Corrigendum: Electrification pathways for Kenya–linking spatial electrification analysis and medium to long term energy planning (2017 Environ. Res. Lett. 12 095008)

Nandi Moksnes®, Alexandros Korkovelos®, Dimitrios Mentis and Mark Howells
KTH Royal Institute of Technology, Brinellvägen 68, 100 44 Stockholm, Sweden
E-mail: nandi@kth.se

Abstract

We have identified input values that were not harmonized with the paper and have therefore submitted this corrigendum. Qualitatively, there are no major differences between the two versions, and the insights generated are unchanged. However, part of the results, figures and discussion needed to be updated based on the new findings. We present those in the form of a corrigendum.

In the model runs there were input parameters that were not harmonized with the published paper as seen in annex in table 1. Therefore, to amend the incurred values, we have re-run the model and updated the following sections of the paper.

In the first paragraph of the Abstract (page 1), electrified population (%) were incorrectly reported. The corrected sentence is:

However, in case of the low demand scenario high penetration of stand-alone systems is evident in the country, reaching out to approximately 51% of the electrified population.

In the fourth paragraph (page 3) the demand from the Ministry of Energy and Petroleum projection is industry demand. The corrected sentence is:

For the industry grid demand modelled in OSeMOSYS the projected demand follows the Ministry of Energy and Petroleum Kenya projection from ‘Development of a Power Generation and Transmission Master Plan, Kenya’.

In the fourth paragraph (page 3) the demand deducted from the projection is the total domestic demand. The corrected sentence is:

The total domestic demand was deducted from the projected demand to avoid double counting the capacity need as seen in figures 2 and 3.

Figures 2 and 3 has therefore been updated to these changes. The corrected figures are:

The current electrification status in figure 4 is updated due to the initial population start was incorrect, and therefore more settlements are connected. The corrected figure is:

On page 6 the grid cost in the first paragraph in 3.1. Low demand scenario should be 0.074 USD kWh⁻¹. The corrected sentence is:

From the Low demand scenario, the optimization from OSeMOSYS gives a grid cost at 0.074 USD kWh⁻¹ which is iterated to OnSSET.

Figures 7–9 are updated based on the new model runs. The corrected figures are:

On page 6 the second paragraph in section 3.1 is updated with stand-alone share to 51% and the range of LCOE is 0.074–0.28 USD kWh⁻¹. The corrected paragraph is:

For the residential electrification optimization, the low demand of 43.8 kWh/capita for rural demand and 423.4 kWh/capita for urban displays a split by technologies with a high share of stand-alone solutions (51%) as seen in figure 8. The preferred stand-alone technology is solar PV in remote areas. As the demand is low in the rural areas the proximity to the grid will in most cases still not lead to a grid connection (only
49% will be grid connected in 2030). The LCOE for the OnSSET analysis ranges between 0.074 USD kWh\(^{-1}\) and 0.28 USD kWh\(^{-1}\) as seen in figure 9, where the existing grid have the lowest cost at 0.074 USD kWh\(^{-1}\) and the stand-alone in the rural areas have a higher LCOE.

On page 6 the fourth paragraph in section 3.1 the investment cost is updated to 22.1 billion and the transmission share is 33%. The corrected sentence is: The investment costs related to the low electrification scenario amounts to 22.1 billion USD, as seen in table 4, where transmission cost represents 33% of the total discounted cost from 2012 to 2030 including the planned grid by KENTRACO of 5666 km and the Last Mile project connecting 1.2 million people.

Table 4 is updated based on the new model runs. The corrected table is:
On page 6 section 3.2 in the second paragraph the grid cost correct value should be 0.062 with the range 0.062–0.28 USD kWh$^{-1}$. The corrected paragraph is:

For the high demand scenario, the optimization from OSeMOSYS gives slightly lower grid cost compared to the low demand scenario at 0.062 USD kWh$^{-1}$. The cost optimal solution for the residential electricity demand (423.4 kWh/capita for rural and 598.6 kWh/capita for urban) has a much higher share of grid connections and mini-grid solutions as compared to the low scenario as seen in figure 11. The LCOE for the geospatial cost optimal solution ranges between 0.062 USD kWh$^{-1}$ and 0.28 USD kWh$^{-1}$ as seen in figure 12 where lower range is where the demand is high per settlement and is situated close to the grid.

The model runs for the high demand scenario are updated and for figures 10–12 the corrected figures are:

On page 7 the first paragraph the transmission share and investment cost is updated to 40% resp. 40.9 billion USD.

For the high energy demand scenario, the costs for both the OnSSET and OSeMOSYS model amounts to 40.9 billion USD where the transmission costs represent 40% of the costs as seen in table 5.

Table 5 is updated according to the results from the high demand model runs and the corrected table is:

| Table 5. Total discounted investment cost for high demand scenario 2012–2030. |
|-------------------------------------------------|-----------------|
| **MUSD**                                         |                 |
| Transmission                                     | 7.53 GW HV transmission and 36 880 916 new connections | 16 331 |
| Mini grid                                        | 653 191 people | 540  |
| Stand alone                                      | 6 717 988 people | 5008 |
| Power plants (including fuel cost and O&M)       | 9.5 GW          | 18 998 |
| SUM (MUSD)                                       |                 | 40 877 |

An increased discount rate will favour power production with a low capital cost such as natural gas. When decreasing the discount rate from 9.8% to 5.75% the electricity generation will favour technologies with a higher capital cost which in this case shifts to geothermal, hydro and solar utility but the shift is not as significant as seen for the 18% discount rate.

The corrected figure 13 is:

On page 7–8 in the last/first paragraph the LCOE is updated to 0.062 and 0.074. Furthermore the number of connections and technology shift is updated. The corrected paragraph should be:
The changes in technology mix for both scenarios is displayed in figure 14 where the grid cost changes from 0.125 USD kWh$^{-1}$ to 0.074 USD kWh$^{-1}$ and 0.062 USD kWh$^{-1}$. The total grid connections are increased by 2.3 million people in favour of Hydro and PV, whereas in the low demand there are only small shifts from hydro and PV to grid.

The corrected figure 14 is as follows:

On page 9 first paragraph the number of connections is updated as well as the LCOE. The corrected sentence should be:
Based on the sensitivity analysis a shift from 0.125 USD kWh$^{-1}$ to 0.062 USD kWh$^{-1}$ would imply 2.3 million more people connected to the grid for the high demand scenario but no major difference in the low demand scenario.

On page 9 in the second paragraph the grid LCOE and energy demand increase (TWh and %) is update based on the model runs. The corrected paragraph should be:

The change of demand from a grid cost at 0.125 USD kWh$^{-1}$
to 0.074 USD kWh$^{-1}$ and 0.062 USD kWh$^{-1}$ would imply with no change in the low demand and an increase of 0.74 TWh for the high demand scenario in 2030. Looking at the total grid demand for the high scenario, 0.74 TWh represents a 1.3% increase of demand in 2030.

In appendix clarifications has been made to table A that the capacity factor is dynamic in the OnSSET model runs. Furthermore, the diesel price is harmonized with OSeMOSYS model runs. The corrected table A is:

In table C a duplicate Transmission and distribution line was removed. The updated table C is:

In table D a duplicate PV utility row was removed. The updated table D is:
### Table A. Technical performance and cost for 2015, OnSSET.

| Parameter | Capital cost (USD kW\(^{-1}\)) | O&M ($ kW\(^{-1}\)) | Fuel cost (USD MWh\(^{-1}\)) | Capacity factor | Efficiency |
|-----------|---------------------------------|---------------------|-------------------------------|----------------|------------|
| PV stand-alone + Li-ion battery (1688 USD kW\(^{-1}\)) | 1633 + 1688 = 3321 | 10 | | Dynamic | – |
| Wind (capacity factor 20, 30, 40%) + Li-ion battery (1688 USD kW\(^{-1}\)) | 2214 + 1688 = 3902 | 49 | | Dynamic | – |
| Diesel generator, Stand alone | 937.85 | 93.4 (assumed 10% of capital cost) | 85 | 50% | 28% |
| Diesel generator Micro grid | 721.4 | 72.1 (assumed 10% of capital cost) | 85 | 70% | 33% |
| Mini grid PV + Li-ion battery (1688 USD kW\(^{-1}\)) | 1363 + 1688 = 3051 | 8 | | Dynamic | – |
| Mini hydro | 2902 | 58 (assumed 2% of capital cost) | | 50% | – |
| Transmission distribution HV/MV/LV | 92 823/9000/5000 per km | | | | 81.8% |

### Table C. Technologies efficiencies modelled.

| Technology | Efficiency |
|------------|------------|
| Coal steam cycle | 35% |
| Medium speed diesel/Heavy fuel oil combined cycle | 45% |
| Geothermal | 10% |
| CSP | 15% |
| PV | 16% |
| Nuclear light water | 36% |
| Biomass, bagasse | 33% |
| Natural gas combined cycle | 55% |
| Transmission and distribution | 81.8% increase to 85% |
| Technology                                                  | Investment cost  | Fixed cost  | Variable cost | Total max capacity |
|------------------------------------------------------------|------------------|-------------|---------------|-------------------|
| Geothermal                                                 | Binary: 5049     | Binary: 63  | Binary: 24.84 | Binary: 3.285     |
|                                                           | Flash steam: 3787| Flash Steam plant: 63 | Flash Steam plant: 9 | Flash steam: 6.715 |
| Wind                                                       | 2044 (2015)/2214|(2030)       | 19.98         | See section 3.4.4 in (Moksnes, 2016) |
|                                                           | 1678             | 62.5        | 9             | –                 |
| Heavy fuel oil combined cycle/Medium speed diesel          |                  |             |               |                   |
| Hydro river run-off <10 MW                                 | 2902             | 2.05        | 4.464         | 0.5               |
| Hydro dam <30 MW                                           | 3409             | 1.39        | 4.104         | 0.55              |
| Hydro dam >30 MW                                           | 3078             | 1.39        | 4.104         | 1.49              |
| PV utility                                                 | 2133 (2015)/1143 | 4.2         | 0 (included in fixed cost) | See section 3.4.4 in (Moksnes, 2016) |
|                                                           | 2181             | 27.7        | 9.252         | 0.192             |
| Biomass CHP (Bagasse)                                      |                  |             |               |                   |
| Natural gas Combined cycle                                 | 770              | 31          | 1.8           | Max 0.54 annually |
|                                                           |                  |             |               | earliest 2018     |
| Coal single cycle                                          | 2903             | 69          | 4.608         | Max 0.9 annually  |
|                                                           |                  |             |               | earliest 2016     |
| Nuclear light water                                        | 6164             | 0 (Included in variable cost) | 15.984 | Earliest date 2023 1.2 GW |
| Concentrated solar power, solar tower with storage         | 7381 (2015)/3508 | (2030)      | 0 (Included in variable cost) | See section 3.4.4 in (Moksnes, 2016) |
|                                                           | 112              | 0           | 0             | –                 |
| Distribution                                               | 16               | 0           | 0             | –                 |
Annex

Table 1. Difference in key input/output between initial submission and corrigendum.

| Corrected values                  | Published paper | Corrigendum (harmonized with paper) | Difference | Unit          |
|-----------------------------------|-----------------|--------------------------------------|------------|---------------|
| Population start (OnSSET)         | 32 527 000      | 46 050 302                           | 13 523 302 | People        |
| Diesel price (OnSSET)             | 0.577           | 0.850                                | 0.273      | USD l⁻¹       |
| Wind MG (OnSSET)                  | 3732            | 3902                                 | 170        | USD kW⁻¹      |
| PV MG (OnSSET)                    | 4101            | 3051                                 | −1050      | USD kW⁻¹      |
| PV SA (OnSSET)                    | 5088            | 3321                                 | −1767      | USD kW⁻¹      |
| SA diesel (OnSSET)                | 70%             | 50%                                  | −0.2       | Capacity factor |
| Demand in OSeMOSYS for high demand|                 | Without flagship demand              |            |               |
| Demand for residential was not adjusted in OSeMOSYS for grid from OnSSET (high demand) | 13 041          | 31 459                               | 18 418     | GWh           |
| Demand for residential was not adjusted in OSeMOSYS for grid from OnSSET (low demand) | 6797            | 9467                                 | 2670       | GWh           |
| Updated capacity factors for wind harmonized with NREL learning curves (OSeMOSYS) | Constant        | Learning curve                       |            |               |
| Capital cost wind (OSeMOSYS)      | 1991            | 2044                                 | 53         | USD kW⁻¹      |
| Capital cost CSP (OSeMOSYS)       | 6254            | 7381                                 | 1127       | USD kW⁻¹      |
| Capital cost large hydro (OSeMOSYS) | 3665          | 3078                                 | −587       | USD kW⁻¹      |