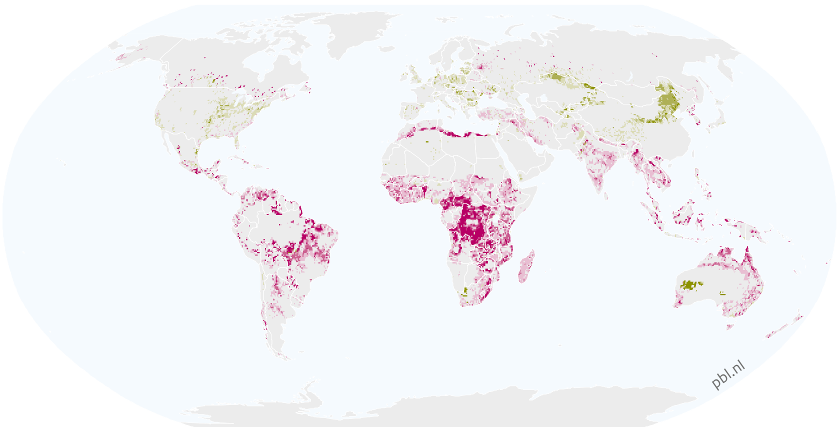
Figure 4.16
Net trade of primary agricultural products per region



Source: PBL; Wageningen Economic Research

The SSP2 Baseline scenario sees a modest increase in the import of primary agricultural products into the China region by 2050. The SSP1 scenario would see a stronger increase.

Figure 4.17
Land-use change SSP2 scenario, 2010 – 2050



Deforestation and conversion of other natural land (% change per grid cell)

Change of agricultural land into forest (reforestation) or other natural land (% change per grid cell)

Under the conditions of the SSP2 Baseline scenario, the China region would see a potential for reforestation in the coming decades (Van der Esch, 2017; Popp et al., 2017; Doelman et al., in review).

production and, in the China region, knowledge on large-scale reforestation in order to revert desertification. While not explicitly addressed in the Global Land Outlook, the latter would provide a useful experience for other regions too (see Figure 4.17). On a general note, restoration experiences could be transplanted to other regions very well and, up to now, there appears to be little international standardisation and knowledge in this area.

Constraints and synergies for China's green transition. This concerns **soil quality**. The relatively large loss of soil organic carbon is not irreparable under a consistent policy framework that promotes land management practices that conserve and restore soils. A balanced retreat from overly high-input agricultural practices, as foreseen in China's Green Transition Pathway, would be one element of this. Improved land and soil management could be a key component in managing other environmental challenges such as river flow and water availability.

A significant **regional risk** appears when the scenario outcomes for the Global Land Outlook are viewed together. While China is assessed as a region with relatively small land-related challenges up to 2050, neighbouring South Asia ranks as facing the most difficult challenges. South Asia comprises India, Pakistan and Bangladesh. The only other part of the world with such unenviable prospects is Africa and the Middle East. Up to 2050, these regions face a combination of high levels of population growth, also in dryland areas, low levels of GDP, marked increases in water stress, limited protein intake, dependence on imports for the food supply, low crop yields, intense pressure to expand agricultural land use and large historical and ongoing productivity loss (Van der Esch et al., 2017, pp. 84–87). In South Asia, farmers are typically smallholders and therefore vulnerable. It should also be noted that water is a key factor in many of these developments.

Note

1 In IMAGE, the Democratic People's Republic of Korea and the Republic of Korea are modelled as one region. However, energy intensity statistics are dominated by the figures for the Republic of Korea.

Robustness and uncertainty of the model-based analyses

The IMAGE framework is used in this study to analyse the global environmental implications of China's Green Transition Pathway as quantified by the Development Research Centre of the State Council of China. Over the past decades, the IMAGE framework has been used for several global and regional environmental analyses, including UNEP's Global Environmental Outlooks, the OECD Environmental Outlooks and the IPCC's work. The IMAGE framework is reviewed regularly by a peer review panel and most components have been published in the scientific literature.
The current report primarily presents energy and climate change results. Comparable projections for land-use change, prepared for the Global Land Outlook, have also been included.

The IMAGE model has been designed to represent global environmental change. For this, the model includes 26 global regions to represent the heterogeneity in environmental and development trends. One of these regions is the China region. This, however, does not mean that IMAGE can be simply applied to assess China's development. The global focus of the model means that it can only represent each region at an aggregated level. Especially detailed elements of the Chinese energy system as well as the Chinese energy and climate policies are only partly represented. However, to strengthen the analysis, DRC data has been used to calibrate IMAGE for the China region. In doing so, details from Chinese regional analysis have been incorporated in a global energy and climate change analysis, making this study better suited to grasping the global environmental implications of China's Green Transition Pathway.

Some generic aspects of uncertainty in the IMAGE framework are outlined below (based on Stehfest et al., 2014).

Structural and methodological uncertainty

Structural and methodological uncertainty (incomplete knowledge of relationships) exists in many parts of the IMAGE framework. This uncertainty can be addressed to some extent by alternative model formulations. Structural uncertainty can also be addressed in model inter-comparison studies and other multi-model studies to compare IMAGE results with the range of outcomes from other models and with results for ranges found in the literature, and to provide information on model functioning. The overall model uncertainty arising from uncertain processes and data can be assessed in systematic sensitivity analyses. This has been done, for example, for many parameters of the energy model TIMER (Van Vuuren, 2007). Key uncertainties relate for instance to the question how fast efficiency measures are implemented and what role saturation processes play in consumption patterns.

Development of driving forces

Uncertainty in the future development of driving forces such as population, economic growth and technology is mostly addressed by exploring variants in assumed reference pathways, such as high/low variants of population projections or different starting years and horizon years, or by assuming contrasting future scenarios. Similarly, uncertainty in policy targets and societal trends is addressed by exploring alternative scenarios and varying one or more key input parameters, such as learning-by-doing parameters, human diet composition or other lifestyle choices. This uncertainty analysis methodology is applied via the different story lines of the Shared Socio-economic Pathways, of which one underlies our model-based analysis.

Level of aggregation

A distinct source of uncertainty arises from the level of aggregation, with socio-economic processes represented by 26 regions, and the terrestrial biosphere modelled at 5 or 30 minute grid cells. At the regional and grid cell level, all behaviour is average behaviour and does not take into account heterogeneity within a region (e.g. in income distribution, economy or farming systems) or a grid cell (e.g. climate, soil or landscape composition). Major differences between countries in a world region are masked and all future trends apply to the average, although countries may actually develop along different pathways.

Maturity of knowledge

Projections made for the well-established fields of energy, climate and air pollution are considered relatively accurate. By contrast, projections made for the much younger fields of land-use change and land degradation are relatively uncertain, especially when modelling these changes worldwide. This is a matter of structural and methodological uncertainty, as explained above. For example, different modelling teams apply different levels, rates and dependencies in future agricultural intensification. They also apply different issue frames. In particular, a number of processes that will contribute to future land scarcity are not fully understood, such as impacts of climate change, land degradation and restoration, and new societal ambitions to protect biodiversity or to limit future climate change.

While the overall balance between demand for and availability of land for agriculture is modelled with relative confidence, the resulting future shifts in global and regional land use cannot be assessed with great precision. Maps are nevertheless shown routinely, also in this report, as they convey the pattern of future pressures and changes. They do not however show the exact locations of such changes.

Contributions made by IMAGE to the Global Land Outlook, of which selected results are incorporated in this report, address these uncertainties with a mix of inter-model comparison, add-on sensitivity analyses and by setting some issues aside for later work (Van der Esch et al., 2017).

Conditionality of the projections

Our analysis of the worldwide impacts of China's green transition takes its cues from the projections by the DRC. These projections are made in terms of the development of key drivers (e.g. population) as well as energy use. Our assessment does not, strictly speaking, certify their plausibility, but is presented in terms of *if* (these projections materialise), *then* (the implications would be …….). In addition, our comparison with recent authoritative scenarios illuminates how ambitiously green the projections for China's green transition are.

Moreover, both the task force report (CCICED, in prep.) and our own assessment highlight some key conditions for this transition to be successful and environmentally beneficial. Many of these conditions are in fact government policy requirements, as outlined in the recommendations of the task force in key areas, such as green industry promotion policies focusing on fair competition.

Our own assessment highlights conditions that need to be fulfilled in order to realise government targets that have already been set. For example, targets such as capping the consumption of primary energy at 5 and 6 billion tce by 2020 and 2030, respectively. In addition, the new business models of the internet economy, of China's fast-growing service sector and of the changing urban-rural interface are as yet unknown and the subject of high expectation. What is certain is that they will raise important challenges that need to be addressed in time. Examples are the transport and waste implications of the famous last mile delivery on behalf of online suppliers, or the landscape implications of renewable energy or an expanding 'experience' tourism industry. The main findings section of this report consolidates our observations on this theme as a short, non-exhaustive list of conditions.

Robustness of conclusions

Whether, and to what extent, these uncertainties actually matter for the robustness of the conclusions of this report has not been explicitly tested. After all, our assessment is meant to be a kick-start only. Explicit evaluations of robustness have been carried out, for example, on IMAGE-based work for the OECD Environmental Outlook (MNP/PBL and OECD, 2008; OECD, 2008) and for global biodiversity (PBL, 2010). However, we are confident that our supporting assessment on the worldwide context amply matches the parent report of the CCICED Green Transition Task Force in accuracy and precision.
Both apply a broad brush.

One important limitation of our work should be underlined, namely that it views the China region as a whole. Further differentiation in dynamics and impacts within China, however important to China's green transition, cannot be distilled from our analysis.
This limits the applicability of our findings to the global view, in keeping with our assignment.

Conclusion of the model-based analyses

In our model-based analysis, we looked into possible development trajectories for the economy and energy system in China in a worldwide context. We also considered the results of comparable work on land resources. The analysis leads to five conclusions.

China's Green Transition Pathway as elaborated by DRC shows important similarities with the scenarios used in international studies. In general, the overall trends in the Green Transition Pathway lie within the bandwith of the IMAGE-SSP scenarios. Still, there are differences in some areas, such as the size of the service sector. Furthermore, China's Green Transition Pathway is characterised by a less dominant role of coal than in any of the SSPs, as well as a larger share of solar and wind. The international comparison emphasises that for this, very strong environmental policies will be needed.

China's Green Transition Pathway reduces energy consumption, greenhouse gas emissions and the emissions of important air pollutants. China's share in global energy use and emissions is larger than that of any other country and China is expected to keep this role in the future. In terms of per-capita resource use, however, consumption in China is often comparable to current high-income countries. The important role of China means that development impacts reach far beyond its borders. The implementation of China's Green Transition Pathway reduces China's share in global carbon dioxide emissions and energy use, and leads to less emissions than currently included in most international baseline scenarios. Therefore, clearly, China's Green Transition Pathway will require additional policy efforts.

As the comparison with baseline projections shows, energy demand sector efficiency improvements are required. In addition, the use of coal should be massively reduced and efforts are required to increase the share of renewable energy such as wind and solar in the overall energy supply.

International current and planned global policies and China's Green Transition Pathway are not enough to achieve a two-degree target. Additional mitigation efforts are required to further reduce greenhouse gas emissions. Most of the additional greenhouse gas emission reductions are achieved by further reducing non-CCS fossil fuel use and replacing it with low-carbon alternatives. Global climate change mitigation in the Two-degree Climate Policy projections do not consider the issue of equity, as equal carbon taxes are applied for all regions to achieve the climate target. Depending on the burden-sharing rules, the required Chinese efforts could become smaller or larger, and China's Green Transition Pathway emissions trajectory could be closer to, or further away from, a two-degree Celsius global warming trajectory.

Total land demand for agriculture in China is projected to remain stable under the conditions of the global baseline scenario. However, other scenarios would bring land-use changes that largely differ from the baseline development, compared to other world regions. China has little margin in terms of available suitable land, which means that elements of China's green transition that influence land demand remain significant. These include agricultural productivity, the proportion of meat in the human diet, bioenergy production and, in specific areas, urbanisation.

In terms of land resources the worldwide context of China's green transition looks problematic. Pressures on land resources – soil, water, biodiversity – worldwide will allegedly become larger than at any other time in human history (United Nations Convention to Combat Desertification, 2017). Keeping China's agricultural demand and production stable during the coming decades, while carefully retreating from overly high-input practices, would arguably be China's largest contribution to managing global land resources and the global food system. Specific risks emerge, in particular a very difficult combination of challenges in neighbouring South Asia (Van der Esch et al., 2017). Opportunities emerge as well, such as China's leverage in Africa and its potentially exportable experiences in large-scale reforestation.

六、模型分析结果

在模型分析中，我们研究了在全球背景下中国经济和能源体系的可能的发展轨迹，同时也考虑了土地资源的相应分析成果。分析得出如下五个结论：

国务院发展研究中心的《中国绿色转型路径》与相关国际研究中使用的情景分析具有重要的相似之处。然而，CGTP预测的煤炭使用量急剧下降则与国际研究成果不符。大量减少煤炭使用量只有通过实施雄心勃勃而且经过深思熟虑的政策才能实现。总的来说，我们发现绿色转型路径的总体趋势与IMAGE-SSP情景有很好的相似性，但是在某些方面存在差异，例如服务业的规模。此外，《中国绿色转型路径》的特点是煤炭的主导作用与任何一个SSPs相比都要小，而太阳能和风能所占份额比较大。国际对比研究强调了这一点，为此，将需要非常强有力的环境政策。

中国绿色转型路径将减少能源消耗，温室气体排放和重要空气污染物排放。中国在全球能源使用和排放中的份额大于任何其他国家，在未来将很可能继续保持这一地位。然而，在人均资源使用方面，中国的消费水平往往与目前的高收入国家相当。中国的重要作用意味着中国的发展影响远远超出中国国界。中国绿色转型路径的实施可以减少中国在全球二氧化碳排放和能源消耗中的份额。绿色转型后的排放量将比目前大多数国际基准情景下的排放量还要低。因此，很显然，中国的绿色转型将需要额外的政策支持。与基准预测的比较表明，能源需求部门需要提高效率。此外，还要大力减少使用煤炭，努力提高风能和太阳能等可再生能源在整体能源供应中的份额。

国际上当前的和计划中的全球政策以及中国绿色转型还不足以实现2oC目标，还需要付出更多的努力减少温室气体排放。大部分额外的温室气体减排都可以通过进一步减少非CCS化石燃料的使用并用低碳替代品替代得以实现。2oC气候政策预测中的全球气候变化减缓措施不考虑公平问题，因为所有地区实行平等碳税以实现气候变化目标。根据责任分摊规则，中国所需的努力可能会变小或者增大，中国绿色转型路径的排放轨迹可能更接近或远离2oC全球变暖轨迹。

在全球基准情景下，中国农业土地总需求预计将保持稳定。然而，其他情景会带来相对较大的差异。中国几乎没有多余的适用农业土地。因此，在中国绿色转型中那些影响土地需求的要素仍然十分重要。它们包括农业生产力、肉类在饮食结构中的比例、生物能源生产，以及城镇化。

在土地资源（如土壤、水资源、生物多样性）方面，中国绿色转型的全球背景看起来是存在问题的。据称，世界范围内的土地资源压力将大于人类历史上的任何时候（“联合国防治荒漠化公约”，2017年）。在未来几十年中国的农业需求和生产保持稳定，同时从过度投入的耕作方法中谨慎回归，有可能成为中国对管理全球土地资源和全球粮食体系的最大贡献。风险已经显现，特别是邻近南亚国家面临的复杂困局(Van der Esch et al., 2017)。机遇也日臻显现，例如中国在非洲的作用，以及在大规模植树造林方面潜在的值得借鉴的经验。

References

Bondeau A, Smith PC, Zaehle S, Schaphoff S, Lucht W, Cramer W, … and Smith B. (2007). Modelling the role of agriculture for the 20th century global terrestrial carbon balance. Global Change Biology, 13(3), 679–706. https://doi.org/10.1111/j.1365-2486.2006.01305.x

Bren d'Amour C, Reitsma F, Baiocchi G, Barthel S, Güneralp B, Erb K-H, and Seto KC. (2017). Future urban land expansion and implications for global croplands. Proceedings of the National Academy of Sciences, 114(34), 8939-8944. https://doi.org/10.1073/pnas.1606036114.

CCICED (in prep.). Speeding Up the Green Transition: China's Potential to 2050. CCICED (China Council for International Collaboration on Environment and Development).

CCICED (2013). Study on China's Environmental Protection and Social Development. Executive report. Beijing, China: CCICED (China Council for International Collaboration on Environment and Development).

CCICED (2016). Interim Report of 'China Green Transition Outlook 2020–2050' Project. CCICED (China Council for International Collaboration on Environment and Development).

Clarke L, Jiang K, Akimoto K, Babiker M, Blanford G, Fisher-Vanden K, … and Van Vuuren DP. (2014). Assessing Transformation Pathways (Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Cambridge (UK) and New York, NY: Cambridge University Press.

Dellink R, Chateau J, Lanzi E and Magné B. (2017). Long-term economic growth projections in the Shared Socioeconomic Pathways. Global Environmental Change, 42, 200-214. https://doi.org/10.1016/j.gloenvcha.2015.06.004

ERI (2016). Global Energy Governance Reform and China's Participation. China's Energy Research Institute (ERI). Grantham Institute at Imperial College London.

Green F and Stern N. (2015). China's 'new normal': structural change, better growth, and peak emissions (Policy brief). Leeds: Centre for Climate Change Economics and Policy, Grantham Research Institute on Climate Change and the Environment. Retrieved from http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2015/06/Chinas_new_normal_green_stern_June_2015.pdf.

IEA (2016a). Partner Country Series - China's Engagement in Global Energy Governance. International Energy Agency, Paris.

IEA (2016b). World Energy Outlook 2016. IEA. https://doi.org/10.1787/weo-2016-en.

IEA (2017). World Energy Balances 2017. IEA. https://doi.org/10.1787/world_energy_bal-2017-en.

KC S and Lutz W. (2017). The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. Global Environmental Change, 42, 181–192. https://doi.org/10.1016/j.gloenvcha.2014.06.004.

Krey V, Masera G, Blanford G, Bruckner T, Cooke R, Fisher-Vanden K, … and Zwickel T. (2014). Annex II: Metrics & Methodology (Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Cambridge (UK) and New York, NY: Cambridge University Press.

Meinshausen M, Wigley TML and Raper SCB. (2011). Emulating atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6 – Part 2: Applications. Atmospheric Chemistry and Physics, 11(4), 1457–1471. https://doi.org/10.5194/acp-11-1457-2011.

MNP/PBL and OECD. (2008). Background report to the OECD Environmental Outlook to 2030. Overviews, details, and methodology of model-based analysis. MNP/PBL Netherlands Environmental Assessment Agency, The Hague, and Organisation for Economic Co-operation and Development, Paris.

Müller C, Stehfest E, Van Minnen JG, Strengers B, Von Bloh W, Beusen AHW, … and Lucht W. (2016). Drivers and patterns of land biosphere carbon balance reversal. Environmental Research Letters, 11(4), 044002. https://doi.org/10.1088/1748-9326/11/4/044002.

National Energy Administration. (2017). "十三五"能源消费增速年均在2.5%左右---国家能源局. Retrieved August 21, 2017, from http://www.nea.gov.cn/2017-01/05/c_135957436.htm

OECD (Ed.) (2008). OECD environmental outlook to 2030. Organisation for Economic Co-operation and Development, Paris.

OECD (2012). OECD Environmental Outlook to 2050. OECD Publishing. https://doi.org/10.1787/9789264122246-en.

Olivier JGJ, Janssens-Maenhout G, Muntean M and Peters JAHW. (2016). Trends in global CO_2 emissions: 2016

Report (No. JRC103425, PBL2315). Joint Research Centre (JRC), Directorate C - Energy, Transport and Climate; PBL Netherlands Environmental Assessment Agency, The Hague.

O'Neill BC, Kriegler E, Ebi KL, Kemp-Benedict E, Riahi K, Rothman DS, … and Solecki W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change, 42, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004.

O'Neill BC, Kriegler E, Riahi K, Ebi KL, Hallegatte S, Carter TR, … and Van Vuuren DP. (2014). A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Climatic Change, 122(3), 387–400. https://doi.org/10.1007/s10584-013-0905-2.

PBL (2010). Rethinking Global Biodiversity Strategies: Exploring structural changes in production and consumption to reduce biodiversity loss. PBL Netherlands Environmental Assessment Agency, in cooperation with Agricultural Economics Research Institute of Wageningen University and Research Centre and Sea Around Us Project of the Fisheries Centre of the University of British Columbia, Canada.

PIB Clean Coal (2017). PIB Clean Coal, Research report on Air Emissions regulations in China. Energy Research Centre of The Netherlands on behalf of PIB Clean Coal.

Popp A, Calvin K, Fujimori S, Havlik P, Humpenöder F, Stehfest E, and Van Vuuren DP. (2017). Land-use futures in the shared socio-economic pathways. Global Environmental Change, 42, 331–345. https://doi.org/10.1016/j.gloenvcha.2016.10.002.

Rao S, Klimont Z, Smith SJ, Van Dingenen R, Dentener F, Bouwman L, … and Tavoni M. (2017). Future air pollution in the Shared Socio-economic Pathways. Global Environmental Change, 42, 346–358. https://doi.org/10.1016/j.gloenvcha.2016.05.012.

Roelfsema M. (submitted). The impact of national climate policies on GHG emissions in the first half of the 21st century.

Schut AGT, Ivits E, Conijn JG, Ten Brink B and Fensholt R. (2015). Trends in Global Vegetation Activity and Climatic Drivers Indicate a Decoupled Response to Climate Change. PLOS ONE, 10(10), e0138013. https://doi.org/10.1371/journal.pone.0138013.

State Council Information Office. (2017). 《"十三五"生态环境保护规划》政策解读. Retrieved August 21, 2017, from http://www.scio.gov.cn/34473/34515/Document/1520094/1520094.htm.

Stehfest E, Van Vuuren D, Kram T, Bouwman L, Alkemade R, Bakkenes M, … and Prins A. (2014). Integrated assessment of global environmental change with IMAGE 3.0: model description and policy applications. PBL Netherlands Environmental Assessment Agency, The Hague.

Stoorvogel JJ, Bakkenes M, Temme AJAM, Batjes NH and Ten Brink BJE. (2017). S-World: A Global Soil Map for Environmental Modelling: S-World: A Global Soil Map for Environmental Modelling. Land Degradation & Development, 28(1), 22–33. https://doi.org/10.1002/ldr.2656.

United Nations Convention to Combat Desertification. (2017). The Global Land Outlook, first edition. Bonn, Germany.

Van der Esch S, Ten Brink B, Stehfest E, Bakkenes M, Sewell A, Bouwman A, … and Van den Berg M. (2017). Exploring future changes in land use and land condition and the impacts on food, water, climate change and biodiversity: Scenarios for the Global Land Outlook. PBL Netherlands Environmental Assessment Agency, The Hague.

Van Meijl H, Havlik P, Lotze-Campen H, Stehfest E, Witzke P, Domínguez IP, … and Valin H. (2017). Challenges of Global Agriculture in a Climate Change Context by 2050 (AgCLIM50). (No. JRC Science for Policy Report, EUR 28649 EN, doi:10.2760/772445). European Commission, Joint Research Centre (JRC).

Van Vuuren DP. (2007). Energy systems and climate policy: Long-term scenarios for an uncertain future. Utrecht University, Utrecht.

Van Vuuren DP, Stehfest E, Gernaat DEHJ, Doelman JC, Van den Berg M, Harmsen M, … and Tabeau A. (2017). Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. Global Environmental Change, 42, 237–250. https://doi.org/10.1016/j.gloenvcha.2016.05.008.

Woltjer G, Kuiper M, Kavallari A, Van Meijl H, Powell J, Rutten M, … and Tabeau A. (2014). The MAGNET Model: Module description. LEI Wageningen UR, Wageningen.

Zhang Q and Crooks R. (2012). Toward an environmentally sustainable future: Country environmental analysis of the People's Republic of China. Asian Development Bank.

Supplementary material

Box A1.1: Key characteristics of China's Green Transition Pathway for energy and climate

	Based on:
1 The total population of China will peak at 1.4 billion in around 2025, and the urbanisation rate will reach 70% by 2030.	- UN Baseline Forecast plus Two-children Policy
2 The total consumption of primary energy should be less than 5 billion tce by 2020 and 6 billion tce by 2030. Total consumption should level off by 2050.	- 13th Five-year Energy Development Plan - The Strategy of Energy Production and Consumption Revolution
3 The non-fossil fuel share should be more than 15% by 2020, and around 20% by 2030. The increase in energy consumption from 2020–2030 should be in clean energy.	- 13th Five- year Environment Protection Plan
4 CO_2 emissions should peak in around 2030.	
5 The industrialisation path of China is similar to East Asian economies, such as those of Japan and South Korea.	- International comparison

DRC, *pers. comm.*

Appendix 1: China's green transition

The Development Research Centre (DRC) of the State Council of China has formulated a quantified green transition development path for China. This is intended as a tool for the study of the Task Force on China's Green Transition Outlook to 2050, reporting to the China Council for International Collaboration on Environment and Development (CCICED). The development path and its quantification by the DRC are referred to here as China's Green Transition Pathway (CGTP). The study by the CCICED Task Force, to which both the DRC work and the present study contribute, will address important changes in a very wide range of issues, sectors and policy areas. Relative to the task force study, the present study focuses on a more limited range of issues. Among these, energy use is of key importance.

Regarding energy use in the coming decades, China's Green Transition Pathway is based on envisaged policies described in the 13th Five-year Energy Development Plan, the Strategy of Energy Production and Consumption Revolution and the 13th Five-year Environment Protection Plan. The scenario intends to break away from the current energy intensity (i.e. energy use per GDP) trends and forms the basis of the analysis in this report. The five key developments quoted in Box A1 underlie this projected greener future.

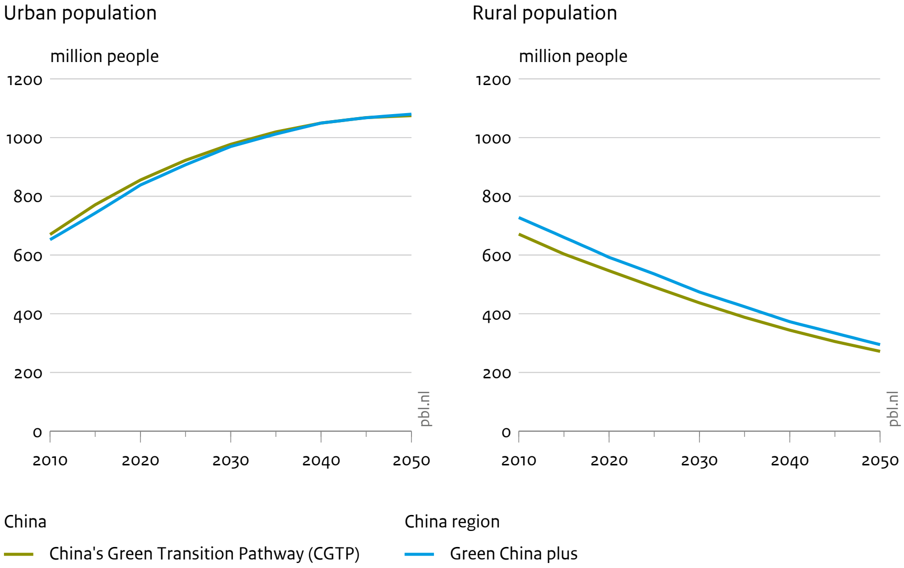
Appendix 2: Details on the Green China plus scenario

This appendix elaborates on how China's Green Transition Pathway by DRC is incorporated in the Green China plus scenario. It should be noted that the IMAGE China region comprises mainland China, Hong Kong, Macau and Taiwan, as well as Mongolia.

Key drivers
Population growth rates have been adopted from China's Green Transition Pathway and applied to the IMAGE SSP2 population data. Figure A2.1 shows that the final population projections in the Green China plus scenario correspond well with China's Green Transition Pathway assumptions.

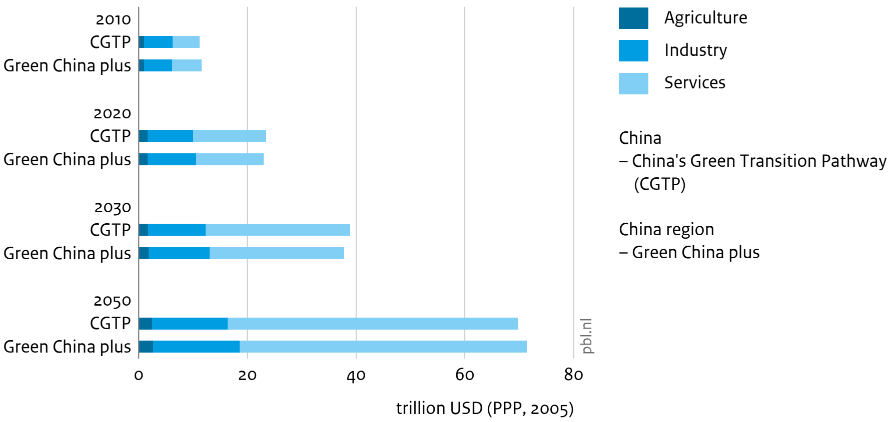
The growth rates of added value per sector have also been applied to the sectoral added value in IMAGE's SSP2. This resulted in an almost perfect match (Figure A2.2), as absolute sectoral GDP data from China's Green Transition Pathway were unavailable and replaced with IMAGE's SSP2 input.

Figure A2.1
Population in China



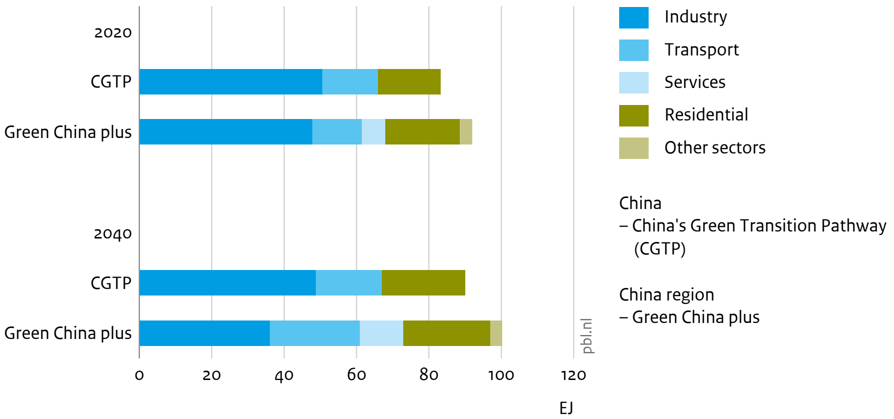
Source: PBL; DRC

Figure A2.2
Gross Domestic Product (GDP) of China



Source: PBL; DRC

Figure A2.3
Final energy demand in China

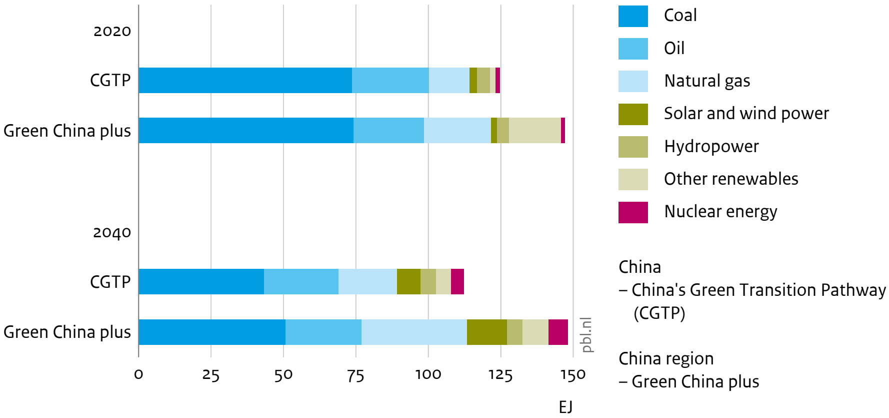


Source: PBL; DRC

Energy
By implementing the sectoral added value growth rates from China's Green Transition Pathway and the worldwide policies assumed by Roelfsema et al. (submitted), the following final energy demand in the Green China plus scenario was obtained (Figure A2.3). The service sector and other sectors are not included in DRC's China's Green Transition Pathway projections. In 2040, there is a slight mismatch between the other sectors, as IMAGE projects a decrease in industrial energy demand due to efficiency improvements. In contrast, IMAGE projects slightly fewer efficiency improvements in the transport sector, resulting in a larger energy demand.

The primary energy supply mix in the Green China plus scenario makes use of the assumptions by Roelfsema et al. (submitted). This scenario contains, for instance, renewable capacity goals for the Chinese power sector. China's renewable capacity targets from Roelfsma et al. were strengthened for the Green China plus scenario. Also, no new construction of coal fired power plants was allowed. Figure A2.4 shows that the energy source shares match reasonably well. There is, however, still quite a difference in the primary energy supply between China's Green Transition Pathway and the Green China plus scenario used in this analysis. This is partly due to the higher efficiency improvements assumed in China's Green Transition Pathway and partly due to the lower demand observed in Figure A2.3.
Fuel-to-electricity efficiencies for wind power, solar power, hydropower and nuclear energy were set to one. As a result, the contribution of renewable energy to primary energy looks rather limited, compared to its share in final energy supply.

Figure A2.4
Primary energy supply in China



Source: PBL; DRC

Abbreviations

BC:	black carbon
bn:	billion (10^9)
BRICS	Brazil, Russia, India, China, South Africa
cap.:	capita
CCICED:	China Council for International Cooperation on Environment and Development
CCS:	carbon capture and storage
CGE:	computable general equilibrium
CGTP:	China's Green Transition Pathway
CO_2:	carbon dioxide
DRC:	Development Research Centre of the State Council (of China)
EJ:	exajoule (10^{18} joules)
ETS:	emissions trading scheme
FAO:	Food and Agriculture Organization
GDP:	gross domestic product
GJ:	gigajoule (10^9 joules). Equals 0.0341 tce
Gt:	gigatonne (10^9 tonnes)
IAM:	integrated assessment model
IEA:	International Energy Agency
IMAGE:	Integrated Model to Assess the Global Environment
kWh:	kilowatt hour
LPJmL:	Lund-Potsdam-Jena managed Land model
MAGICC:	Model for the Assessment of Greenhouse-gas Induced Climate Change
MAGNET:	Modular Applied General Equilibrium Tool
Mt	million (10^6) tonnes
NO_x:	nitrogen oxides
OECD:	Organisation for Economic Co-operation and Development
PBL:	PBL Netherlands Environmental Assessment Agency
SO_2:	sulphur dioxide
SSPs:	shared socio-economic pathways
t:	tonne
tce:	tonne of coal equivalent
TIMER:	Targets IMage Energy Regional simulation model
TJ	terajoule (10^{12} joules)
USD:	United States dollar
UU:	Utrecht University
W/m^2	watts per square metre
WEO:	World Energy Outlook
WHO:	World Health Organization
°C:	degree Celsius

PBL Netherlands Environmental Assessment Agency

Mailing address
PO Box 30314
2500 GH The Hague
The Netherlands

www.pbl.nl/en

January 2018