Narratives, data and assumptions used to model development scenarios and climate sub-scenarios for Rwanda

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Introduction

Agricultural transformation and energy transition will be key for Rwanda to achieve its ambition of becoming a middle-income country in the coming decades. These development processes are often considered complementary and synergistic, but this is not a given. In order to explore the potential co-evolution of agricultural transformation and energy transition in Rwanda, and to highlight the trade-offs and synergies between them, SEI and the Albertine Rift Conservation Society (ARCOS) have undertaken participatory scenario-building activities using SEI’s energy and water planning tools: Long-range Energy Alternatives Planning (LEAP) and Water Evaluation and Planning (WEAP).¹ We believe our results can help inform the upcoming process of developing Rwanda’s Vision 2050 and current implementation of its medium-term National Strategy for Transformation and Prosperity (2018–2024) (Republic of Rwanda 2017).

This document presents an overview of the development scenarios for Rwanda that we co-created with stakeholders² and explored using LEAP and WEAP. It first presents two different narratives of how Rwanda might develop by 2050. It then presents how we translated these narratives into the scenarios in the models, using certain assumptions and data. The results of the analysis will be published shortly.

National development ambitions in Rwanda

Rwanda has committed itself to becoming a middle-income country by 2020, to decrease the national poverty rate to 30%, and to increase the average life expectancy to 55 years by the year 2020 (Republic of Rwanda 2012). The country’s Vision 2020 and Economic Development and Poverty Reduction Strategies (EDPRS I and II) both set out clear intentions to intensify agriculture and increase national energy output (Republic of Rwanda 2007; Republic of Rwanda 2013). For example, agriculture is expected to grow by 8.5% annually and energy generation is expected to grow from 45 MW in 2006 to 563 MW in 2018, mainly through development of hydropower. These ambitions are also present at a sub-national level, with district development plans including provisions to modernise agriculture, invest in energy production and expand many water-intensive activities, such as mining, industrial development, and ecotourism.

The country is also developing its EDPRS III and Vision 2050, which will build further upon these existing ambitions.

These development goals place increasing pressure on limited water and biomass resources. Competition over water resources demanded by hydropower, irrigation, and water supply to major towns and various industries has the potential to create serious conflict. Meanwhile, biomass scarcity causes the country to import biomass from neighbouring countries as well as having to allocate croplands to wood plantations, such as eucalyptus; 21% of biomass consumption in 2009 has been characterised as unsustainable uses of biomass, and “the constant flow of charcoal into Kigali exerts a considerable pressure on the wood resources of the country” (Drigo et al. 2013, p.vii). In addition, an intensified agricultural sector will demand more energy and water per hectare, although a modernised energy sector less dependent on traditional biomass is likely to require less land.

In order to better understand the linkages between different sectors in future scenarios, Rwanda developed its Green Growth and Climate Resilience Strategy (GGCRS) in 2011 (Republic of Rwanda 2011). The GGCRS was developed to guide decisions around natural resource management, investments and policy as well establish demonstration initiatives to support climate resilience activities and community livelihoods, in particular:

- **Land and agricultural transformation**: ensuring sustainable land-use and natural resources management resulting in food security and the preservation of biodiversity and ecosystem services;
- **Energy transition**: achieving energy security and low carbon energy supply, while avoiding deforestation; and
- **Societal impacts**: societal protection, including reduced vulnerability to climate change.

¹ For more details on LEAP and WEAP see www.energycommunity.org and weap21.org, respectively. This work forms part of the project “Using Water-energy-food security nexus to promote climate resilient decisions and model actions in selected landscapes along Akagera Basin” funded by Rwanda’s Green Fund (FONERWA) and the Swedish International Development Cooperation Agency (Sida).

² Stakeholders included representatives from line ministries, regulatory institutions and utilities at the national level, local governments at district-level, NGOs, civil society and the private sector.
Co-created development pathways in Rwanda

Drawing on the national plans and stakeholder engagement, below we present co-created narratives for two development pathways along which Rwanda might travel up to 2050: a pessimistic scenario where development is slow and national plans are weakly implemented and an optimistic scenario where national plans are fully implemented, leading to substantial transformation of the agricultural and energy sectors, whilst also ensuring sustainable use of resources. These are built upon and compared to a reference scenario in which development continues along historical trends under three climate sub-scenarios.

**Reference scenario**

In the reference scenario, Rwanda continues to develop according to historical trends, such as continued annual growth in population and GDP of 2.5% and 7.9%, respectively. Climate change is impacting on the availability of resources via two climate sub-scenarios related to varying rainfall patterns, increased temperature and increased humidity. The reference scenario forms the basis upon which all other scenarios are built.

**Pessimistic scenario**

In the pessimistic scenario, the country’s ambitious development plans are weakly implemented and there is limited consideration of resource use sustainability. Development is slow, and agriculture and energy sectors fail to substantially modernise by 2050. In the agricultural sector, traditional farming techniques prevail on 80% of croplands and fertiliser use levels remain rather low. Consequently, energy needs for agriculture remain low. Meanwhile, in the energy sector, all households eventually have access to electricity but biomass continues to be the major energy source for cooking. Because of an increasing population continuing to use the same type of cookstoves, the demand for biomass for domestic use increases. In general, rural households remain unconnected to the national electricity grid. With increasing demand for land and water for agriculture, as well as increasing demands for wood fuels, there is a large threat to certain habitats such as forests and marshlands, aggravating soil degradation problems. Resource use for food and energy production is given higher priority than meeting environmental flow requirements of limnic (freshwater lake and pond) ecosystems, or biomass return flows in terrestrial systems, resulting in a gradual degradation and threat to the long-term sustainability of these ecosystems.

**Optimistic scenario**

In the optimistic scenario, the country achieves its development goals of modernising agriculture and energy, and manages to do so whilst ensuring sustainable use of its resources. The agricultural sector develops quickly, and by 2050, 40% of the farmland is modernised and managed more intensively than today, with higher fertiliser use, mechanisation and access to irrigation according to the national plans. Agricultural lands also expands 100 000 ha into marshlands.

In the energy sector, a successful cookstoves replacement programme is implemented and forest cover is increased by 30%, ensuring a more stable supply of fuelwood. At the same time, all households have access to electricity by 2030 and many shift towards biogas and LPG for cooking. The agricultural sector becomes dependent on energy inputs, and irrigation affects the flow of water for hydropower generation downstream. Rwanda’s goals to ensure environmental protection of watersheds, soil fertility, forests, biodiversity and ecosystem services mean that regulation is required. Minimum environmental flow requirements are imposed to control water consumption from irrigation and hydropower generation in order to secure the functioning of limnic ecosystems.
Data and assumptions used in the modelling tools

In Table 1 below we set out the data and assumptions used as inputs into the LEAP and WEAP modelling software tools.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Current accounts in 2010</th>
<th>Scenario in 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference</td>
<td>Pessimistic</td>
</tr>
<tr>
<td>Economy and demographics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average GDP growth</td>
<td>7.9%</td>
<td>7.9%</td>
</tr>
<tr>
<td>GDP share</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public service sector</td>
<td>25.3%</td>
<td></td>
</tr>
<tr>
<td>Commercial and industrial sectors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture and fisheries</td>
<td>22.0%</td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td>5.6%</td>
<td></td>
</tr>
<tr>
<td>Other commercial</td>
<td>47.1%</td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>10.5 million</td>
<td></td>
</tr>
<tr>
<td>Growth</td>
<td>2.5%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Density</td>
<td>416 ppl/km²</td>
<td></td>
</tr>
<tr>
<td>Urban-rural population split</td>
<td>17.83</td>
<td></td>
</tr>
<tr>
<td>Urban-rural household split</td>
<td>16.5:83.5</td>
<td></td>
</tr>
<tr>
<td>Poverty rates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>22.1%</td>
<td></td>
</tr>
<tr>
<td>Rural</td>
<td>48.7%</td>
<td></td>
</tr>
<tr>
<td>Climate and ecosystems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation</td>
<td>1300 mm/yr</td>
<td></td>
</tr>
<tr>
<td>Future change</td>
<td>+/-10%</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>19.6 °C</td>
<td></td>
</tr>
<tr>
<td>Future change</td>
<td>+3°C</td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>12.3%</td>
<td></td>
</tr>
<tr>
<td>Future change, dew point temp</td>
<td>+1°C</td>
<td></td>
</tr>
<tr>
<td>Environmental flow requirements</td>
<td>30%</td>
<td>Low priority</td>
</tr>
<tr>
<td>Irrigation demand</td>
<td>Medium priority</td>
<td>Medium priority</td>
</tr>
<tr>
<td>Hydropower water demand</td>
<td>Low priority</td>
<td>Low priority</td>
</tr>
<tr>
<td>Domestic water demand</td>
<td>High priority</td>
<td>High priority</td>
</tr>
<tr>
<td>Soil types</td>
<td>Shallow soil with low water retention capacity in head-flow catchment; sandy clay loam in valley catchment</td>
<td></td>
</tr>
<tr>
<td>Land use and agriculture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest land area</td>
<td>671 000 ha</td>
<td></td>
</tr>
<tr>
<td>Plantation</td>
<td>287 000 ha</td>
<td></td>
</tr>
<tr>
<td>Closed natural forest</td>
<td>108 000 ha</td>
<td></td>
</tr>
<tr>
<td>Degraded natural forest</td>
<td>12 600 ha</td>
<td></td>
</tr>
<tr>
<td>Sector</td>
<td>Current accounts in 2010&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Reference</td>
</tr>
<tr>
<td>------------------------</td>
<td>--------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Bamboo</td>
<td>1 630 ha</td>
<td></td>
</tr>
<tr>
<td>Natural shrubs</td>
<td>260 000 ha</td>
<td></td>
</tr>
<tr>
<td>Wooded savannah</td>
<td>1 770 ha</td>
<td></td>
</tr>
<tr>
<td>Agricultural land area</td>
<td>1 690 000 ha</td>
<td></td>
</tr>
<tr>
<td>Cropland</td>
<td>1 370 000 ha</td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>11.5%</td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>2.4%</td>
<td></td>
</tr>
<tr>
<td>Cereal</td>
<td>1.2%</td>
<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>19.5%</td>
<td></td>
</tr>
<tr>
<td>Sweet potato</td>
<td>4.4%</td>
<td></td>
</tr>
<tr>
<td>Irish potato</td>
<td>3.7%</td>
<td></td>
</tr>
<tr>
<td>Banana</td>
<td>18.3%</td>
<td></td>
</tr>
<tr>
<td>Green bean</td>
<td>12.1%</td>
<td></td>
</tr>
<tr>
<td>Legumes</td>
<td>3.4%</td>
<td></td>
</tr>
<tr>
<td>Vegetables</td>
<td>1.1%</td>
<td></td>
</tr>
<tr>
<td>Fruit trees</td>
<td>0.6%</td>
<td></td>
</tr>
<tr>
<td>Tea</td>
<td>1.0%</td>
<td></td>
</tr>
<tr>
<td>Coffee</td>
<td>2.0%</td>
<td></td>
</tr>
<tr>
<td>Meadow and pasture</td>
<td>322 000 ha</td>
<td></td>
</tr>
<tr>
<td>Urban land area</td>
<td>19 100 ha</td>
<td></td>
</tr>
</tbody>
</table>

Agricultural practices<sup>j</sup>

| Low inputs ("traditional") | | | | |
|------------------------------| | | | |
| Total cropland area          | 98% | 98% | 80% | 60% |
| Productivity                 | 0.5 LAI | 0.5 LAI | 0.5 LAI | 0.5 LAI |

| High inputs ("modernised")<sup>k</sup> | | | | |
|----------------------------------------| | | | |
| Total cropland area                   | 2%  | 2%  | 20% | 40% |
| Productivity                           | LAI | LAI | 1.05 LAI | 1.25 LAI |

Net primary productivity<sup>l</sup>

| Forests                              | | | | |
|---------------------------------------| | | | |
| Forest plantation                     | 16 t dm/ha/yr | 1.0 LAI | 1.05 LAI | 1.25 LAI |
| Closed natural forest                 | 16 t dm/ha/yr |           |           |           |
| Degraded natural forest               | 12 t dm/ha/yr |           |           |           |
| Bamboo                                | 10 t dm/ha/yr |           |           |           |
| Natural shrubs                        | 5 t dm/ha/yr  |           |           |           |
| Wooded savannah                       | 13 t dm/ha/yr |           |           |           |

Agriculture

| Traditional" crop yields / number of crops per year | | | | |
|-----------------------------------------------------| | | | |
| Maize                                               | 1.24 t dm/ha/yr / 2 | | | |
| Sorghum                                             | 0.83 t dm/ha/yr / 2 | | | |
| Cereal                                              | 0.74 t dm/ha/yr / 2 | | | |
| Cassava                                             | 0.49 t dm/ha/yr / 2 | | | |
| Sweet potato                                        | 1.80 t dm/ha/yr / 2 | | | |
| Irish potato                                        | 1.40 t dm/ha/yr / 2 | | | |
### Sector

<table>
<thead>
<tr>
<th></th>
<th>Current accounts in 2010</th>
<th>Scenario in 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference</td>
<td>Pessimistic</td>
</tr>
<tr>
<td>Banana</td>
<td>0.84 t dm/ha/yr</td>
<td>/ 1</td>
</tr>
<tr>
<td>Green bean</td>
<td>0.10 t dm/ha/yr</td>
<td>/ 2</td>
</tr>
<tr>
<td>Legumes</td>
<td>0.42 t dm/ha/yr</td>
<td>/ 2</td>
</tr>
<tr>
<td>Vegetables</td>
<td>0.66 t dm/ha/yr</td>
<td>/ 2</td>
</tr>
<tr>
<td>Fruit trees</td>
<td>0.38 t dm/ha/yr</td>
<td>/ 1</td>
</tr>
<tr>
<td>Tea</td>
<td>1.50 t dm/ha/yr</td>
<td>/ 1</td>
</tr>
<tr>
<td>Coffee</td>
<td>0.50 t dm/ha/yr</td>
<td>/ 1</td>
</tr>
<tr>
<td>Meadows and pastures</td>
<td>6.0 t dm/ha/yr</td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>0.23 t dm/ha/yr</td>
<td></td>
</tr>
</tbody>
</table>

### Energy

<table>
<thead>
<tr>
<th>Electricity access (% of population)</th>
<th>16%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>67%</td>
</tr>
<tr>
<td>Rural</td>
<td>6.4%</td>
</tr>
<tr>
<td>Total electricity generation</td>
<td>281,17 GWh</td>
</tr>
<tr>
<td>Electricity generation by source (% share)</td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td>56.9%</td>
</tr>
<tr>
<td>Hydropower</td>
<td>39.8%</td>
</tr>
<tr>
<td>Solar</td>
<td>0.1%</td>
</tr>
<tr>
<td>Methane</td>
<td>3.2%</td>
</tr>
</tbody>
</table>

### Cookstove penetration (% share of hhs)

#### Urban wood stoves

<table>
<thead>
<tr>
<th></th>
<th>35.1%</th>
<th>35.1%</th>
<th>20%</th>
<th>0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed improved mud stove</td>
<td>12.6%</td>
<td>12.6%</td>
<td>10%</td>
<td>0%</td>
</tr>
<tr>
<td>Potable improved mud stove</td>
<td>4.5%</td>
<td>4.5%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Three-stone stove</td>
<td>30.4%</td>
<td>30.4%</td>
<td>20%</td>
<td>0%</td>
</tr>
<tr>
<td>Improved wood stove</td>
<td>17.3%</td>
<td>17.3%</td>
<td>10%</td>
<td>0%</td>
</tr>
<tr>
<td>Tier 3 wood stove</td>
<td>0%</td>
<td>0%</td>
<td>15%</td>
<td>40%</td>
</tr>
<tr>
<td>Pellet gasifier</td>
<td>0%</td>
<td>0%</td>
<td>25%</td>
<td>60%</td>
</tr>
</tbody>
</table>

#### Urban charcoal stoves

<table>
<thead>
<tr>
<th></th>
<th>61.9%</th>
<th>61.9%</th>
<th>0%</th>
<th>0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-pot metal charcoal stove</td>
<td>30.4%</td>
<td>30.4%</td>
<td>20%</td>
<td>0%</td>
</tr>
<tr>
<td>Camanake ivuguruye</td>
<td>6.3%</td>
<td>6.3%</td>
<td>30%</td>
<td>60%</td>
</tr>
<tr>
<td>Improved single pot charcoal stove</td>
<td>1.3%</td>
<td>1.3%</td>
<td>40%</td>
<td>0%</td>
</tr>
<tr>
<td>Modern charcoal</td>
<td>0%</td>
<td>0%</td>
<td>10%</td>
<td>40%</td>
</tr>
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</table>

#### Rural wood stoves

<table>
<thead>
<tr>
<th></th>
<th>35.9%</th>
<th>35.9%</th>
<th>20%</th>
<th>0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed improved mud stove</td>
<td>32.4%</td>
<td>32.4%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Improved wood stove</td>
<td>26.8%</td>
<td>26.8%</td>
<td>20%</td>
<td>0%</td>
</tr>
<tr>
<td>Mud stove</td>
<td>3.7%</td>
<td>3.7%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Portable improved mud stove</td>
<td>1.2%</td>
<td>1.2%</td>
<td>20%</td>
<td>0%</td>
</tr>
<tr>
<td>Tier 3 wood stove</td>
<td>0%</td>
<td>0%</td>
<td>30%</td>
<td>70%</td>
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<tr>
<td>Pellet gasifiers</td>
<td>0%</td>
<td>0%</td>
<td>10%</td>
<td>30%</td>
</tr>
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</table>
## Sector

### Current accounts in 2010<sup>a</sup>

<table>
<thead>
<tr>
<th>Sector</th>
<th>Reference</th>
<th>Pessimistic</th>
<th>Optimistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural charcoal stoves</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single-pot metal charcoal stove</td>
<td>63.6%</td>
<td>63.6%</td>
<td>50%</td>
</tr>
<tr>
<td>Multi-pot charcoal stove</td>
<td>19.4%</td>
<td>19.4%</td>
<td>10%</td>
</tr>
<tr>
<td>Improved single-pot charcoal</td>
<td>9.1%</td>
<td>9.1%</td>
<td>5%</td>
</tr>
<tr>
<td>stove</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canamake ivuguruye</td>
<td>7.8%</td>
<td>7.8%</td>
<td>25%</td>
</tr>
<tr>
<td>Modern charcoal</td>
<td>0%</td>
<td>0%</td>
<td>10%</td>
</tr>
</tbody>
</table>

### Scenario in 2050<sup>b</sup>

<table>
<thead>
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<th>Reference</th>
<th>Pessimistic</th>
<th>Optimistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary fuel for cooking (% share of hhs)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firewood and pellets</td>
<td>31.4%</td>
<td>27.9%</td>
<td>22.5%</td>
</tr>
<tr>
<td>Charcoal</td>
<td>62.7%</td>
<td>42.3%</td>
<td>22.7%</td>
</tr>
<tr>
<td>LPG</td>
<td>1.1%</td>
<td>10%</td>
<td>50.0%</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.7%</td>
<td>0.7%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Biogas</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Others</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>Rural</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firewood and pellets</td>
<td>92.6%</td>
<td>77.9%</td>
<td>62.9%</td>
</tr>
<tr>
<td>Charcoal</td>
<td>2.9%</td>
<td>2.9%</td>
<td>2.9%</td>
</tr>
<tr>
<td>LPG</td>
<td>0.1%</td>
<td>10%</td>
<td>20.0%</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Biogas</td>
<td>0.1%</td>
<td>2%</td>
<td>10.0%</td>
</tr>
<tr>
<td>Others</td>
<td>4.3%</td>
<td>4.3%</td>
<td>4.1%</td>
</tr>
<tr>
<td>Mechanisation (128 l diesel/ha)</td>
<td>5%</td>
<td>15%</td>
<td>50%</td>
</tr>
</tbody>
</table>

### Fertiliser use

<table>
<thead>
<tr>
<th>dm = dry matter, ha = hectares, hh = household, l = litre, LAI = leaf area index, LPG = liquefied petroleum gas, t = metric ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 kg/ha/yr</td>
</tr>
</tbody>
</table>

### Notes

<sup>a</sup> In both WEAP and LEAP models, 2010 was chosen as the base year to provide a statement of “current accounts”. In WEAP, historical data for 1971–2014 was used; in LEAP historical data for 2005–2010 was used.

<sup>b</sup> Numbers in each scenario represent the data and assumptions used as inputs in the model to define the particular development pathway.

<sup>c</sup> See https://data.worldbank.org/.

<sup>d</sup> Based on average data for 2000–2016.

<sup>e</sup> Based on data for 2012.

<sup>f</sup> Smakhtin (2008) and Republic of Rwanda (2013).

<sup>g</sup> Percent of mean annual flows.

<sup>h</sup> Figures here represent the whole of Rwanda. Only 60% of these values were included in the Akagera catchment area modelled in WEAP, split across all catchments proportional to areas in sub-watersheds. Land-use changes in the optimistic scenario start in 2020, end in 2030 and remain constant from then onwards.

<sup>i</sup> Land use based on Drigo et al. (2013), NISR (2016) and https://data.worldbank.org/ and http://www.fao.org/faostat/en/#data. There is a high degree of variation between land-use data sets.

<sup>j</sup> Agricultural practices based on Republic of Rwanda (2012), NISR (2016) and Ministry of Agriculture and Animal Resources (2009).

<sup>k</sup> Irrigation takes place on these lands when the soil moisture is not enough to meet plant water demands, and there is water available for irrigation.

<sup>l</sup> Net primary productivity based on Cao and Woodward (1998), Moore et al. (2018) and Scurlock et al. (2002).

<sup>m</sup> The LEAP model was downscaling to match the WEAP model of the Akagera catchment. By overlaying a Rwanda population map onto the Akagera catchment map, we were able to estimate that the catchment area contained 72% of Rwanda’s total population. For household energy demand in LEAP, the population was determined as 72% * (total population – 75% boarding school and 50% university students). By conservative estimates, boarding school students make up a majority of secondary school students, whereas around half of students at university reside there. In order to avoid double counting, they were subtracted from the population when determining household demand and instead their energy consumption contributed to public service sector energy demand. Data was compiled from Republic of Rwanda (2013), Drigo et al. (2013), Ministry of Infrastructure (2013), Africa Energy Services Group (2012), NISR (2012a) and NISR (2012b).

<sup>n</sup> These figures were calculated by combining data on cooking fuels and cooking technologies.
Parameterisation and calibration of the WEAP model

Crop yields in “current accounts” were estimated by initially using the parameter values for each crop type in the WEAP crop library. Since those values were derived from crops grown under high input conditions in the United States, the leaf area index (LAI) related parameters were adjusted to 50% of their original value (Table 1, agricultural practices/low inputs/productivity). Subsequently, the harvest index of each crop was modified so that the crop yields under low input/traditional management matched measured values (Table 1, croplands/yields). The derived harvest indices were then also used for high input/modernised land-use areas, for all scenarios; that is, the harvest index remained the same in all scenarios. Instead, to estimate differences in yields as a function of management, the LAI-related parameters in the crop library were adjusted (Table 1, agricultural practices/productivity) to depict the effect of the different management regimes.

The hydrology module of WEAP was calibrated using measured stream flow data from stream gauges throughout Rwanda, by modifying the hydraulic conductivity for the two soil types described in the table above (Table 2). Because of the high uncertainty in measurements, a relatively high deviation between simulated and measured stream flows was deemed acceptable.

### Table 2. Comparison between modelled and simulated stream flows

<table>
<thead>
<tr>
<th>Stream-flow gauge station</th>
<th>Modelled (M)/Observed (O)</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mwogo / Nyabisindu</td>
<td>M</td>
<td>9.3</td>
<td>6.0</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>5.5</td>
<td>3.0</td>
<td>6.3</td>
</tr>
<tr>
<td>Nyabarongo / Mwika</td>
<td>M</td>
<td>49.0</td>
<td>31.6</td>
<td>58.3</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>37.8</td>
<td>14.5</td>
<td>40.5</td>
</tr>
<tr>
<td>Nyabarongo / Nagaru</td>
<td>M</td>
<td>84.4</td>
<td>51.8</td>
<td>99.0</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>68.0</td>
<td>18.5</td>
<td>70.4</td>
</tr>
<tr>
<td>Nyabarongo / Kigali</td>
<td>M</td>
<td>48.4</td>
<td>30.8</td>
<td>57.3</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>94.5</td>
<td>33.5</td>
<td>100.2</td>
</tr>
<tr>
<td>Nyabarongo / Rifune</td>
<td>M</td>
<td>207.8</td>
<td>115.3</td>
<td>237.4</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>131.6</td>
<td>31.1</td>
<td>135.2</td>
</tr>
<tr>
<td>Nyabarongo / Risumu</td>
<td>M</td>
<td>257.7</td>
<td>78.1</td>
<td>269.2</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>339.0</td>
<td>216.4</td>
<td>401.8</td>
</tr>
</tbody>
</table>

Linking WEAP and LEAP

Annual hydropower production was estimated by WEAP and used as input in LEAP in all scenarios. In addition, in the optimistic scenario 80% of the WEAP values for annual increment (net primary productivity) in forest biomass and 80% of WEAP values for crop residues were used as an input in LEAP for woody biomass available to meet demand for woodfuel and charcoal and crop residues available to meet demand for pellets. Thus, 20% of the net primary productivity in forest biomass and 20% of crop residues were left in the ecosystems to ensure a sustainable withdrawal of biomass for energy.
References


