International Labour Organization

STRENGTHEN2

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Employment impact assessment of the National Feeder Roads Programme, Rwanda

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International Labour Organization (ILO)

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Acronyms and abbreviations

ACLED	Armed Conflict Location and Event Data Project
DID	Difference in difference
DNB	Day Night Band
EmpIA	Employment impact assessment
EU	European Union
GDP	Gross domestic product
GIS	Geographic information systems
MININFRA	Ministry of Infrastructure
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalised Difference Vegetation Index
NISR	National Institute of Statistics Rwanda
NTL	Night-time lights
RS	Remote sensing
SSA	sub-Saharan Africa
VIIRS	Visible Infrared Imaging Radiometer Suite
WOCBA	Women of child bearing age

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Executive Summary

The ILO STRENGTHEN2 project is conducting employment impact assessments of EU-funded investments in sub-Saharan Africa, to promote the creation of more and better jobs. This report presents an employment impact assessment (EmpIA) of the National Feeder Roads Project (NFRP) in Rwanda. The report assesses the EU part of the project, which was completed at the end of the 2016/17 fiscal year. The project aimed to connect agricultural areas and markets, improving access to food, economic and social services. The programme would contribute to poverty reduction through promoting economic growth and food security.

Geographic information systems (GIS) data and methods were applied to assess the long-term economic and employment impacts of the project. Night-time lights (NTL) satellite imagery was the main dataset used, which provides a measure of light emissions at night and can be applied as a proxy for economic activity. The treated road, that was rehabilitated as part of the corridor project was compared to two untreated roads with similar characteristics. The increase in NTL brightness was compared pre and post treatment, whilst controlling for population, conflicts and other variables to analyse the economic impact of the road rehabilitation. The increase in NTL was translated into GDP using the national level elasticity and then further translated into employment, to estimate the percentage increase in employment caused by the improved road. This was estimated across four years following completion of the project and analysed at different distances from the road, to highlight where the impacts were greatest. GIS was also used to analyse access to social infrastructure, to assess its contribution to improving physical access to social services. Travel time to the nearest health and education facility was calculated and the population coverage was compared before and after the implementation of the project.

The results show that areas that received a rehabilitated road had an increase in night-time light luminosity between 2.3-3.1 per cent at the administrative level, between one and four years following completion of the project. It is estimated that this produced an increase in GDP between 0.8 and 1.5 per cent. Taking into account the elasticities between lights/GDP and GDP/employment, this produces an increase of between 0.3-0.4 per cent. The largest impacts could be observed within 1 kilometre of the rehabilitated roads. Although the increase in employment is relatively low compared to previous assessments, due to the nature of the project focusing on feeder roads, it is expected that other benefits, such as increases in incomes can also be observed. It is recommended that this analysis is replicated using labour force survey data to assess these dimensions of employment.

When presenting the results in terms of million Euro invested and km of road built, based on the project cost of 40 Euro million, GDP is estimated to have increased by 0.04 per cent per million Euro invested, using the maximum increase of four years after completion of the project. For employment, this equates to an increase of 0.01 per cent per million Euro. When looking at the results per 100 km of road constructed or rehabilitated, based on the total of 700 km of roads rehabilitated, this is equivalent to an increase in GDP of 0.2 per cent and an increase in employment of 0.06 per cent per 100 km of road.

When assessing access to social infrastructure and the potential impact the project had on access to social infrastructure, results show that the project increased access to health facilities for 8 per cent of women, within a 15-minute travel time. Access to education for school-age children increased from 65 per cent to 71 per cent, for a 15-minute walking or driving travel time to the nearest school. The results indicate that the project brought economic development to the area but also increased access to social services for the existing population, which will provide additional benefits in poverty reduction. It is recommended that similar assessments are produced in other countries and project sectors to build upon this methodology and promote it for use in employment impact assessments.

Résumé exécutif

Le projet STRENGTHEN2 de l'OIT réalise des évaluations de l'impact sur l'emploi des investissements financés par l'Union Européenne en Afrique subsaharienne, afin de promouvoir la création d'emplois plus nombreux et de meilleure qualité. Ce rapport présente une évaluation de l'impact sur l'emploi du Projet de Routes Nationales de Desserte au Rwanda. Le rapport évalue la partie européenne du projet, qui s'est achevée à la fin de l'année fiscale 2016/17. Le projet visait à relier les zones agricoles et les marchés, en améliorant l'accès aux services d'alimentation, économiques et sociaux. Le programme contribuerait à la réduction de la pauvreté en favorisant la croissance économique et la sécurité alimentaire.

Les données et les méthodes de Systèmes d'Information Géographique (SIG) ont été utilisées pour évaluer les impacts du projet à long terme sur l'économie et l'emploi. L'imagerie satellite de luminosité nocturne constitue la base de données principale, offrant une mesure des émissions de lumières nocturnes et pouvant être appliquée comme un indicateur de l'activité économique. La route traitée, qui a été réhabilitée dans le cadre du projet de corridor, a été comparée à deux routes non traitées présentant des caractéristiques similaires. L'augmentation de la luminosité nocturne a été comparée avant et après traitement, tout en contrôlant des variables telles que la population, des conflits et autres variables pour analyser l'impact économique de la réhabilitation de la route. L'augmentation en luminosité nocturne a été convertie en PIB en utilisant l'élasticité au niveau national, puis convertie à nouveau en emploi, afin d'estimer le pourcentage d'augmentation de l'emploi causé par l'amélioration de la route. Cette augmentation a été estimée sur quatre ans suivant l'achèvement du projet et analysée à différentes distances de la route, afin de mettre en évidence les endroits où les impacts étaient les plus importants. Les SIG ont également été utilisés pour analyser l'accès aux infrastructures sociales, afin d'évaluer leur contribution à l'amélioration de l'accès physique aux services sociaux. Le temps de trajet jusqu'au centre de santé et d'éducation le plus proche a été calculé et la population couverte a été comparée avant et après la mise en œuvre du projet.

Les résultats montrent que les zones qui ont connu une réhabilitation de route ont vu une augmentation de la luminosité nocturne entre 2,3 et 3,1 pour cent au niveau administratif, entre un et quatre ans après la fin du projet. On estime que cela a produit une augmentation du PIB comprise entre 0,8 et 1,5 pour cent. En tenant compte des élasticités luminosité/PIB et PIB/emploi, cela produit une augmentation comprise entre 0,3 et 0,4 pour cent. Les impacts les plus importants ont pu être observés dans un rayon d'un kilomètre autour des routes réhabilitées. Bien que l'augmentation de l'emploi soit relativement faible par rapport aux évaluations précédentes, en raison de la nature du projet concentré sur les routes de desserte, d'autres avantages, tels que l'augmentation des revenus, ont pu également être observés. Il est recommandé de reproduire cette analyse en utilisant des données d'enquête sur les forces de travail pour évaluer ces dimensions de l'emploi.

Si l'on présente les résultats en termes de millions d'euros investis et de kilomètres de routes construites, sur la base du coût du projet de 40 millions d'euros, on estime que, par million investi, le PIB a augmenté de 0,04 pour cent, en utilisant l'augmentation maximale de quatre ans après l'achèvement du projet. Pour l'emploi, cela équivaut à une augmentation de 0,01 pour cent par million d'euros. Si l'on considère les résultats par 100 km de route construite ou réhabilitée, sur la base d'un total de 700 km de routes réhabilitées, cela équivaut à une augmentation du PIB de 0,2 pour cent et à une augmentation de l'emploi de 0,06 pour cent.

Lorsque l'on évalue l'accès aux infrastructures sociales et l'impact potentiel du projet sur l'accès aux infrastructures sociales, les résultats montrent que le projet a amélioré l'accès aux installations de santé pour 8 pour cent des femmes, dans un temps de trajet de 15 minutes. L'accès à l'éducation pour les enfants en âge d'aller à l'école est passé de 65 pour cent à 71 pour cent, pour un temps de trajet de 15 minutes à pied ou en voiture jusqu'à l'école la plus proche. Les résultats indiquent que le projet a apporté un développement économique à la région, mais a également amélioré l'accès aux services sociaux pour la population existante, ce qui aura d'autres conséquences positives sur la baisse de la pauvreté. Il est recommandé de réaliser des évaluations similaires dans d'autres pays et dans d'autres secteurs de projet afin de s'appuyer sur cette méthodologie et de promouvoir son utilisation dans les évaluations de l'impact sur l'emploi.

1. Introduction

The STRENGTHEN2 project is a joint initiative of the European Union and the ILO that aims to maximize employment impact assessment (EmpIA) in sub-Saharan Africa, for the creation of more and better jobs. STRENGTHEN2 is working to assess the employment impact of EU-funded infrastructure investments in Rwanda, among other countries. The National Feeder Roads Project (NFRP) was completed in 2016/17 and aimed to enhance access to markets in areas with high agricultural potential, through improving the road network. The objectives also included improving consumer access to safe and affordable food, economic and social services to improve food security and poverty reduction. The project was funded by the European Union (EU) and the Government of Rwanda (GoR), for a total of €40 million, which was put forward for the rehabilitation of 700 km of road and maintenance of a further 500 km. This report presents the EmpIA for the project, using geographic information systems (GIS) analysis and night-time lights (NTL) data to assess the long-term employment effects. It also analyses the improvements to accessing social services that the project aimed to achieve. It outlines the country context for Rwanda, the project description, methodology, results and discussion and recommendations.

Once infrastructure projects are complete, it is important to assess their impacts on employment in order to understand the long-term effects that interventions have produced, although these impacts are arguably the most difficult to measure. Investments in roads increase long-term employment outcomes through road maintenance and by enabling improved access to the labour market and basic services, including health and education, which assists in accessing more and better jobs. Operationalizing the use of GIS in EmpIA is relatively new, but there has been work done in utilizing geospatial data and satellite imagery for analysing the economic impacts of transport infrastructure. Much previous literature has shown the potential of NTL data as a proxy for economic activity, such as the work of Henderson, Storeygard and Weil (2012) at the country level in the form of GDP, along with a case study in Kenya that was produced by the STRENGTHEN2 project prior to this assessment (Game and Kang 2023). The high spatial and temporal resolution of the data makes it a valuable source, especially in areas where economic and employment data may be lacking from traditional sources. The use of NTL data for assessing the economic impacts of road projects has recently been applied in countries such as Haiti (Mitnik, Sanchez and Yañez-Pagans 2018) and the West Bank (BenYishay et al. 2018). This work aims to build upon the past literature to demonstrate the applicability of NTL data for assessing the economic impacts of road investments. The analysis will be taken a step further by translating the change in economic activity into a change in employment, in order to assess the employment effects related to specific investments. It offers a comparison to the STRENGTHEN2 assessment of the Merille-Marsabit road project in Kenya (Game and Kang 2023), with a focus on feeder roads that provides an interesting contrast to the larger road in Kenya.

While physical access to labour market is key for increasing long-term employment, road rehabilitation programmes also increase access to a range of social infrastructure. This benefits the population through enabling access to health facilities, schools and financial services. To assess the impact that the NFRP had on access to such infrastructure, travel time scenarios were calculated using GIS to analyse the change in travel time to social infrastructure, due to the rehabilitated roads. Access to health facilities, with a focus on women for assessing maternal health coverage, were analysed, along with access to schools for children.

2. Country situation analysis

Rwanda is a country located in the Great Lakes region of Central Africa, bordered by Uganda, Tanzania, Burundi and the Democratic Republic of Congo. Rwanda's total area is 26,338 square kilometres. Currently, the National Institute of Statistics of Rwanda (NISR) estimates the population to be 13.3 million in 2022, projected to increase to 17.6 million in 2035 and 22.1 million in 2050 (NISR, RPHC4: Population Projections 2014). Around 70 per cent is youth, with 27.6 per cent between the ages of 16 and 30. Women and girls represent 52 per cent of the population and only 18.4 per cent of the total population are living in urban areas.

Over the last two decades, Rwanda's economic growth has been on the rise. An analysis of the macroeconomic trends shows that the overall economy has grown at a significant rate, averaging annual GDP growth rates of 8 per cent. Rwanda's GDP per capita increased from US$673 in 2011 to US$837 in 2019, before the COVID-19 pandemic. In 2020, Rwanda observed a decline in GDP per capita, which was estimated to be US$804 due to the pandemic. This recovered in 2021, where the Rwandan economy grew by 10.9 per cent from the observed contraction in 2020 and GDP per capita grew to US$854 (NISR, GDP National Accounts 2021).

In the latest Labour Force Survey (LFS) of February 2022, at the time of writing, the labour force participation rate, which is the percentage of total working population, either employed or unemployed, was at 54.5 per cent. The rate was higher for the male population than the female population over time, with the gender gap around 13.6 per cent. This rate is high in urban areas compared to rural areas, attributed to the diversity of job opportunities in urban areas as compared to rural areas where the number of employment opportunities is limited, and most people are involved in subsistence agriculture. The country has a substantial number of working age population who are involved in subsistence agriculture (estimated at 41.9 per cent) and consequently excluded from the count of the labour force according to the 2013 international standards on statistics of work, employment and labour underutilization.

The ratio of employment to the working age population, which is an important indicator of the capacity of the economy to provide employment to a growing population, is at 45.5 per cent. The ratio is higher in urban areas as compared to rural areas, with the gap estimated at 8.2 percentage points, and higher for males than females, with the gender gap standing at 13.2 percentage points at the national level. The majority of employed population are engaged in agriculture, forestry and fishing (52.5 per cent). Other sectors that employed a substantial number of population were construction (9.2 per cent), wholesale and retail trade; repair of motor vehicles and motorcycles (10.1 per cent), transportation and storage (4.7 per cent), manufacturing (4.4 per cent), education and activities of households as employers (3.8 per cent, and 3.7 per cent respectively). The category of employees and paid apprentices recorded the highest share of employment across all rounds of the labour force survey followed by own-account workers, contributing family workers, employers, and member of cooperatives.

Like many other developing economies, Rwanda suffers from labour underutilization (unemployment, time-related underemployment and potential labour force). The total number of potential labour force which is not currently either studying or working is 21.1 per cent, which represents an underutilization of 52.8 per cent. The labour underutilization rate was higher among females at 58.8 per cent, than males at 46.7 per cent (NISR, Labor Force Survey 2022). In February 2022, the unemployment rate stood at 16.5 per cent, from 23.8 per cent in November 2021, higher among the population living in urban areas as compared to those living in rural areas of Rwanda (17.8 per cent and 16.1 per cent respectively). In Rwanda, the youth population is defined as persons 16 to 30 years of age. The unemployment rate among the youth has been relatively higher than the unemployment rate among adults over time. The rate among the youth stands at 22.8 per cent and among adults (31+ years) at 11.9 per cent. In the same period, the time-related underemployment rate was at 28.4 per cent, implying a high rate of employment that is unsatisfactory in terms of insufficient hours, insufficient compensation or insufficient use of one's skills.

Regarding infrastructure in Rwanda, the quality of the road network has improved during the last decade due to substantial new investment and sustained improvement in maintenance. However, there are still issues that need to be addressed to improve the quality of infrastructure. In 2018/19, the total network of roads countrywide was 44,671 km, of which 1,973 km are paved. 72 per cent of the total paved roads are national roads and 97 per cent of the national paved road network is deemed to be in good condition (MININFRA 2021). Although improvements have been made, the Ministry of Infrastructure (MININFRA) highlighted areas that need to improve to increase access to quality transport infrastructure. Issues include a lack of all-season roads in rural areas, lack of road traffic management and a lack of integrated public transport, among others. In regard to energy in Rwanda, according to statistics from Rwanda Energy Group (REG), the number of households accessing electricity has increased from 10 per cent in 2010 to 73 per cent in June 2022. The average access to electricity in urban areas is estimated at 96 per cent versus 74 per cent in rural areas (REG 2022). The Energy Sector Strategic Plan of 2018/19-2023/24 aims to achieve 100 per cent electricity access to households by 2024; 52 per cent of households will be electrified with the grid and 48 per cent with off-grid systems.

3. Project description

To improve the market accessibility of agricultural products, the Ministry of Agriculture and Animal Recourses (MINAGRI) of Rwanda started to mobilize resources for the implementation of the National Feeder Roads Program (NFRP) in 2012. The programme aimed to rehabilitate and maintain roads that link the agricultural areas with the commercial centres or processing plants in 27 districts. The programme was funded by EU, World Bank, The Netherlands, African Development Bank, International Fund for Agricultural Development and USAID.

The implementation of the EU-funded portion of the NFRP started in 2013 when the EU and the Government of Rwanda reached a financing agreement of €40 million for the Sector Policy Support Program for Rural Feeder Roads on 4 October 2013. The main proportion of the financial support, €36 million, was earmarked for the Sector Budget Support, which funds 700 km of rural roads rehabilitation and 500 km of rural roads maintenance in seven districts, including Nagoma, Bugesera, Huye, Muhanga, Ngororero, Rubavu, and Rulindo. The disbursements of the Sector Budget Support were fully made in four annual tranches (6 million, 8 million, 12 million, and 10 million) from the 2013/14 fiscal year to the 2016/17 fiscal year, when the project was completed. The rehabilitated roads are presented in Figure 1. Feeder roads were selected for rehabilitation based on a feeder road prioritization study that applied a multi-criteria analysis including criteria based on national and local objectives, that fell within areas of road network technical parameters, economic efficiency and social impact. Roads that had lower combined scores across categories were prioritised for rehabilitation.

By improving the trafficability of the rural roads, the Sectorial Policy Support Program for Rural Feeder Road (hereby the Program) was expected to connect areas of high agricultural potential with the market and improve the consumers' access to safe and affordable food, as well as basic economic and social services. The Program also helped set up a sustainable system and reinforce the capacities of local government. These objectives would contribute to poverty reduction through the promotion of equitable and inclusive economic growth and strengthening food security.

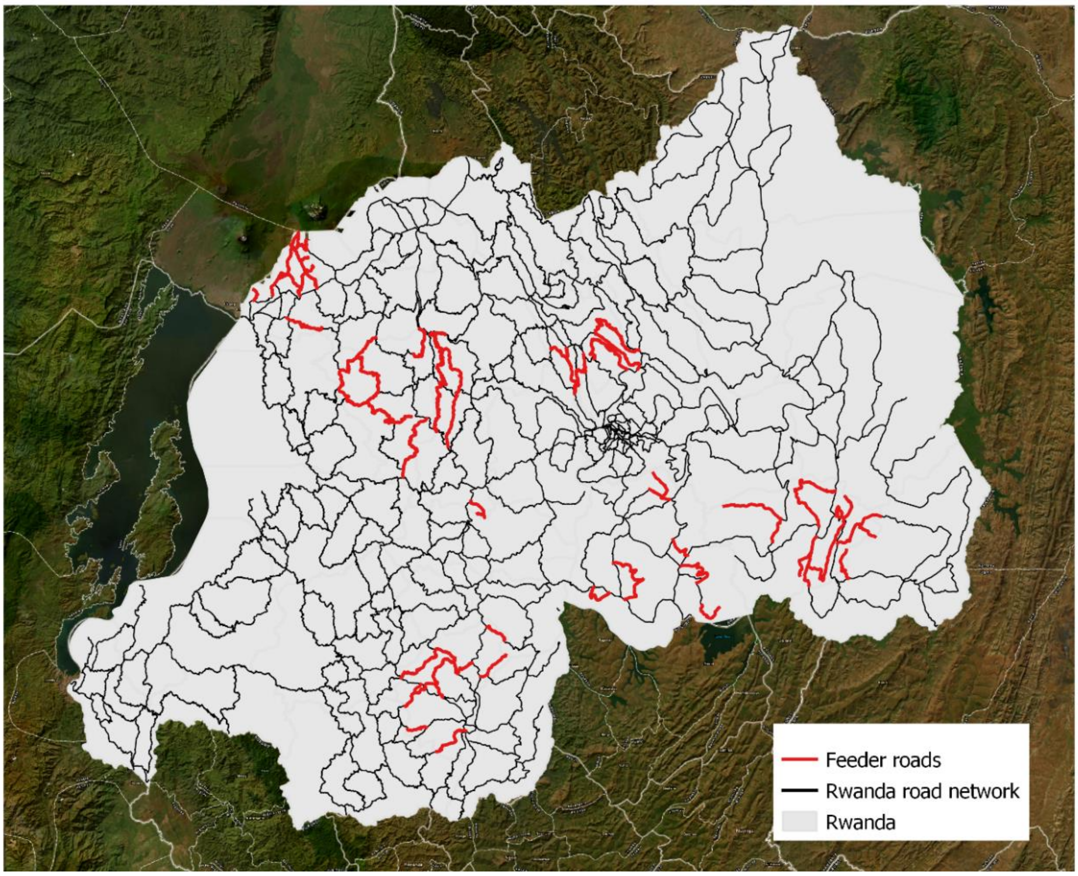
Now the project is completed, during the implementation period, 799.5 km of rural feeder roads were constructed or re-paved, exceeding the target of 700 km; 514.27 km of rural feeder roads were extended and improved on the drainage system, exceeding the target of 500 km. The rehabilitation and maintenance work connected segmented rural roads and improved the road networks in remote areas. The increased drainage capacity reduced the possibility of waterlogging and sequent road interruptions. The passibility of roads for vehicles and bikes significantly improved. Table 1 outlines the roads that were rehabilitated and maintained during the project, across the seven districts.

▶ **Table 1. Rehabilitated roads as part of the NFRP**

District name	Length of roads rehabilitated (km)	Length of roads maintained (km)	Budget executed in Rwandan francs (RWF)
Bugesera	134.6	81	3 185 900 650
Ngoma	141.7	102	4 089 254 580
Huye	97.9	97.9	4 569 558 789
Muhanga	100.9	23	4 892 304 032
Ngororero	130.3	90	5 567 778 123
Rubavu	92	63.5	4 938 501 353
Rulindo	104	53.5	8 125 920 030

Source: Ministry of Agriculture and Animal Resources (2018)

▶ **Figure 1. Rwanda road network and EU-funded feeder roads included in the NFRP**



Source: Feeder roads (MINAGRI 2018), Rwanda road network (OSM 2022), Rwanda country boundary (GADM 2012)

4. Data

GIS and remotely sensed satellite data were downloaded, processed and combined to conduct the assessment into the economic and employment impacts. The different data sources and processing required are outlined below.

4.1. Roads

The NFRP spreads across seven districts in Rwanda, which were used as the study area for the analysis. The feeder roads that were improved as part of the programme were applied as the treatment group. Feeder roads are considered to cover any road which links the agricultural areas with commercial centres or with a processing plant, often referred to as “Farm to Market Roads”. The feeder roads standards provide the width of 6 m with the possibility to upgrade to 7 m for sections in National Roads and District Roads Class 1. The priority feeder roads identified by the project cover different categories of roads as per the Road Act: National, District Class 1, District Class 2 and unclassified roads as defined here below. District Road Class 1 roads can be defined as roads linking different sectors’ headquarters within the same district, or those roads that are used within the same sector. District Road Class 2 shall be arterial roads that connect District roads to rural community centres that are inhabited as an agglomeration. District class 1 and 2 roads that were not part of the roads rehabilitated under the project that fell within the seven districts, were used as the control or “untreated” group for comparison. Data on roads, including those that were targeted as part of the project, were obtained from the Ministry of Finance and Economic Planning (MINECOFIN), where they were originally collected and stored by the Ministry of Agriculture and Animal Resources (MINAGRI).

4.2. Night-time lights

Monthly NTL data from NASA’s Visible Infrared Imaging Radiometer Suite (VIIRS) Day Night Band (DNB) instrument were used as the dependent variable of interest. Due to the timing of the project, it was possible to use only NTL data from the VIIRS satellite. Many previous studies have also had to use data from the previous satellite, Defense Meteorological Satellite Program (DMSP) (pre-2012), where further effort would have to go into calibration of luminosity values between satellites, which can cause some discrepancies in the outcome. NTL data were obtained from the beginning of 2012 to the end of 2020 at monthly intervals. NTL data values are presented as “radiance” or “brightness” values.

Due to the background noise in high-frequency VIIRS data, NASA implemented the Black Marble product suite which calibrates luminosity emissions from non-human activities that can interfere with the NTL radiance. The product uses a novel “Turning off the Moon” approach that combines cloud-free, atmospheric-, terrain-, vegetation-, snow-, lunar-, and stray light-corrected VIIRS DNB radiances, daytime DNB surface reflectance, Bidirectional Reflectance Distribution Function (BRDF) / Albedo, and Lunar irradiance values to minimize the influence of extraneous artifacts and biases (Román et al. 2018; Román and Stokes 2015). After adjusting for these systematic sources of uncertainty and measurement error, the VIIRS DNB’s ultra-sensitivity and daily frequency enables one to accurately detect short-term changes in rural areas that are often characterized by low light.

Although the monthly Black Marble suite brings high quality NTL data, it does not necessarily decrease the volatility of light emissions of pixels. Compared to the relatively stable annual DNB series, the monthly series captures the seasonal pattern of lights. The VIIRS instruments boards two satellites, NOAA/NASA Suomi NPP and NOAA-20, on a polar orbit, to generate a full global image twice a day. The satellites pass all locations on earth at the same local times to keep the observation consistent and reduce the effects of sun and moonlight. Consequently, the observed light emission intensity will be low in the summertime due to the late sunset time and become higher in winter because of the early sunset. The variances of observations would not correctly indicate the real artificial light intensity that could be generated by the local infrastructures, which could make the DNB radiance series a poor proxy for socio-economic development. Even though Rwanda is in the tropical zone, the intensity of the NTL can still vary due to the seasonal farming, grazing, festivals and other interventions.

To calibrate the light radiance, the DNB series was first smoothed with a high-pass exponential smoothing method to remove outliers and fill missing values. Then, a Seasonal and Trend decomposition based on Loess (STL) was used to remove the seasonal component of the DNB series for each pixel. Following the work of Cleveland et al. (1990), we decomposed the DNB radiance series into three components.

4.3. Additional GIS and remote sensing (RS) data

A range of GIS data were used in the analysis to include as control variables of interest. All data was resampled to a spatial resolution of approximately 450 m x 450 m to match the resolution of the NTL imagery. To control for other factors that could potentially influence the NTL brightness, a range of variables were included in the analysis. The Normalised Difference Vegetation Index (NDVI) provides a measure of vegetation greenness and can be used to identify changes in land use over time; this was obtained on an annual basis for the time period of focus (2012–20) from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) dataset. To control for population growth, annual gridded population estimates from Worldpop were also included, which provides a population count across the country at the approximate 100 m grid cell. Precipitation data from the Integrated Multi-satellite retrievals for GPM (IMERG) were obtained on a yearly basis at a resolution of approximately 10 km. Locations of conflicts during 2012–20 were obtained from the Armed Conflict Location and Event Data Project (ACLED) and filtered to include larger-scale conflicts such as explosions or riots, which could have influenced NTL brightness in target areas. Finally, information on the presence of other infrastructure projects that were completed during the time period of focus and could have had an impact on the NTL brightness, were controlled for in the study. Table A.1 in the Annex outlines a list of the other road and energy projects that fell within the study area and were accounted for in the work. This information was obtained from annual reports produced by MINAGRI.

For the accessibility analysis, when analysing the travel time to health facilities and schools for the population that benefitted from the NFRP, a range of GIS data was used to calculate the travel time scenarios. This included landcover data from the European Space Agency Climate Change Initiative (ESA CCI), which shows different landcover classes at 20 m resolution across Africa. Digital Elevation Model (DEM) from the Shuttle Radar and Topography Mission (SRTM), presenting the ground elevation in metres for each grid cell was also used. Data on the locations of health facilities were obtained from the Esri Rwanda GeoPortal from the Ministry of Health and school locations from the Ministry of Education. Health facilities were subset to include main hospitals and health centres. Population data was again taken from Worldpop, however age and sex structures were utilized, to look at access to healthcare for women of childbearing age (WOCBA) between the ages of 15 and 49 and children between the ages of 1 and 9 for access to pre-primary/primary education and ages 10–19 for access to secondary education.

5. Methods

5.1. Econometrics

This analysis replicates the methodology applied in the first assessment produced by STRENGTHEN2 in Kenya (Game and Kang 2023), which follows the methods outlined by Mitnik, Sanchez and Yañez-Pagans (2018), with their assessment of road projects in Haiti. They examined the impacts of transport infrastructure investments on economic activity, discovering a 6 to 26 per cent increase in NTL following a road investment and a 0.5 to 2.1 per cent increase in GDP. They applied a difference in difference (DID) approach at both communal section and pixel level and discovered that the highest impacts were concentrated within two kilometres of the road. Other previous work has investigated the effects of transport investments on NTL, including BenYishay et al. (2018) who applied a quasi-experimental framework to look at the impact of projects in the West Bank at the pixel level. They discovered an increase in NTL due to these investments and that proximity to multiple roads results in a further increase in NTL. The STRENGTHEN2 EmpIA of the Merille-Marsabit road project and wider Isiolo-Moyale transport corridor in Kenya (Game and Kang 2023), followed the same approach as Mitnik, Sanchez and Yañez-Pagans (2018) and found that the improved sections led to an increase in NTL between 11 per cent for one year after project completion, up to 22 per cent after four years. This translated to an increase in GDP between 4.6 to 9.6 per cent across the one to four years, respectively and an estimated 1.4 to 3 per cent increase in employment.

The analysis aims to use NTL data to assess the economic and employment impacts of the NFRP. It assesses the impacts of the road at both the administrative Level 4, the smallest administrative level where data was available for Rwanda, and at pixel level (approximately 450 m x 450 m resolution). The analysis focuses on how impacts vary over time, or years after treatment, and as distance from the road improvement increases.

Administrative units within 2.5 km distance from the road are used in the benchmark regressions and there is a total of 1211 such units in the study area that fall within this distance from both the treated and control roads. The pixel-level analysis was performed to investigate how impacts change across distance, where distances up to five kilometres from the roads were examined, with the end point of 5 km being selected based on the findings. The results of the impact on GDP and employment were derived from the administrative level analysis. Monthly NTL data was used in the analysis for the years 2012-20, providing a total of 108 monthly measures. For the administrative level analysis, NTL pixels that fell within each administrative unit were summed to get the total NTL brightness for each unit. Due to the large number of zero NTL values in the pixel-level data, a result of the rural characteristics of the study area, the inverse hyperbolic sine transformation (HIS) was applied to the brightness values, following Mitnik, Sanchez and Yañez-Pagans (2018). This was then adopted as the dependent variable of interest.

A DID approach was applied to investigate the relationship between treatment (administrative areas that fell within 2.5 km of the road improvement) and NTL brightness. Starting from a reduced form specification, this was then built upon to include monthly, individual (administrative-level) fixed effects and the covariates of population, conflicts, NDVI and precipitation. These different regressions were run for each year after completion, a span of four years, to understand when the largest effect could be identified. From this, a preferred specification was decided which was then used for the interpretation of final results and applied to the analysis at pixel-level, looking at how NTL varies as a result of changing the distance from the road.

The equation below presents the general econometric specification that was applied:

$$Y_{i,t} = \alpha + \beta_1 Treated_i + \beta_2 X_{it} + \beta_3 Z_{it-j} + \lambda_i + n_t + \epsilon_{i,t}$$

Where Y is the NTL brightness for the administrative unit or pixel, $Treated$ i is the treatment variable that has a value of 1 for the month and year the area received a road improvement and 0 otherwise; λ_i is individual or administrative area fixed effects and n_t is monthly fixed effects; X_{it} is the control variables including population, precipitation, NDVI, conflicts and presence of other infrastructure projects; and Z_{it-j} presents lagged variables, where a lag of one year was tested, as per Mitnik, Sanchez and Yañez-Pagans (2018). Lags were on the basis of one year, as apart from the NTL data, variables were obtained on an annual basis.

Different models were run, starting from the most reduced specification, to introducing fixed effects and finally including covariates which then led to deciding on a preferred specification. Each model addresses a different type of variation, where the simple specification including no fixed effects is looking at overall variation. Including administrative fixed effects addresses variation over time and both administrative and time-fixed effects address variations over time within administrative units.

5.2. Translating NTL to GDP/employment

National level quarterly GDP data was sourced from the National Institute of Statistics of Rwanda (NISR) for the years of analysis. Quarterly employment data was also obtained from NISR on the number of people employed. The national level elasticity between the NTL brightness and GDP was computed, following the method of Henderson, Storeygard and Weil (2012). The translation to employment was then tested by calculating the national elasticity between GDP and employment.

5.3. Access to social infrastructure

To analyse the impact of the road project on access to social infrastructure, including health facilities and schools, travel time scenarios were simulated using the World Health Organization (WHO) AccessMod 5 (AccessMod, 2022). AccessMod is a software to measure physically accessibility to facilities, by combining and overlaying geospatial data and inputting travel information. The tool enables the user to calculate travel time by modelling scenarios of their choice, where the mode of transport of combined walking and driving was selected for this scenario, to study how this improved after the rehabilitation of the roads. AccessMod calculated the least-cost path to facilities, taking into account the road network and terrain (land cover and elevation) which can affect travel speed. Physical barriers that cannot be crossed, such as rivers, are also factored into the model. A total travel time to facility of up to 60 minutes was set as the cut off, based on the Ministry of Health (MoH) targets for walking travel time to health facility during the time of project completion (MoH 2021). This target has since changed to 45 minutes, aimed to be achieved by 2024. For schools, an official target could not be found, so the same time limit was analysed.

Different travel speeds were set based on road class (primary, secondary, tertiary, feeder road) and landcover type. A detailed breakdown of assigned speeds and associated classes are presented in Annex A.2. Landcover speeds were based on Tobler’s formula (Tobler 1993), which assumes a top walking speed of 5 km/h on a flat surface. Road travel speeds were taken from nationally set speed limits and previous work looking at travel time to healthcare in Rwanda (Munoz and Kallestal 2012). Two scenarios were modelled for investigating access to health facilities and schools. The first scenario used the road network and travel speeds prior to the implementation of the feeder roads project, which assigned a travel speed of 20 km/h to feeder roads before being rehabilitated. This was based on information in the National Feeder Roads Policy and Strategy (2017), which states that roads with a poor “level of service”, which takes into account travel speed, roughness and passability, where the original feeder roads would fall into this category, have speeds of less than 30km/h. An impact study of feeder roads in another district outside of this study (RTDA 2020) stated that the rehabilitation of feeder roads intends to improve the condition of the district network so it can ensure an average speed of 40 km/h. Therefore, this was selected as the speed for the second scenario, which modelled the travel time after the completion of the road project.

6. Results

6.1. Descriptive statistics

Tables 2 and 3 show the descriptive statistics for each of the variables included in the analysis, spanning the years 2012 to 2016, prior to the completion of any of the sections of the road. The first table, showing the untreated areas, are administrative areas that were included in the control group and did not receive a rehabilitated road. The treated areas are those that fell within the 2.5 km buffer around the road project. Treated administrative areas had a slightly higher NTL luminosity compared to those that were not treated, and they also had a marginally higher population. Both categories had a small number of conflicts but a similar level of other infrastructure projects completed during the years of focus, where a value closer to one indicates a higher presence.

▶ Table 2. Untreated administrative area summary statistics

	Mean	St. Dev.
NTL luminosity	0.07	0.844
Conflicts	0.002	0.046
Infrastructure	0.75	0.433
Population	134.305	164.82
IHS of NTL luminosity	0.032	0.242

Source: Own research

▶ Table 3. Treated administrative area summary statistics

	Mean	St. Dev.
NTL luminosity	0.088	0.722
Conflicts	0.005	0.073
Infrastructure	0.758	0.428
Population	136.498	123.74
IHS of NTL luminosity	0.047	0.273

Source: Own research

6.2. Main results

Tables A.3 to A.6 in the Appendix present the main results from the DID estimation, looking at different years after completion of the final section of the road. Table A.3 starts with one year after completion, all the way through to table A.6 which presents four years after completion of the road project. The main results, using the preferred specification, are presented in figure 2 for each of the four years. Following the previous assessment in Kenya and the regressions of Mitnik, Sanchez and Yañez-Pagans (2018) and starting from the most reduced specification in column 1 in the tables, step by step, different elements were introduced into the models as outlined in each column in the tables. Administrative and time-fixed effects were first introduced, shown in columns 2 and 3, respectively. This was followed by variables for population, conflicts, NDVI, precipitation and other infrastructure projects, in column 4. Lagged covariates were the final component to be included, where a lag of one year was tested in column 5. When looking at the coefficients of the covariates, as Mitnik, Sanchez, and Yañez-Pagans (2018) did not include a clear justification for the inclusion of precipitation and NDVI, both raised issues of reverse causality, so they were excluded from the preferred specification. Due to this and the outcomes of these regressions, including from the previous EmpIA in Kenya, it was decided to include only population, conflicts and other infrastructure projects, with no lag, as these were most relevant with regard to the potential impact on the NTL data. Lagged data were not included in the preferred specification because similarly to Kenya, coefficient estimates from the lagged results did not conform to theoretical expectations. This was the model specification that was used for the pixel-level analysis.

All the regressions for the different years after treatment follow a similar pattern, but what is surprising in the results is the change of sign that occurs in regressions (1) and (3) in the tables. A negative effect can be seen in column (1) and (3), however, this changes to positive with the inclusion of administrative area fixed effects in column (2) and again in columns 4 to 6 with the introduction of the control variables. Column 4 presents results after the inclusion of the control variables of population, NDVI and precipitation. The presence of conflicts is also included, taking the form of a dummy variable with a value of 1 if a conflict occurred in the administrative area during the month and 0 otherwise. The same format of a dummy variable is used for the presence of other infrastructure projects completed during the time period. The treatment effect increased after adding these covariates and increased further after including covariates with a lag of one year in column 5. As highlighted above, the final preferred specification, included only the current variables of population, conflicts and other infrastructure projects due to findings from the previous EmpIA in Kenya and the chosen specification in that study. This specification is presented in column 6 in the tables and the bar graph in figure 2. The coefficient for one year after treatment using this specification is 0.023, increasing up to 0.031 when looking at three years after treatment, before decreasing at four years after treatment to 0.022. When exponentiating the coefficient for interpretation of the results, using (exp(X) -1), this is equivalent to a 2.3 per cent increase in NTL, one year after completion for administrative areas that received a rehabilitated road. This increases to 3 per cent two years after completion before peaking at 3.1 per cent three years after. The change then decreases following four years after completion of the project, where the increase in NTL is only 2.2 per cent.

Looking at the different years after treatment, the impact continues to increase over time, with the smallest effect being seen within four years after the completion of the project. This may be due to the effects of the COVID-19 pandemic, as four years after project completion corresponds with the year 2020/21 and is also in line with the national decrease in GDP growth that occurred during that year, highlighted in the country situation analysis above. An increase can be seen in three years after treatment, with a coefficient of 0.031 using our preferred specification, which equates to a 3.1 per cent increase in NTL. It was decided to use three years after treatment as the main result as it does not vary greatly from the other years and still provides a relatively conservative estimate of the impact of road improvement on NTL, which was correspondingly the basis of our estimates of GDP and employment elasticities. employment elasticities. Table 4 presents the results of the regressions for three years after project completion.

▶ Table 4. Administrative level treatment effect, three years after project completion

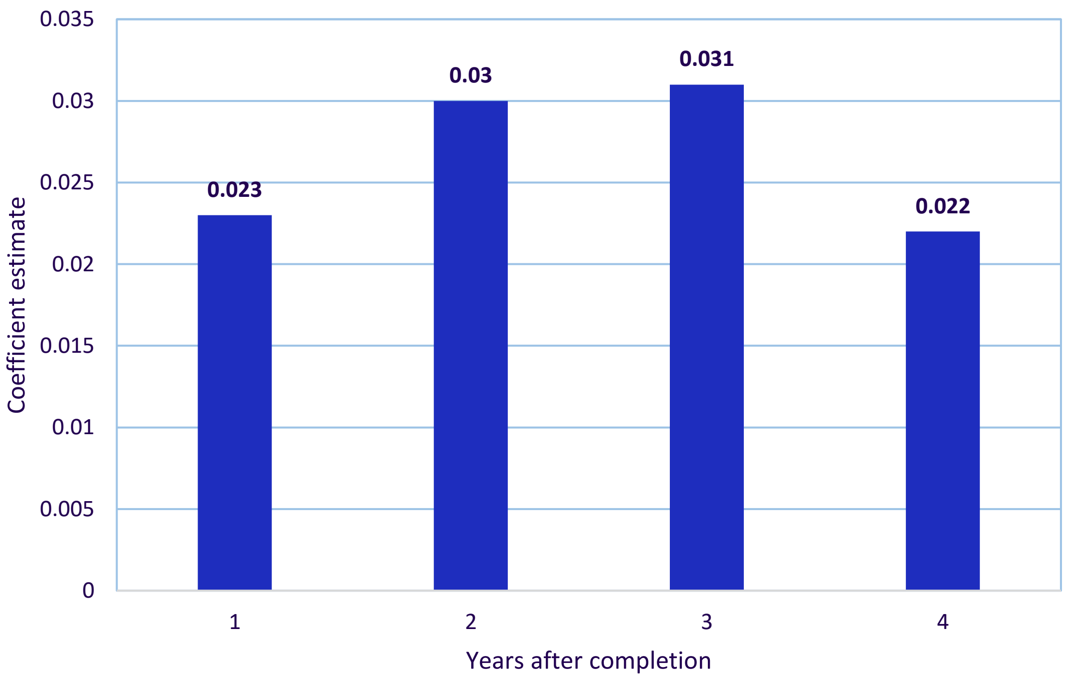
	NTL luminosity					
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment	-0.049***	0.100***	-0.028***	0.052***	0.061***	0.031***
	(0.009)	(0.007)	(0.009)	(0.007)	(0.007)	(0.007)
Observations	101,472	101,472	101,472	101,472	86,976	101,472
Adjusted R-squared	0.000	0.700	0.704	0.825	0.836	0.798
Admin area FE	NO	YES	YES	YES	YES	YES
Time FE	NO	NO	YES	YES	YES	YES
Covariates	NO	NO	NO	YES	YES	YES
Lagged covariates	NO	NO	NO	NO	n-1	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Own research

▶ Figure 2. Coefficient estimates for years after completion of the road project



Source: Own research

6.3. Pixel-level results

The above text outlines the results for the analysis at the administrative area, which were then used as the preferred specification to estimate the impact on GDP and then employment from the road project. The analysis was also conducted at the pixel level to investigate how impacts on NTL vary based on distance from the road project. Understanding if the effects are concentrated around the road improvements is important from a planning and policy perspective, for the targeting of future investments.

Using the 2.5 km buffer around roads and three years after treatment to facilitate comparison with the administrative area results above, table 5 presents the main result at the pixel level. The treatment effect of 0.014, which is equivalent to a 1.4 per cent increase in lights following the completion of the road, is lower than the effect observed at the administrative area but remains positive and statistically significant. This smaller result at pixel level follows a similar pattern to Mitnik, Sanchez and Yañez-Pagans (2018) and the STRENGTHEN2 work in Kenya (Game and Kang 2023), where the coefficient estimates for the pixel level analysis were much lower compared to that at administrative level.

▶ Table 5. Impact on NTL luminosity following road improvement, at the pixel level, within 2.5 km of the road

	NTL luminosity
treatment	0.014***
	(0.001)
inf	0.002
	(0.004)
conf	0.001
	(0.002)
pop	0.001***
	(0.000)
Observations	2,355,034
Adjusted R-squared	0.903

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Own research

To test for heterogeneity in results and explore how effects vary across distance from the road, the buffer outside the road was changed using increments of 1 km. Five regressions are run, looking at five 1 km buffers surrounding the road. Table 6 outlines the results, where the largest impact can be seen closest to the road, at 0-1 km distance, with an impact of 1.1 per cent; this decreases but remains statistically significant at 1-2 km away from the road, with a 0.4 per cent increase in lights, when exponentiating the coefficient for interpretation as per the formula above. Between 2 to 3 km from the roads there is an increase of 0.7 per cent, but after this, the sign changes and the effect becomes negative and loses statistical significance, although it is very small. This may suggest that after a 3 km distance, effects drop off or that there is even a slight decline in NTL in areas with a road improvement after this distance. This effect remains small but becomes positive and statistically significant for a distance of between 4 to 5 km from the road. A similar result was found in the Kenya study, where the largest effect could be observed within 1 km of the road. However in Kenya, there was a small but negative treatment effect after a distance of 2 km from roads.

▶ **Table 6. Impact on NTL luminosity following road improvement, at the pixel level, changing the distance from the road**

	NTL luminosity				
	1 km	2 km	3 km	4 km	5 km
treatment	0.011***	0.004***	0.007***	-0.001	0.003***
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Observations	1,554,284	840,715	496,903	474,096	359,520
Adjusted R-squared	0.883	0.932	0.965	0.958	0.914

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Own research

6.4. NTL and GDP

To more fully understand the economic and employment impacts of road investments, it is instructive to express changes in NTL in terms of changes in GDP and then employment. As mentioned, previous EmpIA and literature has demonstrated the applicability of NTL as a proxy for economic activity in the form of GDP. National level GDP data was available on a quarterly basis for Rwanda, which was used to establish the relationship between GDP and NTL.

The main results are presented in table 7, which presents the elasticity between GDP and NTL, using the quarterly GDP data for the years that coincide with NTL data (2012-2020). The elasticity is 0.347, which is slightly lower than the elasticity obtained from the EmpIA in Kenya of 0.424 but still in line with Henderson, Storeygard and Weil (2012), who estimated an elasticity of around 0.3 for a group of low- and middle-income countries. Assuming that this elasticity holds at the administrative level 4, this suggests an estimated 0.8 per cent increase in GDP one year after completion of the project, increasing to a 1.1 per cent increase in GDP in both two and three years after. Four years after completion saw an increase in GDP of 0.8 per cent in areas that received a rehabilitated road.

▶ **Table 7. Elasticity between annual GDP and NTL luminosity, at national level**

	lnGDP
lnNTL	0.347**
	(0.149)
Observations	40
R^2	0.124
Note:	*p<0.1; **p<0.05; ***p<0.01

Source: Own research

6.5. Translating into employment

Now that the economic impact of the road improvement project has been estimated in the form of GDP, work can be done on translating this into employment impact. There are two approaches to doing this. The first is to follow on from the previous NTL/GDP elasticity and then look at the relationship between GDP and employment. The second approach calculates the direct elasticity between NTL and employment.

Using quarterly employment data from Labour Force Surveys (LFS) conducted by NISR that is available back to 2016 on the number of persons employed per year, the relationship between GDP and employment is presented in table 8. The log difference was used to investigate the elasticity between GDP and employment. It should be noted that as the data on employment is available only from 2016, which results in a limited number of observations for the regressions. The coefficient is 0.38, which is in line with the previous EmpIA conducted in Kenya (Game and Kang 2023), which produced an elasticity of 0.34, and which is in line with previous work that studied the relationship at the provincial level in China (Charpe 2022). Taking the lights/GDP elasticity of 0.34 and this coefficient of 0.38 produces a combined coefficient of 0.13. From this indirect approach of calculating the NTL/GDP and GDP/employment elasticities, it is estimated that the areas that benefitted from the project resulted in an estimated 0.4 per cent increase in employment compared to locations that did not receive a rehabilitated road. This is based on three years after completion. Following one year after project completion, the increase in employment is 0.3 per cent.

When comparing this result to the EmpIA of the Merille-Marsabit road in Kenya (Game and Kang 2023), which produced an estimated increase in employment between 1.7 and 3 per cent, this result is much lower. However, this is to be expected, as the road in Kenya was a main road that was part of a transport corridor. The NFRP focusses in rural locations and aims to connect agricultural areas to markets, so it is arguable that rather than an increase in employment and the number of jobs created, larger changes may be found in incomes of workers. It will be necessary to further examine this with additional LFS data to accurately assess these changes.

▶ **Table 8. Relationship between annual employment and GDP**

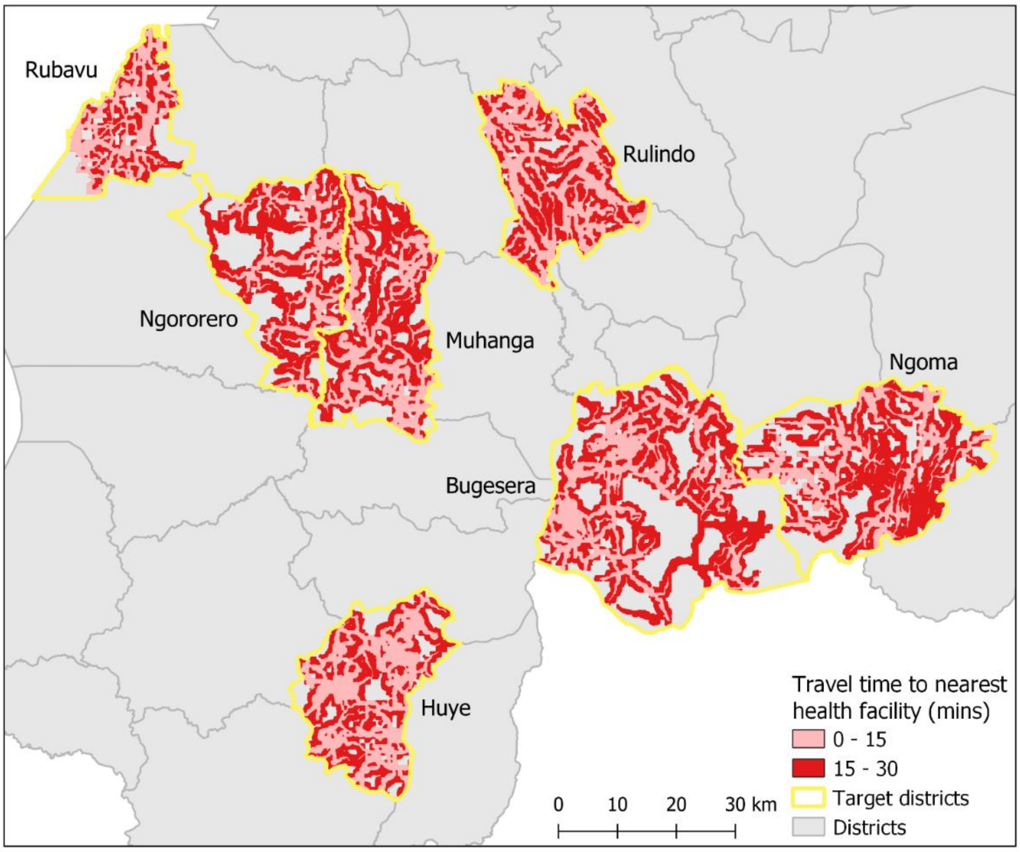
	lnEmp
lnGDP	0.384**
	(0.083)
Observations	18
R^2	0.571
Note:	*p<0.1; **p<0.05; ***p<0.01

Source: Own research

6.6. Access to social infrastructure

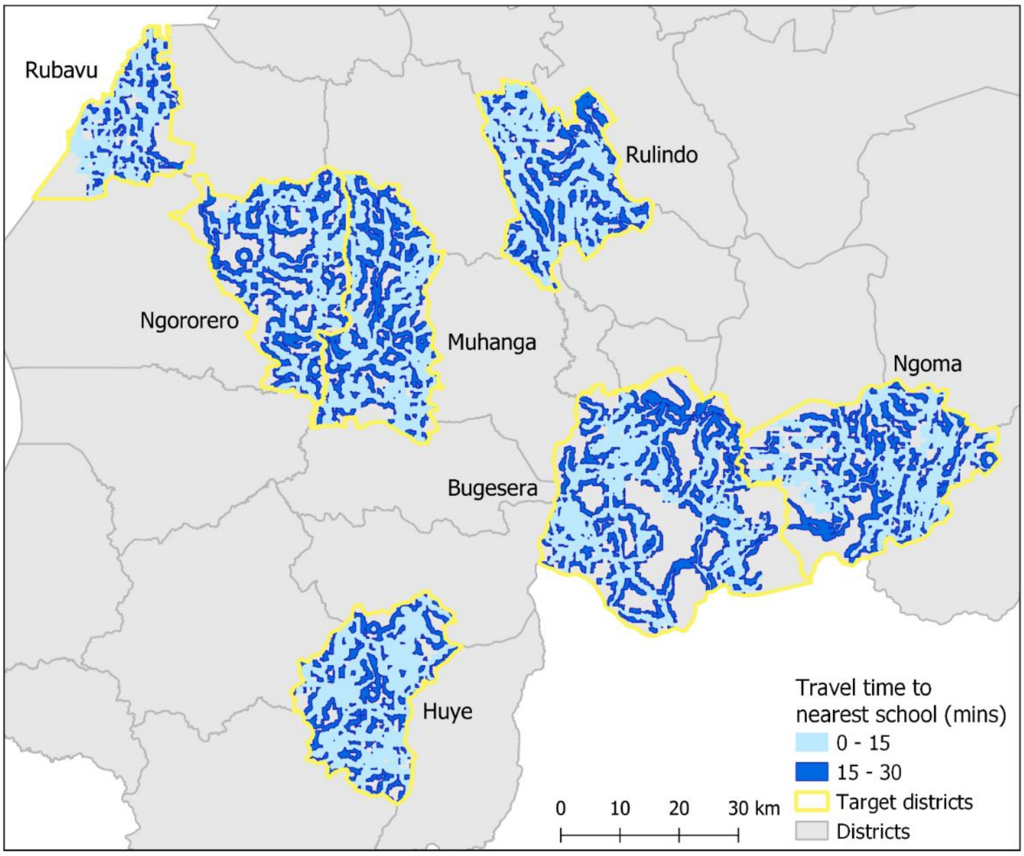
Looking at the impacts of the NFRP on geographic accessibility to social infrastructure, which improves access to social services for the benefitting population, it was discovered that in all seven districts, the access to schools and health facilities improved due to the rehabilitated feeder roads. Figures 3 and 4 present the accessibility maps for a combined walking and driving time of 30 and 60 minutes to the nearest health facility and school, respectively, in each of the seven districts.

▶ **Figure 3. Travel time to nearest health facility up to 30 minutes away**



Source: Own research

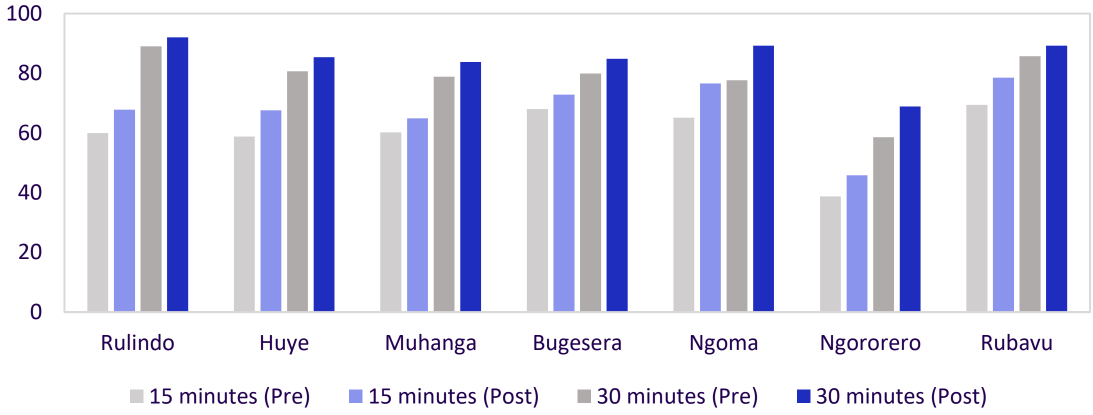
▶ **Figure 4. Travel time to nearest school up to 30 minutes away**



Source: Own research

When investigating access to health facilities and assessing coverage for women between the ages of 15 to 49, as an indicator for access to maternal healthcare, each district already had an existing high percentage of women within 60 minutes from the health facility (above 95 per cent in most cases), so the overall coverage within 60 minutes only increased up to 1.7 per cent across districts following completion of the project. Results for the population within each 15-minute travel time increment up to one hour, are presented in in the Annex, table A.7. Figure 5 outlines the percentage of women covered before and after the rehabilitated roads separated by district, up to a travel time of 30 minutes to the nearest health facility, which are where the largest changes can be observed. It shows the travel time for both scenarios, (Pre) - before the road rehabilitation project and (Post) - after the project has been completed. Ngoma district saw the largest increase, where the rehabilitated roads increased coverage to health facility from 65 to 77 per cent, within a 15-minute travel time. When looking at up to 30 minutes, 89 per cent of the population are now within walking and driving distance to a health facility, compared to the 78 per cent before the project. On average, there was an 8 per cent increase in population within 15 minutes to a health facility across all districts and a 6 per cent increase for within 30 minutes, as a result of the improved feeder road scenario.

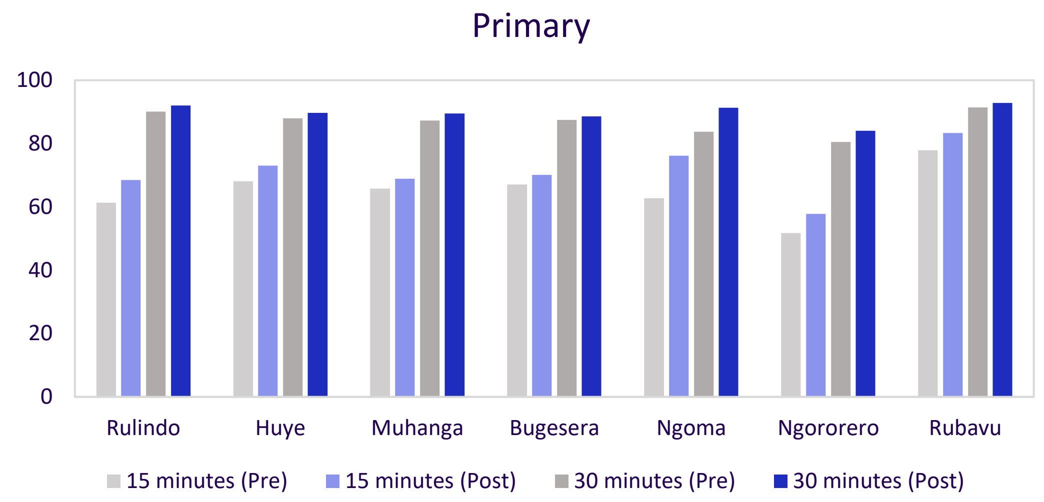
▶ Figure 5. Percentage of WOCBA within 15 and 30 minutes from the nearest health facility, for pre and post the completion of the project



Source: Own research

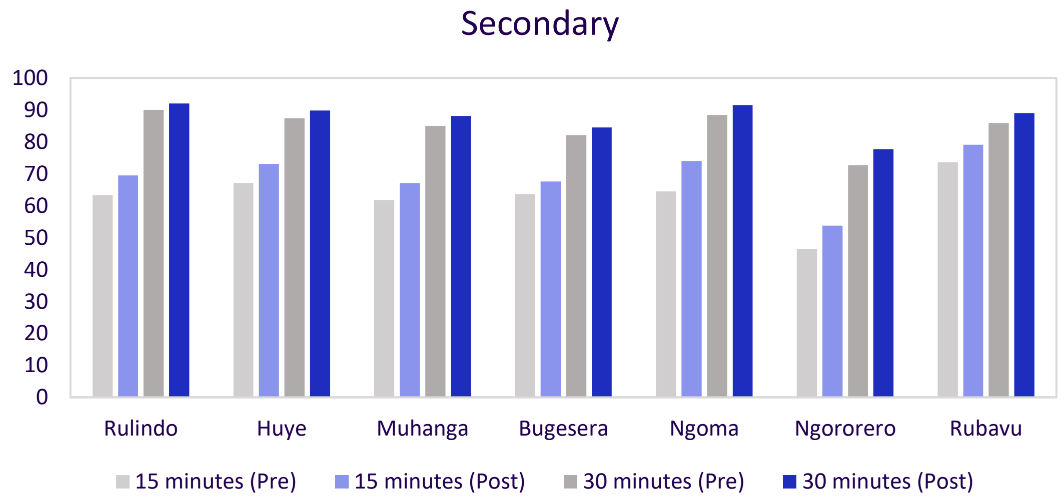
When investigating access to schools and assessing coverage for children, the full table of results for primary and secondary school coverage are in the Annex, A.8. Figure 6 displays the results for the changes in travel time pre and post the rehabilitated roads, for children's access to the nearest primary school. The average travel time for 15 minutes to the nearest primary school increased from 65 per cent before the project, to 71 per cent after project completion. For secondary schools (figure 7), the coverage was slightly lower but still increased from 63 per cent to 69 per cent. The school-age population within 30 minutes travel time increased by 3 per cent after completion of the project for both primary and secondary schools. Although for both schools and health facilities, there were increases in coverage following the rehabilitation of the feeder roads, this analysis also highlights districts that still have decreased coverage compared to others. For example, Ngorero district has a lower coverage, where 69 per cent of women are within 30 minutes travel time to a health facility, even following the completed road project. This highlights potential areas for targeting future interventions to increase population access to these essential services.

▶ **Figure 6. Percentage of school-age children within 15 and 30 minutes from the nearest primary school, for pre and post the completion of the project**



Source: Own research

▶ **Figure 7. Percentage of school-age children within 15 and 30 minutes from the nearest secondary school, for pre and post the completion of the project.**



Source: Own research

7. Conclusion and research recommendations

The NFRP in Rwanda has provided an increase in economic activity and employment to areas receiving a rehabilitated road as part of the project. This work builds upon previous literature that studies the impacts from roads using NTL data and the first EmpIA produced by STRENGTHEN2, that applied this methodology to a larger road project in Kenya (Game and Kang 2023). This assessment provides a valuable comparison for a different type of road project, feeder roads, and further develops an innovative approach to measuring long-term employment effects.

The results highlight an increase in economic activity in the form of GDP and employment due to the project, although the increase is relatively small. Results show that the project produced an estimated increase in NTL brightness between 2.3-3.1 per cent at the administrative level, from one to three years after the project was completed. The highest impact, 3.1 per cent, could be observed three years after completion, with a slightly lower but still positive effect after four years, of 2.2 per cent. The slight decrease could be due to the effects of the COVID-19 pandemic, as four years after project completion corresponds with the year 2020. Taking the preferred result of three years after completion and the elasticity between lights and GDP, it is estimated that the administrative areas around the rehabilitated roads saw a 0.8 per cent increase in GDP compared to those that did not receive a road improvement. The pixel-level analysis highlights impacts that are concentrated within 1 km of the road project, where beyond this the impact appears to be negligible. This finding is in line with the previous assessment in Kenya and other literature. When translating this increase in GDP to employment, using the indirect method of measuring the relationship between GDP and employment, it is estimated that the project produced a 0.4 per cent increase in employment three years after completion. It is important to note that these results should be interpreted with caution, due to issues such as the change of sign observed in the regressions and limited information on employment to produce the elasticities. However, the work highlights the applicability of the night-time lights data and attempts to address issues such as the potential heterogeneity in placement of road projects, by studying the impacts across distance at the pixel level.

When presenting the results in terms of million Euro invested and km of road built, based on the project cost of 40 Euro million, GDP is estimated to have increased by 0.04 per cent per million Euro invested, using the maximum increase of four years after completion of the project. For employment, this equates to an increase of 0.01 per cent per million Euro invested. When looking at the results per 100 km of road constructed or rehabilitated, based on the total of 700 km of roads rehabilitated, this is equivalent to an increase in GDP of 0.2 per cent and an increase in employment of 0.06 per cent, per 100km of road.

When comparing to the EmpIA of the Merille-Marsabit road project in Kenya that follows the same analysis, the economic and employment effects of the NFRP are lower. This could be due to the rural nature of the project, compared to the road in Kenya that was larger and formed part of a transport corridor. The NFRP project focusses on improving accessibility between agricultural areas and markets, so may not attract a large amount of new economic activity and employment to areas benefitting from the rehabilitated roads. Rather, people working in agriculture in areas targeted by the project may experience changes in employment quality, through things such as increased incomes due to better access to markets to sell produce or a shift may occur from existing subsistence farming to employment in agriculture. Although it is not possible to examine this dimension using the night-time lights data, it is recommended to further analyse the employment impacts of feeder road projects, with the inclusion of LFS data with geographic information. This would allow access to additional variables on employment and it will be interesting to study how these outcomes change as a result of feeder road rehabilitation. This being said, when looking at the results per million Euro invested across the two studies, the results are similar and achieve the same amount of employment increase, at 0.01 per cent per million Euro. For Rwanda, the GDP is slightly higher per million Euro, at 0.04 per cent compared to the 0.03 per cent increase in Kenya. Based on the results per 100 km of roads constructed or rehabilitated, the feeder roads project in Rwanda is lower, with an increase in GDP per 100 km of road of 0.2 per cent, vs 1.92 per cent in Kenya. For employment, the feeder roads achieve an increase of 0.06 per cent per 100 km of road, compared to 0.6 per cent in Kenya.

Aside from the employment impacts, the project has also increased access to social infrastructure, which is important for improving physical access to social infrastructure for workers among the population and overall poverty reduction. On average, the NFRP increased access to maternal healthcare, within a 15-minute combined walking and driving travel time for 8 per cent of women and for 6 per cent within a 30-minute timeframe. The largest improvements could be seen in Ngoma district, where the rehabilitated roads created a 12 per cent increase in coverage for the population within 15 minutes walking and driving time to the nearest health facility. When assessing education across the districts, 71 per cent of school-age children are within a 15-minute walk and drive from primary schools, compared to 65 per cent before the completion of the project. A 6 per cent increase was observed for access to secondary education. Although this demonstrates the improvements the project has produced in terms of physical accessibility, there are still clear gaps in access in some districts that are recommended to be addressed through further intervention. To expand this analysis further, other modes of transport, such as bicycle and motorcycle could be assessed, which are widely used in Rwanda for transport. The results from this analysis provide a valuable indication to coverage of health and education in these rural areas and should be taken into account for future policy setting and decision-making.

Overall, as there are only a few specific previous examples of this work being applied to transport investments, it is recommended that this analysis be replicated in different settings to further explore the potential of harnessing these data to measure the impacts of infrastructure projects. This includes the addition of LFS data to further examine the impacts of such interventions related to employment quality. Streamlining the methods and highlighting the applicability of the data further will encourage the workflow to be operationalized within development banks and other institutions to measure the long-term impacts of their investments. GIS and remotely sensed data also offer the opportunity to measure the impacts of the project in other sectors, such as agriculture or energy, and this should also be further explored.

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Annex

▶ **Table A.1. List of completed infrastructure projects within the study area and time period of the assessment**

Project Name	Year of Completion	Sector
Huye Urban Road	2015	Transport
Kivu Belt Lot 3 (Bralirwa-Rubavu)	2015	Transport
Rubavu urban road - 5.4km	2017	Transport
Gashora and Rwabusora Bridges	2018	Transport
Kivu Belt Lot 4	2019	Transport
Huye-Kitabi-53km	2020	Transport
Kivu Belt Lot 7	2020	Transport
Musanze-Rubavu - 67km	2020	Transport
Huye-Gisagara - 13.8km	2020	Transport
Musanze-Rubavu	2020	Transport
Muhanga-Ngororero-Mukamira - 98km	2020	Transport
Gihira Hydro Power Plant	2017	Energy
Keya Hydro Power Plant	2018	Energy
Nyabarongo Hydro Power Plant	2014	Energy

Source: Own research

▶ Table A.2. Travel speeds and classes used for calculating travel time to social infrastructure

Category	Travel speed (km/ph)
Landcover	
Dense vegetation	2
Medium vegetation	3
Sparse vegetation	4
Bare ground	5
Water bodies	0
Roads	
Primary (national) roads	60
Secondary	40
Tertiary	30
Feeder / rural roads	20

Source: Own research

▶ Table A.3. Administrative level treatment effect, one year after project completion

	NTL luminosity					
	(1)	(2)	(3)	(4)	(5)	(6)
treatment	-0.020	0.100***	-0.022*	0.030***	0.039***	0.023**
	(0.014)	(0.009)	(0.013)	(0.010)	(0.010)	(0.011)
inf				0.198***	0.251***	0.237***
				(0.050)	(0.062)	(0.058)
conf				-0.010	-0.043	-0.008
				(0.020)	(0.031)	(0.021)
ndvi				0.195***	0.203***	
				(0.006)	(0.013)	
pop				0.187***	0.247***	0.208***
				(0.002)	(0.014)	(0.002)
prec				0.068***	0.100***	
				(0.026)	(0.028)	
Observations	72,480	72,480	72,480	72,480	57,984	72,480
Adjusted R-squared	0.000	0.710	0.713	0.835	0.846	0.807
Admin area FE	NO	YES	YES	YES	YES	YES
Time FE	NO	NO	YES	YES	YES	YES
Lagged covariates	NO	NO	NO	NO	t-1	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

▶ **Table A.4. Administrative level treatment effect, two years after project completion**

	NTL luminosity					
	(1)	(2)	(3)	(4)	(5)	(6)
treatment	-0.034***	0.101***	-0.021**	0.047***	0.053***	0.030***
	(0.011)	(0.007)	(0.010)	(0.007)	(0.008)	(0.008)
inf				0.360***	0.433***	0.394***
				(0.072)	(0.085)	(0.076)
conf				-0.018	-0.013	0.004
				(0.019)	(0.022)	(0.020)
ndvi				0.190***	0.148***	
				(0.005)	(0.009)	
pop				0.185***	0.210***	0.204***
				(0.002)	(0.013)	(0.002)
prec				0.067***	0.102***	
Observations	86,976	86,976	86,976	86,976	72,480	86,976
Adjusted R-squared	0.000	0.704	0.707	0.828	0.840	0.802
Admin area FE	NO	YES	YES	YES	YES	YES
Time FE	NO	NO	YES	YES	YES	YES
Lagged covariates	NO	NO	NO	NO	t-1	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

▶ **Table A.5. Administrative level treatment effect, three years after project completion**

	NTL luminosity					
	(1)	(2)	(3)	(4)	(5)	(6)
treatment	-0.049***	0.100***	-0.028***	0.052***	0.061***	0.031***
	(0.009)	(0.007)	(0.009)	(0.007)	(0.007)	(0.007)
inf				0.370***	0.468***	0.410***
				(0.068)	(0.074)	(0.072)
conf				0.034*	0.034	0.113***
				(0.020)	(0.023)	(0.027)
ndvi				0.198***	0.166***	
				(0.005)	(0.008)	
pop				0.179***	0.201***	0.199***
				(0.002)	(0.013)	(0.002)
prec				-0.012	0.005	
Observations	101,472	101,472	101,472	101,472	86,976	101,472
Adjusted R-squared	0.000	0.700	0.704	0.825	0.836	0.798
Admin area FE	NO	YES	YES	YES	YES	YES
Time FE	NO	NO	YES	YES	YES	YES
Lagged covariates	NO	NO	NO	NO	t-1	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

▶ **Table A.6. Administrative level treatment effect, four years after project completion**

	NTL luminosity					
	(1)	(2)	(3)	(4)	(5)	(6)
treatment	-0.066***	0.095***	-0.042***	0.048***	0.058***	0.022***
	(0.008)	(0.006)	(0.008)	(0.006)	(0.006)	(0.007)
inf				0.063***	0.086***	0.053***
				(0.018)	(0.019)	(0.019)
conf				-0.010	-0.011	0.047**
				(0.014)	(0.015)	(0.019)
ndvi				0.200***	0.165***	
				(0.005)	(0.008)	
pop				0.172***	0.187***	0.193***
				(0.002)	(0.014)	(0.002)
prec				0.067***	0.091***	
Observations	114,760	114,760	114,760	114,760	100,264	114,760
Adjusted R-squared	0.000	0.697	0.700	0.820	0.831	0.794
Admin area FE	NO	YES	YES	YES	YES	YES
Time FE	NO	NO	YES	YES	YES	YES
Lagged covariates	NO	NO	NO	NO	t-1	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

▶ **Table A.7. Percentage of WOCBA within a travel time to the nearest health facility, before and after the completion of the NFRP**

District	Minutes	Population covered before (%)	Population covered after (%)
Rulindo	0-15	60	68
Huye	0-15	59	68
Muhanga	0-15	60	65
Bugesera	0-15	68	73
Ngoma	0-15	65	77
Ngororero	0-15	39	46
Rubavu	0-15	69	79
Rulindo	15-30	29	24
Huye	15-30	23	18
Muhanga	15-30	24	22
Bugesera	15-30	17	14
Ngoma	15-30	23	15
Ngororero	15-30	27	26
Rubavu	15-30	17	11
Rulindo	30-45	8	5
Huye	30-45	9	8
Muhanga	30-45	9	8
Bugesera	30-45	7	6
Ngoma	30-45	7	5
Ngororero	30-45	19	16
Rubavu	30-45	5	3
Rulindo	45-60	2	2
Huye	45-60	4	3
Muhanga	45-60	3	2
Bugesera	45-60	3	3
Ngoma	45-60	2	1
Ngororero	45-60	9	7
Rubavu	45-60	3	2

▶ Table A.8. Percentage of school-age children within a travel time to the nearest pre-primary/primary and secondary school, before and after the completion of the NFRP

		Primary		Secondary	
District	Minutes	Population covered before (%)	Population covered after (%)	Population covered before (%)	Population covered after (%)
Rulindo	0-15	61	68	63	70
Huye	0-15	68	73	67	73
Muhanga	0-15	66	69	62	67
Bugesera	0-15	67	70	64	68
Ngoma	0-15	63	76	65	74
Ngororero	0-15	52	58	46	54
Rubavu	0-15	78	83	74	79
Rulindo	15-30	29	24	27	22
Huye	15-30	20	17	20	17
Muhanga	15-30	22	21	23	21
Bugesera	15-30	20	18	19	17
Ngoma	15-30	21	15	24	18
Ngororero	15-30	29	26	26	24
Rubavu	15-30	14	9	12	10
Rulindo	30-45	7	6	7	5
Huye	30-45	7	5	8	6
Muhanga	30-45	8	6	9	7
Bugesera	30-45	7	6	8	7
Ngoma	30-45	10	6	7	5
Ngororero	30-45	13	11	15	13
Rubavu	30-45	3	2	5	3
Rulindo	45-60	2	1	2	1
Huye	45-60	3	3	2	2
Muhanga	45-60	2	2	3	2
Bugesera	45-60	2	2	4	4
Ngoma	45-60	4	1	2	1
Ngororero	45-60	4	3	8	6
Rubavu	45-60	1	1	2	1

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