Chapter 5

An integrated look at the nexus bottlenecks

This chapter first identifies general patterns that emerge in the way the bottlenecks affect the different policy objectives laid out in Chapter 1. It then discusses the major trade-offs and synergies between the bottlenecks at the regional level. The chapter ends with putting the analysis in this report into context, including a discussion of the robustness of the results.

5.1. An integrated look at the nexus for the various policy objectives

This section looks at the different policy objectives laid out in Section 1.2 and especially Figure 1.1: welfare, environmental quality, food security, water security and energy security. The aim is to identify general patterns that emerge across the different bottlenecks in the way the bottlenecks affect these objectives.

Welfare

In terms of the welfare effects of the nexus bottlenecks, it is clear that the constraints posed by the bottlenecks tend to lead on balance to relatively modest negative effects at the global level, depressing GDP and consumption levels to somewhat below their baseline level. But there are always some countries which can benefit from the changes in international competitiveness of countries. Especially the ASEAN economies and countries in Latin America can benefit from the fact that their competitive position is less affected than that of their major trading partners. Thus, they can reap a larger share of the global market. This is not least driven by the fact that these countries are capable of expanding their land use at relatively low costs to accommodate the bottlenecks and thus avoid major price increases.

At the other end of the spectrum are the countries that rely heavily on the scarce resources. This is especially the case for the water resource in India and the land resource in China. The various bottlenecks also strengthen the negative welfare effect in India, highlighting the role of this region as a fragile hotspot. Section 5.2 teases out these regional effects in more detail. The quantitative analysis also illustrates how the exploitation of the least critical (or scarce) resource can overcome the negative economic consequences of the other resources.

Although the modelling assessment cannot quantify the effects on different household groups, the increasing food prices (see also the discussion on food security below) that result from all three nexus bottlenecks, suggest that the welfare of the poorest households may be especially adversely affected. Especially in the countries with a negative effect on consumption will increases in food prices and the associated increase in the budget share of households spent on food lead to equity concerns that warrant further investigation.

Environmental quality

Two main effects of nexus bottlenecks on the environmental quality of the land surface are changes in pristine forest cover and the carbon stock. Pristine (or mature) forest in the biophysical modelling context concerns forest lands not drastically impacted by human activities.[1] In the baseline, pristine forest global cover decreases by around 4.5% between 2015 and 2060, the land bottleneck adds some 2.5%, the energy bottleneck doubles the loss and all bottlenecks combined go at the expense of 8% more loss than the baseline. Many environmental services are provided by pristine forests such as habitat for species, genetic resources, local and regional water and climate regulation, carbon sequestration and tourism. Hence the loss means these services are seriously affected in particular in the biggest loser regions and countries.

The other key quality of land is the carbon stocks it contains in soils and in living and dead biomass. Conversion of natural land to other purposes such as crop land or clearing for timber, tends to release important shares of these stocks and hence contribute to a net release to the atmosphere where it raises the atmospheric concentration of CO_2, the biggest contributor to man-made climate change. As new plants and trees start to grow on the once natural land, these start to rebuild carbon stocks, but a slow rate and in any cases not close to the original level, certainly not within many decades, Under current climate conditions, retained until 2060 in the baseline and the nexus bottleneck scenarios, the terrestrial biosphere loses some 70 Gt of carbon; the land and energy bottlenecks add 12% and 33%, respectively, to that volume.

Food security

Food security is one of the key policy objectives that is threatened by the nexus bottlenecks. All three bottleneck scenario lead to deteriorations in food security as reflected in increasing food prices and increased budget shares spent on food. Furthermore, in most regions the import share of food increases, indicating increased pressure on self-sufficiency. The consequences are especially pronounced in India, and the land bottleneck (primarily the effect of urban sprawl), which directly takes away fertile agricultural land, poses the biggest threat. The combination of all bottlenecks further amplifies the increase in food prices, while climate change further increases food budget shares and reliance on food imports, especially in India and Indonesia.

This effect of the nexus bottlenecks on food security can also have important social repercussions. It is likely that especially the poorest households are hurt by the nexus bottlenecks. As discussed above, this can lead to equity issues and loss of welfare for these groups. Of course, this has to be seen in a context of a baseline where food production rises significantly in the coming decades, as do per capita incomes. Thus, the negative effects are mostly in deviation from baseline, not with respect to 2015 levels.

The potential productivity of agriculture per unit of area depends strongly on local climate conditions, soil quality and availability of water. In practice, actual yields also depend on the intensity and adequacy of land management, including fertiliser application, pest and disease controls, seed quality, irrigation, mechanisation, etc. In order to maximise farm income, using the most productive, accessible land offers the best prospects. Good land may be un-accessible for a variety of reasons: it may be out-competed by other uses than food production; it may be remote from existing settlements, roads or waterways; its use may be restricted due to nature conservation concerns, etc. In the baseline, all these considerations play a role in determining where agriculture is located and what that implies for average yields.

The water bottleneck reduces the growth on those parts of irrigated land for which less or no water can be sourced. In order to make up for the loss, more rainfed production is needed and this affects the average productivity. For the world as a whole the negative impact on yields is small, as the biggest share of production is not affected by the reduced water availability and well-managed rainfed yields are close to those of irrigated crops. For a small set of regions, however, the yield reductions are more serious. In particular where alternative sites are scarce, total food production can get under pressure with implications for food security and self-sufficiency.

Water security

Water security is a key condition for human development. Water is indispensable to sustain food and fodder production, human settlements, industries, electric power production and ecosystem requirements. At the global level the average annual amount of renewable fresh water, that is the surplus of precipitation minus evaporation and transpiration to the atmosphere, exceeds the demand. But the spatial allocation, seasonal and inter-annual variability and uneven distribution of population density over the land surface make that large parts of the human population are confronted with periods of water scarcity. Over and above the quantitative aspect addressed here, widespread water pollution adds to the problem as it reduces the usability of water unless large-scale treatment is applied. Many people live under severe water stress, which implies a high likelihood of facing periods of shortages.

Agricultural production to feed local people and contribute to exports depends strongly on irrigation to make up for insufficient precipitation, and in many areas irrigation relies critically on non-renewable aquifers. Even though the projected increase in total irrigation water demand is very moderate, depletion of non-renewable sources is bound to reduce future water security. Withdrawals for non-agricultural purposes are expected to increase stronger than irrigation, and an increasing number of people will face more severe water stress. The increase is concentrated in river basins already water stressed today and growth in population and economy activity per capita.

The sector shares of water demand vary strongly between the regions, but in many regions irrigation dominates in 2015. In 2060 the demand for the non-agriculture sectors increases strongly in most emerging and currently less developed regions in Asia, Africa and Latin America. In OECD regions the water demand is projected to decrease due to limited population growth, efficiency improvements and structural shifts in electric power technology and in industry towards less water-intensive sectors. The combined effect of increasing demand for non-agricultural uses, and depletion of aquifer stocks, will have serious implications for water security in many regions and countries, including India, Middle East, North Africa, Mexico and the Caspian region. Also specific parts of others regions, including Mediterranean Europe, South-west United States, and arid parts of Other Africa and Other Asia are affected.

Energy security

Finally, the implications of the nexus bottlenecks for energy security are much less clear than the implications for some of the other policy objectives. The most important interactions between water scarcity and energy security and between climate change and energy supply could not be captured in the modelling analysis. Thus, while land bottlenecks are likely to have a very minor impact on energy security, energy security threats from water bottlenecks are potentially more significant. Annex B discusses some of these potential risks and interactions.

In itself, it is clear that energy is in a strict sense not likely to be a scarce resource in the coming decades. While energy is certainly a critical resource in terms of its economic importance, the large traded volumes of energy and the availability of alternative energy sources such as wind and solar energy imply that supply risks are fairly low. A bioenergy policy could improve energy security at the national level, but the quantitative analysis shows that this comes at a trade-off with the other nexus resources, especially land, and can thus threaten other policy objectives such as food security.[2] Similarly, one can speculate that a when water scarcity becomes a significant bottleneck, advanced technologies such as desalinisation can "transfer" some of these stresses to the other resources in the nexus, in this case energy. Such a transfer would, however, likely come at the expense of other policy objectives, such as welfare.

5.2. Regional trade-offs and synergies between the nexus bottlenecks

The impacts from LWE bottlenecks vary by a great extent across regions depending on endowment, vulnerability to climate impacts, past and future socioeconomic trends. The results of the modelling analysis highlights that an assessment of the main bottlenecks in the nexus for specific regions need to focus on the local interactions between the demand and supply of food, water and energy, as these drive local bottlenecks. Therefore, for each region the insights from the modelling and scoping analysis can be brought together in an integrated perspective on the local nexus issues.

At the macro level, Canada is largely unaffected by the nexus bottlenecks; there are some small sectoral impacts from the various bottleneck scenarios, but these are small and to some extent related to the specific setup of the scenarios (e.g. on bioenergy). Mexico is slightly more affected, but the biophysical and economic repercussions of the bottlenecks remain largely limited to a reduction in yields, mostly stemming from the water bottleneck, without major repercussions for the rest of the economy as this is to a large extent compensated by an increase in cropland to preserve agricultural production.

The situation in the United States is more complex: there are significant differences between the various regions within the United States. For instance, major parts of the South West are in a state of systemic water deficit and occasionally face long periods of drought that may multiply with climate change. In these regions of the country, the nexus bottlenecks may pose critical problems at the local level. In other parts of the United States, where water is more abundant, the nexus bottlenecks are much less of a threat. Overall, the modelling analysis illustrates that the macroeconomic implications of the water bottleneck are very limited, urban sprawl (as simulated in the land bottleneck) can lead to significant reductions in agricultural value added, and the use of land for bioenergy might boost the economy. Technological developments can also influence these effects. For instance, shale gas and shale oil may put additional stress on the water system, but there is also an institutional capacity to transform the water, energy and agricultural sectors to accommodate specific shocks as they arise, and flexibility in the system allows that a bottleneck for one specific resource can be compensated by increased use of the other resources, not least using energy to increase water supply there where it is most needed.

The European OECD countries, both inside the EU and outside, operate in close international linkages between their economies. This means that specific shocks caused by the nexus to one individual country can relatively easily be compensated by changes in international trade patterns. While in several countries, especially in the south of Europe, yields are affected by the water bottleneck, and the land bottleneck affects a few countries as well, the macroeconomic repercussions for the group as a whole remain very limited.

For Australia and New Zealand, the specific bioenergy shock that is simulated in the energy bottleneck scenario has strong repercussions for agriculture as it induces a shift from exporting agricultural commodities to bioenergy, to exploit the changes in competitive position across regions and commodities. Regarding the water bottleneck, Australia is in a similar position to the United States: specific regions are very dry and vulnerable to water scarcity, but macroeconomic implications are projected to be small.

Japan and Korea may face some challenges from land scarcity and urban sprawl, as simulated in land bottleneck scenario, but on balance these countries are projected to be less affected by the developments in the nexus than most others. And while they rely on irrigation for rice production, their dependence on non-renewable water sources is very limited, and hence the impact of the water bottleneck is small.

The nexus bottlenecks are very strong in large parts of Asia, and China is no exception. To accommodate productivity losses from a lack of irrigation water for rice production in the water bottleneck scenario, land expansion is required. The land bottleneck puts even stronger pressure on land markets. This is costly in China, leading to a significant loss of GDP, around 3% for all bottlenecks together.

The non-OECD EU countries and rest of Europe region are also regions where the land bottleneck can threaten agricultural production and thus the macro economy, while increased bioenergy production might stimulate GDP. This situation is amplified in Russia: the specific bioenergy scenario projections show substantial economic gains for Russia from the increased bioenergy production, especially from improved competitive position on the international markets. To some extent, this comes at the expense of the Caspian region, where conditions are less favourable and all bottlenecks have a dampening effect on economic growth.

In Brazil, water is abundant at the country level, but there are water stressed regions in the South. Agriculture depends on surface water availability and the energy system is vulnerable to water stress. Climate change and energy security policies have boosted large-scale development of bioethanol production, thereby increasing competition for land and water. But in both Brazil and the rest of Latin America, there is economic pressure to accommodate nexus shocks by increasing land supply at the expense of forest and other natural areas. By exploiting the relatively abundant land resource, the Latin American countries can improve their trading position and reap a larger share of the global market for their exports, thereby boosting their economy, at the expense of environmental quality.

In the Middle East and North Africa, water bottlenecks are the biggest threat and can seriously threaten crop yields and agricultural value added; climate change may exacerbate this even further. The countries in the Middle East face extreme water scarcity and have developed their resource supply systems accordingly: energy is used to compensate for the lack of water. The energy consumption of the water sector has increased in recent years because of strong economic and demographic growth, subsidies to energy consumption and to agriculture production, deeper groundwater pumping and long distance transport and desalination. Land resources in the region are limited; i.e. 93.5% of all potentially suitable land is already in agricultural use in Middle East (see Chapter 3). A global surge in bioenergy production can also harm consumption levels by depressing energy exports and energy prices, although the region is more flexible in dealing with changes in fuel prices than other fuel exporters as it contains some of the lowest marginal cost producers of oil. Nonetheless, the GDP impacts of the bottlenecks remain limited in the Middle East, not least because the baseline projection entails a significant diversification of the economies in this region, making them more versatile and less sensitive to agricultural and energy shocks. Also, some countries in this region are at the forefront of using the relatively abundant resource to compensate for the scarcity of other resources, not least relieving water shortages through highly energy-intensive novel production methods. In contrast, the GDP impacts are larger in North Africa, as the economic pressure of the bottlenecks cannot as easily be accommodated by diversifying the economy.

There are interesting differences between the biophysical and economic consequences of the nexus bottlenecks for the ASEAN economies, on the one hand, and India on the other. Both rely strongly on irrigation with a big share of irrigation water provided by non-renewable resources, and both have strong demographic developments and economic growth. But the ASEAN economies can increase crop land use in response to the bottlenecks to improve their international trade position and thus boost their economy. In contrast, India, where yield losses are stronger, cannot easily accommodate the bottlenecks and is projected to have the strongest losses in agricultural value added and GDP of all regions in the world. Indonesia and the countries in the Other Asia group are intermediate cases between these extremes.

Africa is the continent facing globally the strongest demographic growth within the next decades. In addition, many African countries suffer from a lack of access to water and/or energy which results in a high vulnerability from climate change impacts. Land for agriculture is scarce in several Sub-Saharan countries, but abundant in others such as in the Congo basin. Due to the limited use of irrigation, groundwater depletion has little impact on agriculture. But important water bottlenecks can appear from the change in rainfall due to climate change. The simulated additional bioenergy production in the energy bottleneck scenario also leads to a significant reduction in forest land, and thus has negative consequences for environmental quality. Other effects might be expected from the impacts on the potential for hydropower which is a key technology for improving energy security in the region. Like in India, the strong economic growth in the baseline also makes these countries vulnerable when the growth in resource use that supports high growth is threatened. And like in India, the interaction between the different bottlenecks worsens the situation.

5.3. On the robustness of the modelling results

The analytical results presented in this report are subject to considerable uncertainty in underlying data and modelling, including the baseline projection that was used as starting point for the analysis of nexus bottlenecks impacts. The longer the time horizon, the more "known unknowns" and also "unknown unknowns" induce excursions from the baseline reported here. Uncertainties can occur in every stage of the process of calculating the biophysical and economic consequences of the land-water-energy nexus, and include:

- Uncertainties in projecting the socioeconomic drivers of economic growth (baseline);
- Uncertainties in projecting agricultural production, land use and yields (baseline);
- Uncertainties in projecting the water and energy use of agricultural and other economic activities (baseline);
- Uncertainties in specifying the policy shocks (policy scenarios);
- Uncertainties in specifying the consequences of the policy shocks on agricultural production, land use and yields (policy scenarios);
- Uncertainties in specifying the reactions of economic agents (firms and households) to the policy shocks and associated changes in the biophysical system (policy scenarios).

It is beyond the scope of this report to quantify each of these uncertainties, and they are not mutually independent (and hence very difficult to quantify). In an effort to capture some of such structural uncertainties, other studies develop a set of projections, reflecting alternative narratives of how the future could unfold (Riahi et al., 2016). By repeating nexus bottleneck assumptions for each of the alternative pathways, a range of impacts would result rather than a point estimate as in this report. For practical reasons and because multiplying the number of scenarios does not necessarily increase the clarity of the policy insights, the single CIRCLE project baseline is used in this report.

In order to reduce the reliance of the numerical results on specific baseline assumptions, all scenario results are expressed in terms of deviations from baseline. This ensures that biases and uncertainties that occur in the baseline as well as the policy scenarios are filtered out. Bottleneck deviations from the baseline are thus more robust than absolute numbers for the different scenarios. So, more than precise absolute numbers, the results indicate where a specific bottleneck hits harder than elsewhere, and which bottlenecks matter most for which world region.

Uncertainties from limited availability of authoritative data behind key variables arise at all stages. Reliable data at the appropriate disaggregation level is even more scarce, and there are limitations in which factors and relationships can be captured by the models. Regarding the baseline projection, one of the key assumptions is the evolution of agricultural productivity improvements, as summarised in yield growth for the various regions. The input data on crop yield changes (physical production per hectare) are calibrated with the utmost care, and encompass plausible regional and crop-specific trends as they are likely to evolve in the coming decades. The projections of IMAGE and ENV-Linkages are also fully harmonised on this point. One method of validating the yield projections was the participation by the modelling teams in the Agricultural Model Intercomparison Project AgMIP (Von Lampe et al., 2014). Such multi-model comparison exercises allow identification of which baseline projections are features of the model, and which assumptions need adjustment to ensure all projections are plausible. Despite ongoing efforts to enhance and expand the analytical tools with the aim to be as relevant and robust as feasible, any results can only be understood within the inherent limits posed by current capabilities.

Finally, LWE nexus bottlenecks explored represent stylised impacts of potential issues arising, for the sake of the analysis assumed to manifest themselves across all world regions in a similar fashion and at the same point in time. Results have to be viewed in this context, and they do not make it possible to assess the likelihood of their emergence in place and time as reported here. For example, in the water bottleneck all aquifers in a certain category are assumed to run out in one particular year, while in reality a much more diverse set of local and regional impacts may unfold. Nonetheless, the notion that many aquifers are being used in a way that jeopardises their continued operation makes that sooner or later consequences as presented here are bound to occur. A systematic exploration of all possible sources of uncertainty goes beyond the scope of this report. But the structural relationships implied by the combined biophysical and economic analysis make for sufficiently robust findings and implications for policy making.

5.4. Final remarks

The question is to what extent the interdependencies between each of the three constituents land, water and energy of the LWE nexus have repercussions at the macroeconomic and global level and, thus, support the urgency of promoting integrated policies for the nexus. The modelling analysis in this report does not provide an unambiguous positive answer, certainly not at the global level where bottleneck impacts are very moderate, and only a very small interaction effect emerges from the combined bottlenecks.

A multitude of convincing arguments, however, present themselves at the finer regional scale. And it seems safe to suggest that zooming to much finer scales would reveal even more striking examples where compounded problems with land, water and energy issues call for a co-ordinated, integral policy. As underlined by the stark differences in results of the modelling analysis at the regional level, different individual bottleneck challenges and different interlinkages play out in different regions of the world and in different parts of those regions. Examples include the impact of declining water supply from aquifers on yields, and thereby on agricultural land area in order to keep food security at bay. Another example is the exploitation of improved competitive position by producers that are relatively less affected by the bottlenecks than their competitors.

With this in mind, allocating vast areas to grow feedstock for biofuels, or not limiting groundwater use from non-renewable aquifers for irrigation purposes, warrants due attention in the (sub-) regions concerned. And the same holds for uncontrolled urban sprawl, and for the land needed to provide other ecosystem goods and services such as timber, water and local climate regulation, carbon storage, tourism and to reduce and eventually halt the loss of biodiversity. The bottlenecks explored here indicate that land is probably the strongest interconnector, so integral land planning approaches are important to balance the different concerns and interests.

Other feedback mechanisms between the three domains do not stand out as strongly. It is important to note that the caveats and missing links in the current study play their role in this conclusion, not least the partial treatment of the resources and their biophysical and economic linkages, and the top-down nature of the modelling exercise. In addition, the stringency of the bottlenecks that are analysed in the models affect the severity of the biophysical and economic consequences, and the more stringent the bottlenecks, the stronger the interdependencies are likely to be.

The nexus is further put in perspective by comparing it with the effects of climate change; on the whole climate change tends to add to the losses incurred by the nexus shocks. The negative consequences of climate change worsen the most vulnerable regions, not least because to some extent the regions most threatened by the nexus bottlenecks are also most at risk from climate change. But these linkages also represent potential indirect benefits for climate change policies. The energy conservation part of climate change policies induce obvious benefits due to less stress on fossil fuel resources, water withdrawal and water pollution from the energy sector. In addition, reduced electricity demand diminishes the vulnerability of the power sector to water stress. Biofuels have to be considered with their associated effects on land and water use. Supporting renewables, such as wind and solar photovoltaic technologies, often contributes to increasing water security, but may lead to new bottlenecks due to the reliance on specific scarce materials.

In around half the regions, the key results for the combined scenario fall within one percent of the sum of the individual three bottlenecks. This suggests that in these regions not much is gained from treating the issues in one overarching policy framework at the macro level, rather than pursuing each issue individually and on regional hotspots. In the other regions, highlighted in Section 5.2, the interactions from combining the bottlenecks are more pronounced and suggest that adding an overarching nexus vision to policy making has clear benefits. The finding in this report could thus help to focus future research and priorities for policy responses for addressing critical nexus resources.

Notes

1. This includes areas used by humans in earlier periods, but sufficiently long ago to have reached a semi-natural state with biodiversity largely restored. Excluded are areas completely deforested and areas in more intensive timber production schemes. Human activities which affect forests but at a smaller scale and over a relatively short time period, such as gathering and hunting and collection of firewood for local use, are not considered here. Forests as considered here consist of large, consecutive areas with close to 100% canopy cover, and thus not smaller patches of trees in biomes such as wooded tundra and savannah in IMAGE.
2. While direct competition with crop production for food is avoided when concentrating on second generation bioenergy, there is still a competition for land and thus a negative impact of bioenergy on food security.

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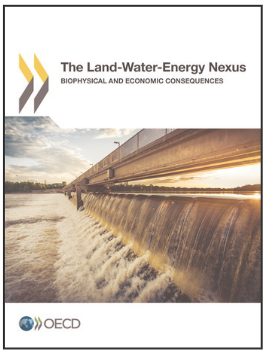

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