Identification and Spatial Mapping of Economic Clusters in CAREC: A GIS-based Analysis for the PRC, Pakistan and Tajikistan

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Visiting Fellow 2020

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Abstract

Investment in infrastructure that improves connectivity is considered a major intervention to boost regional economies. However, the transformation of a transport corridor into an economic corridor depends upon several determinants. Major factors pointed out in the new economic geography (NEG) literature are transport costs and market linkages. Whereas lower transport costs help with returns to scale, better market linkages increase profitability through the proximity between supply and demand. A cumulative causation process sets in as location choices of firms and workers mutually reinforce one another when transport costs are low, leading to the emergence of economic clusters. The CAREC transport corridors have been designed to improve connectivity in the largely landlocked Central Asian region. This paper aims at spatially mapping urbanization trends and identifying potential sites for economic activities along corridors in three CAREC countries—China (XUAR), Pakistan, and Tajikistan. Using multiple criteria decision modeling on geo-referenced data of urban settlements and areas of agricultural or mining activity, the study determines optimal locations for future economic zones. The study also highlights the potential of nightlights data for estimating changes in the levels of economic activity in the influence zone of a corridor. The spatial mapping and analysis primarily use remote sensing satellite imagery. The information in the spatial maps will be useful for the design of policy interventions and future investments in the region.

Keywords: CAREC, GIS, Spatial, Economic Corridor, Economic Zone

JEL Classification: R11, R12, R58

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Abbreviations

ADB	Asian Development Bank
BCP	border crossing point
BRI	Belt and Road Initiative
CAREC	Central Asia Regional Economic Cooperation
CPEC	China Pakistan Economic Corridor
CPMM	Corridor Performance Measurement and Monitoring
DMSP	Defense Meteorological Satellite Program
GICHD	Geneva International Centre for Humanitarian Demining
GIS	geographic information system
MCDA	multiple criteria decision analysis
NEG	new economic geography
NGDC	National Geophysical Data Center
NOAA	National Oceanic and Atmospheric Administration
PRC	People's Republic of China
SEDAC	Socioeconomic Data and Applications Center
SEZ	special economic zone
TFI	trade facilitation indicator
USGS	United States Geological Survey
VIIRS	Visible Infrared Imaging Radiometer Suite
WDI	World Development Indicators
XUAR	Xinjiang Uyghur Autonomous Region (of the PRC)

1. Introduction

Investments in the building of regional transport corridors have a spectrum of objectives. Starting with the short-term target of improving connectivity by enhancing the transport infrastructure, it is expected that the subsequent increase in trade will lead to growth and the development of regional economies in the long run. However, as explained by Srivastava (2011), no formal framework is adopted at the planning and design stages to incorporate the potential gains arising from the transformative process of a corridor. The five stages of corridor development listed in the literature correspond to a functional distribution which is spread over the domains of (i) improved transport, (ii) trade facilitation, (iii) logistics support, (iv) urban growth, and (v) economic development. This stepwise design is intuitive and understandable, but it is hard to determine the pace and extent of transition from one stage to the other. Besides, the operational segregation between stages (ii) to (v) has overlaps, which makes it difficult to delineate the transition process and predict the progress on the growth trajectory. However, despite the blurred boundaries, there is consensus in the literature that the transformation sequence across the stages has to be maintained.

The standard indicators used to assess the performance of a corridor are based on transport statistics such as cargo volumes, ease of doing business indices, and highway traffic speed. As these numbers mostly indicate port to port operations, relying on them as indicators of inclusive local development and sustainable regional growth could be ambiguous as one hardly gets any information about the spillover effects of the corridor. The potential of regional corridors in spurring economic growth can be estimated by general equilibrium models where the corridor dynamically interacts with regional characteristics and creates patterns of growth and development. In this study we apply the new economic geography (NEG) model which postulates a pecuniary interpretation of the erstwhile Marshallian agglomeration economies using a mixed model of love for variety preferences, increasing returns to scale and transport costs (Fujita et al., 1999, Baldwin et al., 2011). The NEG model can help in monitoring, analyzing, and projecting the impact of a transport corridor on the regional economy. A major objective of investments in a transport corridor is to lower transport costs. The physical links provided by a transport corridor through its nodes may not only connect the cities *en route* but also provide better accessibility to the adjacent area (between the nodes). This study attempts to analyze the impact of corridors and the transformation process induced by them on economic activity by investigating geographic information systems (GIS)-based, geo-referenced data for the calculation of important indicators such as land cover change, population density growth, and road network density. Nightlights intensity variation is used as a proxy for economic activity (Henderson et al., 2012) within the influence zone of a transport corridor for a spatiotemporal analysis. For example, urban growth within the influence zone of a corridor at a faster pace than the national average is an indicator that the adjacent area benefits from corridor spillovers.

The spatial identification of human settlements and the temporal analysis of the level of economic activity along the CAREC transport corridors, helps to assess their impact on local, national, and regional economies. Besides, regional economies can benefit from information about market potential to explore and enhance market linkages. The findings of the study will be useful in determining an overall economic growth path through agglomeration benefits, increased intra-regional trade, better employment opportunities, and improved competitiveness. On the policy side, such knowledge will aid informed decision-making by national governments and international agencies investing in the region. The use of spatial maps could be beneficial for (i) improved urban planning, (ii) identifying optimal locations for establishing special economic zones (SEZs), and (iii) decision-making about optimal investments in human resources.

A review of earlier research and studies of the CAREC region indicates that the availability of reliable and standardized data on a regional level is a concern. The periodicity of data collection, its geographic reach, and depth of collection depends on the policies of national statistical offices. An ADB study (Azis, 2014) highlights this issue for freight and passenger data. This paper therefore adopts the unconventional approach of using satellite imagery to capture change in population density, growth of urban settlements (new or existing), change in land use, and investment in local connecting roads, and to derive from these conclusions about economic activity change. To our knowledge, this study is the first attempt to analyze the transformation of a CAREC transport corridor from a simple transport infrastructure to a driver of economic growth by using satellite imagery data and GIS-based techniques such as multiple criteria decision analysis (MCDA). We therefore highlight the need for further research on this topic.

Results indicate that population density is an important variable to indicate change in human settlements owing to a transport corridor. In the case of the XUAR (China) and Pakistan, the population growth rate within the influence zone is higher than the national annual growth rate; however, this is not the case for Tajikistan. Using MCDA, we are able to identify optimal locations for agriculture-based and mining-based industry. The nighttime lights data observed from 2012 to 2019 and used as a proxy for economic activity, indicates the spread of cities and new settlements, which are reasonable indicators of enhanced economic growth.

The paper is organized as follows. The next section discusses the scope of transport corridor development in which we also propose some indicators to capture the spillovers for growth and development. As CAREC and CPEC both constitute important investments in transport infrastructure, we discuss potential synergies that can be developed for the benefit of the countries in the region. The paper includes an extensive literature review that details how to model transport investments, and the use of GIS datasets and GIS-based techniques that are applied in this study. Our results are mostly manifested through maps, but we add discussion about them for explanatory purposes. The last section concludes the study while pointing out avenues of further research and limitations of the current work.

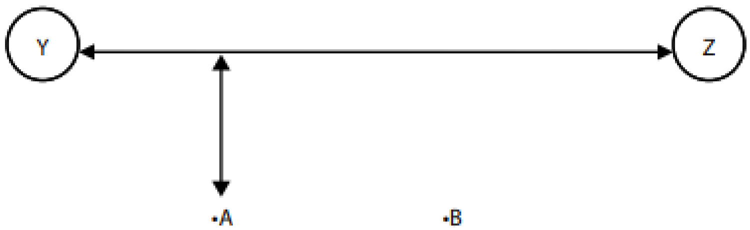
2. Scope of corridor development

Policies dealing with mega projects, such as a transnational corridor, have design and implementation implications on various scales involving local, national, and regional tiers (Azis, 2014). As such, it is important to categorize the CAREC transport corridors correctly to comprehend the scale of operations and expected outcomes. The ADB Operations Manual (2010)[1] defines transnational projects that require collective efforts and actions of all involved countries as regional projects. This definition also applies to such projects that lead to regional agreements on trade and investment and to the strengthening of the institutional capacity of member countries. A review of the CAREC transport corridor map indicates that a substantial portion of each route falls within more than one member country, and hence each transport corridor is essentially a regional venture. Nonetheless, each corridor carries significant importance for the individual member country's national economy as well and can therefore generate positive externalities locally. Following the Srivastava (2011) classification that categorizes regional corridors on the basis of their scope and scale, our objective is to determine the transformation of the CAREC transport corridors in a range from narrow to broad. Such transformation indicates that the corridor is generating spillovers—an impact on the local economy adjacent to the transport network. As Srivastava (2011) states: 'for corridors to be viable they must make economic sense through encompassing actual or potential economic growth. Corridor development does not create economic strength so much as it channels,

1. Available at https://www.adb.org/sites/default/files/institutional-document/31483/oml3.pdf

focuses, and amplifies the potential for economic growth. Thus, a corridor from nowhere to nowhere through nowhere would not be very meaningful. Similarly, a corridor linking two substantive nodes but with no potential for growth in between is also of limited interest.' By definition, narrow corridors connect cities on the planned route only and hence have no influence (zone) outside the road.

Figure 1: Broad and narrow corridors



Source: Srivastava (2011)

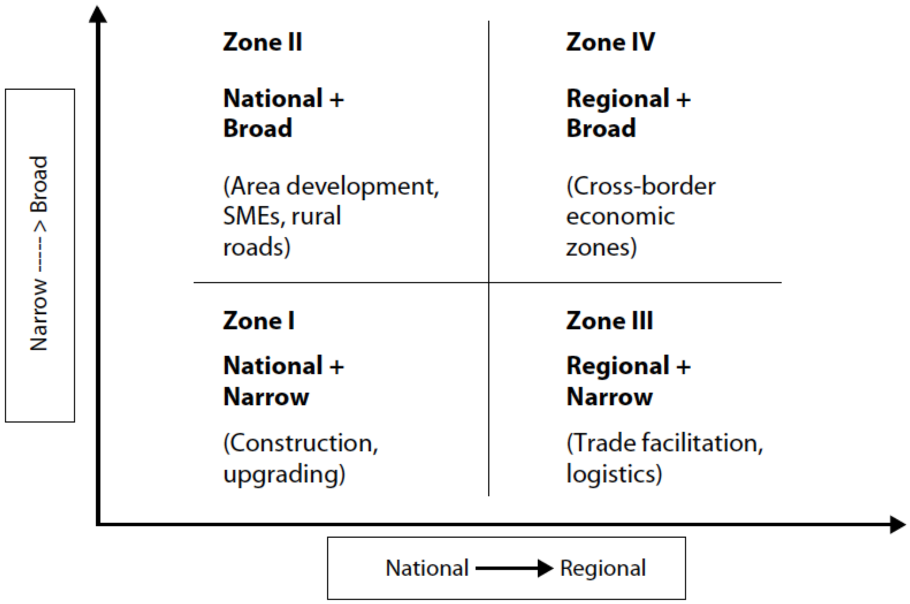
Figure 1 has been used by Srivastava (2011) to define the influence zone of a corridor in order to explain the difference between a narrow and broad corridor using transport costs as variable. Here Y and Z are two nodes on a transport corridor, and A and B are two outside, off-the-highway locations at a distance A and B from the highway, respectively. Let C_A represent the cost of moving from location A to the highway, and $C_B$represent the same for location B. These costs depend on factors such as the distance between the location and the highway, the speed or time to travel, and local tolls/ taxes. In this situation, moving goods or passengers between A and B is a binary choice problem, going directly across versus going via the highway. If the cost of directly moving from A to B is C_{AB} and the cost of traveling on the highway is C_H, then for all peripheral locations like A and B wherever equation (1) is satisfied that location shall constitute a part of the influence zone of the corridor.

$$C_A + C_B + C_H \leq C_{AB} \quad (1)$$

Accordingly, a broad corridor is the one whose spillover effects are visible in the adjoining areas. Such effects are usually not taken into consideration whenever some scheme is devised to collect corridor performance data. Srivastava (2011) uses the corridor dimensions determined by broad/narrow and regional/national for the assessment of the corridor development as shown in Figure 2.

The long-term aim of corridor investment is the ultimate transition from Zone I to Zone IV, whereby the corridor transforms from a narrow project of only limited national significance to a broad venture with regional implications. According to Srivastava (2011), Zones II and III are interchangeable in terms of sequencing. Using the GIS data mentioned earlier, our objective for this study is to determine the extent of transformation from narrow to broad in case of CAREC corridors 5 and 6. The GIS-based approach we employ here will be useful in identifying growth in human settlements, connectivity through local roads, and levels of economic activity.

Figure 2: Corridor development stages



Source: Srivastava (2011)

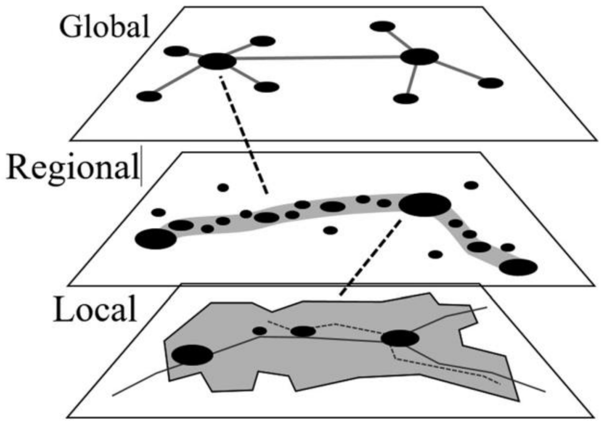
2.1. Indicators for measuring corridor impact

The CAREC program has developed a comprehensive empirical tool 'Corridor Performance Measurement and Monitoring' (CPMM) for measuring the efficiency of operation by tracking the time and cost of moving cargoes along the six CAREC corridors and across border crossing points (BCPs). The CPMM comprises a set of trade facilitation indicators (TFIs) that reflect the aggregate annual performance and efficiency of the transport corridors. As the objective of the transport corridors is to improve trade and transportation initiatives in the region, the indicators, when compared over time and across corridors, provide good measures for performance evaluation. The TFIs include (i) time taken to clear a BCP, (ii) cost incurred at a BCP, (iii) cost incurred to travel through a corridor sector, and (iv) speed of travel along CAREC corridors.

However, an important concern in the context of analyzing the utility and purpose of a corridor is to determine the extent of its inclusivity regarding the distribution of economic benefits and the sustainability of the economic growth that sets in. Typically, in the case of CAREC we find that the CPMM approach is currently being employed to assess the operational functioning of the corridors in the narrow sense and hence, even if the numbers improve over time, they cannot provide any conclusive evidence that a corridor has graduated to the broad category. To determine whether the corridor use is at regional level, and the corridor has progressed to the broad category, we suggest that as well as using development and efficiency statistics, information on certain geographic variables is collected and analyzed to comprehend the spatial and temporal impact. Such information, when assessed against certain pre-determined benchmark values, is helpful in defining the actual transition process to a corridor in the broad sense. We recommend that the indicators proposed in Table 1 are considered for this purpose. In this study we use some of the indicators mentioned in the broad/narrow category while the others can be used in future research. However, it is important to point out that for a meaningful interpretation of the proportions mentioned in Table 1, the numbers must be normalized so that the figures are comparable across countries and are not entirely driven by a scale effect. These indicators, if deployed along with the

CPMM, will not only represent the performance of the transport corridor but also its transition to an economic corridor.

Figure 3: Spatial footprint of transportation



Source Rodriguez et al. (2006)

The economic stimulus generated by transport corridors leaves a socio-economic footprint that is most conspicuously visible on a local scale. As is evident from Figure 3, the spatial impact of the corridor depends on the scale at which it is observed: global, regional, or local. What might appear just as lines connecting dots on a global level, emerges as an influence zone on a regional level and a thriving urban settlement on a local level. Location choice models underline the significant transport costs faced by industry for its inputs and outputs. Investing in a highway system is expected to influence the location of economic activity and hence the local distribution of the population. This results from the growth in capital investments and employment generation that is caused by the relocation of firms and labor from less competitive regions. The transport network stimulus further induces industrial clustering owing to Marshallian (localization) and Jacobean (urbanization) spillovers. It is perceivable that this will also drive change in land use and increase the extent of the local built-up area.

Table 1: Indicators to identify corridor development

Zone Type	Indicator
National	Proportion of domestic route vehicles to total transport vehicles on the corridor Proportion of domestic passengers to total passengers on the corridor Proportion of domestic cargo to total cargo movement on the corridor Proportion of domestic trade (in monetary terms) to total trade passing through the corridor Employment trends in the national industry to measure employability of the corridor-related services (for example, logistics sector)
Regional	Proportion of transnational route transport vehicles to total transport vehicles on the corridor Proportion of transit trade with origin or/and destination outside CAREC member countries to total trade on the corridor (monetary terms) Proportion of cargo destined for other CAREC member country/countries to the total cargo moving on the corridor Proportion of passengers destined for other CAREC member country/countries to the total number of passengers travelling on the corridor National expenditure on border management and development (personnel, trainings, equipment, and buildings) costs as indicator of commitment for regional cooperation
Broad/Narrow	Investments and developments made in SEZs, tourism, hospitality, and logistics sectors. Percentage of land use/land cover change Proposed/approved land use along the corridor by national authorities (industrial zones, housing societies, commercial centers) Road density within influence zone of the corridor Population density within influence zone of the corridor Nightlight luminosity index within influence zone for all countries along the corridor Approved plans for development of industrial zones, tourist spots (budgetary allocations).

Source: Author's proposed list of indicators

2.2. Scope of the study

This study aims to identify economic clusters by using remote sensing imagery such as population plots, nightlight data, spatial road inventory, and land use data. This geo-referenced data is used for the spatial mapping of transport networks, urban centers, and other points of interest such as potential locations for agricultural and mining activity. This data is used to substantiate the economic corridor development discussion.

For the purpose of this study, the scope of research is limited to three countries in the CAREC region—China, Pakistan, and Tajikistan—which are geographically connected with each other through CAREC corridors 5 and 6. As Pakistan and China have progressed well on the China-Pakistan Economic Corridor (CPEC), we include some discussion about this corridor as well. The inclusion of CPEC is useful for identifying how the CAREC and CPEC corridors can mutually benefit each other.

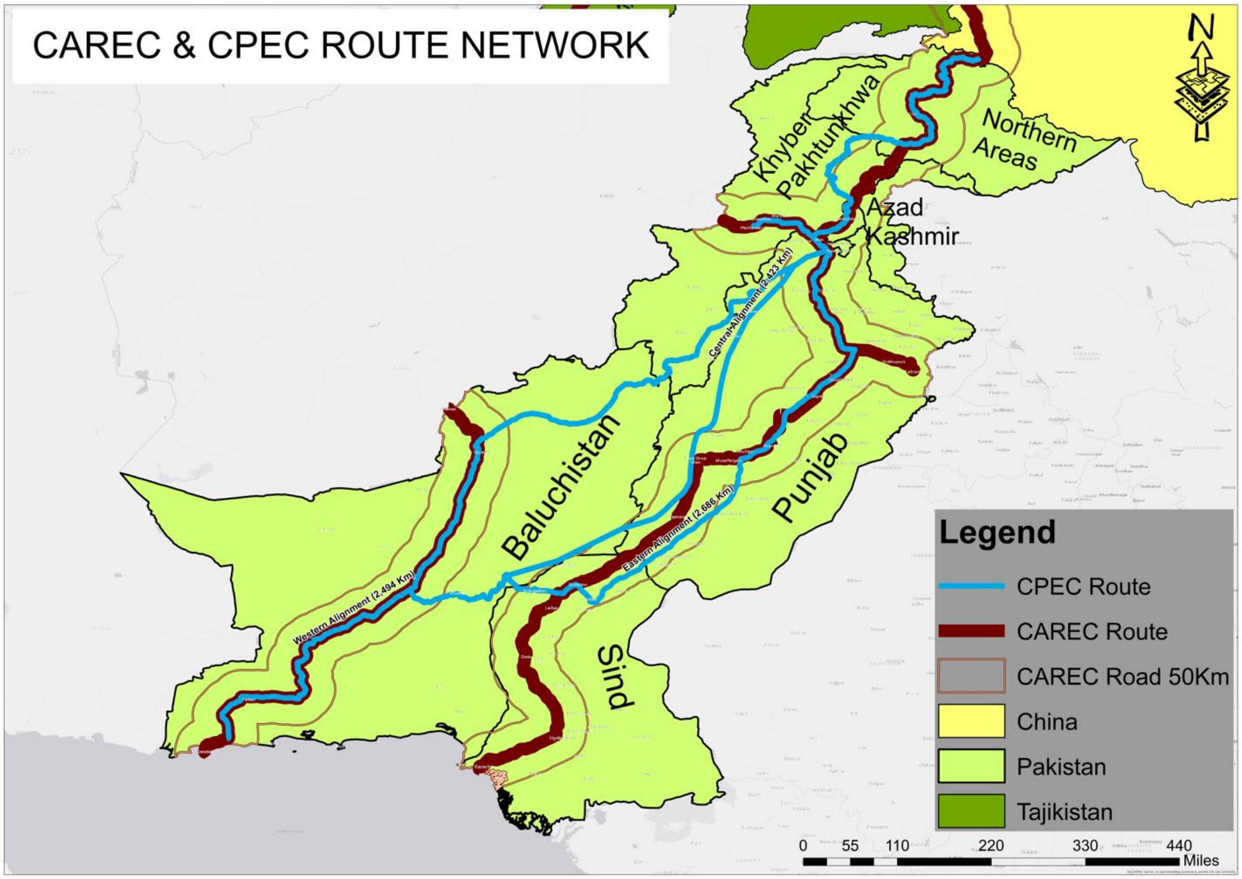
2.3. Transport corridor synergy—CAREC and CPEC

Infrastructure projects have always been accorded a high priority in the development agenda globally. Whereas CAREC is an almost two-decades-old initiative to improve the transport infrastructure in Central Asian landlocked economies, 'to promote development through cooperation, leading to accelerated economic growth and poverty reduction' (as stated on the CAREC website), the Belt and Road Initiative (BRI)—a giant development project unveiled in 2013—is a Chinese bid to enhance regional connectivity between three continents—Asia, Europe, and Africa—through overland and maritime routes (Hasan et al., 2020).

Pakistan joined CAREC in 2010 and since then about US$1.47 billion[2] has been invested in trade and transport projects in the country through CAREC to improve the infrastructure. On the other hand, CPEC has a diversified portfolio that includes projects in energy and infrastructure development. The planned amount to be spent on road and rail infrastructure is about US$13 billion, which is about 23% of the total investment in the CPEC[3] project. Most of the countries that are members of the CAREC program are landlocked and improvements in their own and transit countries' infrastructure could massively help to alleviate their geographic disadvantages and significantly enhance the share of trade in their GDPs (Limao and Venables, 2001). This calls for the attention of policy makers, analysts, and researchers to explore opportunities that might emerge as a result of the proximity of CAREC and CPEC. Our hypothesis (based on Derudder et al., 2018) is that the ability of individual countries, particularly landlocked ones, to benefit from the two huge projects will depend on the emerging connectivity map. Both CAREC and CPEC will alter the connectivity map for existing urban centers, potential locations for industrial activities, and transport and trade costs. This will in turn alter firm productivity, employment opportunities, and trade routes. As a consequence, spatial location will play a major role owing to differences in the degree of connectivity. A map showing CAREC and CPEC routes through Pakistan is given in Figure 4. Although the CPEC route shown overlaps with CAREC corridors at several locations, CPEC adds value for the CAREC countries because of interconnectivity between corridors 5 and 6. Besides, the CPEC focus on building infrastructure to increase production and improve productivity through SEZs will help in industrial capacity building and the optimal use of resources.

2. https://www.carecprogram.org/?page_id=9
3. https://cpec.gov.pk/infrastructure

Figure 4: Map of CAREC and CPEC corridors in Pakistan



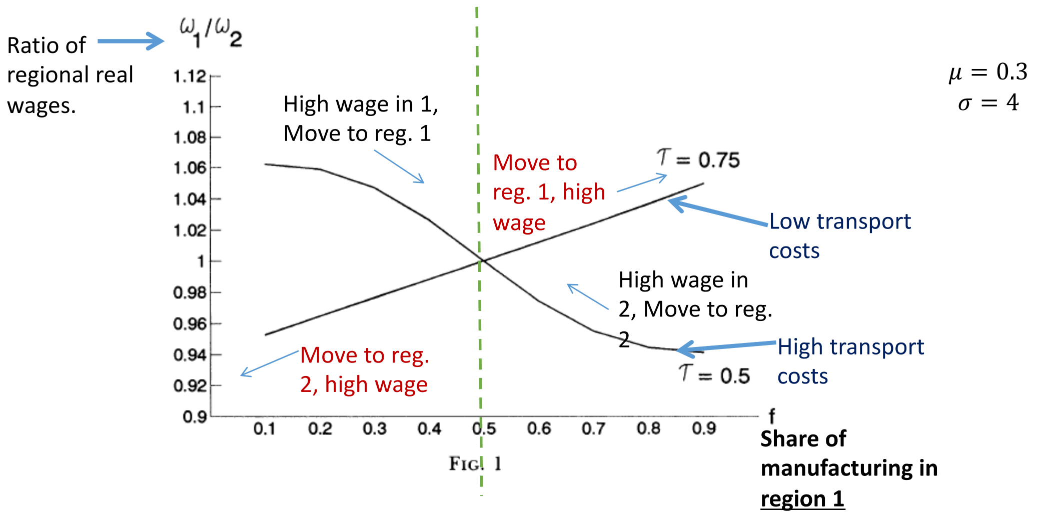
Source: Author's map (CAREC Route refers to corridors 5 and 6 with the 50km influence zone on either side)

To ensure better use of the potential opportunities provided by the two corridors for trade and industry development, it is imperative to segregate strong connections from weak links and prioritize further investments accordingly. Derudder et al. (2018) states that strengthening weak connections to other networks brings benefits to the connected entities, and that it is therefore recommended to follow a stepwise approach. The first step should be the identification of weak links such as spots where trade costs are significantly high owing to inefficient infrastructure or complex regulatory procedures. Next, the focus should be on the provision of services, removing gaps in trade and transit agreements, and smoothening and simplifying regulatory and policy frameworks. Finally, economic centers that connect via the network and have an adequate supply of factors of production can leverage their role for optimizing the benefits of the two corridors. However, to achieve these steps, targeted interventions such as logistics support and spatial planning are necessary to ensure the integration of the centers in relevant value chain networks.

3. Literature review

The spatial implication of a transport corridor that is planned to improve connectivity can be explained by referring to the NEG model (Krugman, 1991). The NEG model explains the clustering of economic activities based on parameters of the consumer utility function, the elasticity of substitution between manufactured goods, and Samuelson's (1954) iceberg transport cost function.

Figure 5: Clustering and dispersal of firms and workers



Source: Krugman (1991)

Figure 5 shows Krugman's (1991) model whereby spatial outcomes under varying transport costs depend upon the interaction of two types of force. The centripetal force attracts firms, industries, and workers together to form large industrial clusters. The NEG model explains the erstwhile Marshallian notion of agglomeration economies in pecuniary terms using Hirschman's (1958) market linkages—a centripetal force. In Hirschman's study, backward linkages happen when investments in an industry increase profits owing to cheaper accessibility to inputs and forward linkages exist when investments in an industry increase profits owing to proximity of demand. In contrast, the forces that act to disperse industrial activity spatially are called centrifugal forces. These forces originate either from urban diseconomies (congestion, pollution) or high factor costs in large cities (wages, rents). The NEG model explains the formation of dense core regions by relying on the cumulative causation process on account of the centripetal forces' self-reinforcement which implies that industry will locate where demand is large, and demand will be large where there is more industry and hence more variety. It is important to determine which of the centripetal or centrifugal forces dominates in case the economy is opened up through trade liberalization or removal of constraints on transportation. Krugman and Elizondo (1996) argue that, as the economy is opened up, the cost of trade with the rest of the world declines, and hence the magnitude of centripetal forces operating through forward and backward linkages declines. Consequently, as local input and output demand falls, the dispersive centrifugal forces dominate the location choice of industry. However, this result may be reversed if it is assumed that centrifugal forces are caused by demand from immobile consumers alone, as in the case of Monfort and Nicolini (2000). In their findings, trade leads to further divergence between the regions—hence, the formation of urban-rural style settlements.

Instead of adopting the extreme position of dominance of centrifugal forces or centripetal forces, more realistic models consider the heterogeneity among regions. Generally, heterogeneity of regions involves differences in the access to foreign markets and unequal factor endowments in various regions. Trade liberalization induces border regions to grow faster than interior regions (Villar, 1999). The model suggests that, as economies open up, border regions may benefit from their geographic location.

The focus of this study is on the role of transport infrastructure, either building new roads or expansion of existing ones, for improved connectivity. Anticipating growth in trade and logistics, such investments are widely considered in the literature as drivers of economic growth in a developing region. Moreover, efficient infrastructure services increase and expand linkages with global value chains and distribution networks by lowering transaction costs, hence increasing potential profitability. Therefore, the building of transport corridors is expected to strengthen the linkage between national and regional economies as follows: First, transport corridors act as a source of agglomeration economies via shared inputs and economies of scale externalities for firms and industries. Second, regional transport networks facilitate trade and passenger flows across countries. Third, better infrastructure and cooperation at regional level encourages faster regional integration (De and Ghosh, 2005).

There are several definitions of transport corridors in the literature. According to a very simple but intuitive definition, it is a route that links economic centers (Arnold, 2006). In particular, transport links or corridors are essential for the movement of goods, services, capital, people, and information across countries. The evolutionary stages of the development of transport corridors as presented by Srivastava (2011) have been mentioned earlier. Broadly, an economic corridor is an infrastructural investment that acts as a catalyst for economic activities and hence spurs growth and development at national and regional levels. An important contribution of Srivastava (2011) is the highlighting of the role of a corridor for improving transport between the planned nodes but also the adjacent areas.

There is plenty of empirical literature that aims to assess the impact of economic corridors. A study by Kumagai et al. (2009) analyses the dynamics of the location of industries as well as the population at subnational levels in East Asia in the long run and the impact of infrastructure projects on the economy. The study found that it is necessary to reduce border crossing costs along with the development of physical infrastructure. To study the impact of infrastructural improvements on the regional economy, Warr et al. (2009) use input-output analysis. Their study finds a marginal increase in inter-regional trade volumes in the short run, along with a rise in real consumption in both regions. In the long run, much larger benefits accrue to both regions. The study identifies new capital investment and the immigration of workers as the driving forces behind the growth. In another study, Gutierrez et al. (2010) measured monetized spatial spillovers of transport infrastructure by comparing the costs of the infrastructure with the accessibility benefits. This paper proposes a methodology to measure net accessibility benefits by monetizing spatial spillovers of transport infrastructure investment and by distributing the costs of the planned infrastructures among the subnational regions. Using a matrix of inter-regional spillovers based on accessibility indicators, the study shows that the subnational regions in Spain benefited even from indirect investments made under the national transport policy. Improved accessibility is the desired outcome of a transport system. It is important because it determines the locational advantage of a region relative to all other regions and hence is considered a major factor for the social and economic development of a region (Wegener and Bökemann, 1998).

From a theoretical point of view, there is a well-known relationship between transport infrastructures, accessibility, and regional development. Transport infrastructures support a whole variety of dependent economic activity and serve to integrate the economic system and facilitate its transactions on a geographic scale (Linneker and Spence, 1996). The literature frequently connects improved accessibility owing to investment in transport infrastructure with economic development and formation of dense urban settlements by highlighting the link between transport geography and economic geography (for example, MacKinnon et al., 2008). Most studies estimate the extent of urbanization and population change using statistical techniques, but recently they also employ GIS to understand spatial dynamics (Sudhira et al., 2004). In this paper we employ GIS techniques to determine spots of high population growth and potential development sites for SEZs.

For a successful SEZ, it is important to select a site that meets predetermined selection criteria. This obviously depends on the objectives and targets of the SEZ and how the choice of location will help in attaining an optimal outcome. However, as also indicated in the literature, the optimization depends on various determinants, which might conflict with one another (Rikalovic et al., 2014), hence implying a potential tradeoff in decision-making. Consequently, a lot depends on the selection of decision variables and the weights assigned to them, and the analysis might indicate multiple sites, each of which has its own advantages and limitations. Studies have estimated that about 80% of information used by managers and decision-makers are spatial in nature. The spatial decision problems often require that multiple alternatives be evaluated using multiple criteria based on *a priori* knowledge and expectations of the policy maker or stakeholder. GIS provide powerful tools to solve multi-criteria spatial problems using algorithms for spatial analysis. As such, they have a significant influence on the spatial decision-making process. For the purpose of the SEZ site selection, GIS-based spatial tools perform an MCDA. However, before employing the tools, the researcher needs to focus on developing the decision-making criteria: determine the uncertainty band that is expected around the true model with a certain probability; seek out methods to deal with the potentially varying degrees of tradeoff among the choice variables; and find ways to resolve likely conflicts in the results.

Various researchers—Henderson et al. (2012) and Clark et al. (2017), among others—have used the intensity of lights at night as a data source for indicators that not only reflect economic growth but are also valuable in performing social and political analysis of geographic regions around the world. This study also maps the luminosity of nightlight in the corridor influence zone to determine potential spots that have experienced significant changes in economic activity.

4. Data and methodology

4.1. Data

Economic growth and urban development in the influence zone of a transport corridor can—as discussed in the literature review—be measured using remote sensing imagery, spatial road data, land use data, and image analysis software. The following data sets are used for the study:

4.1.1. Population density from LandScan: Based on GIS and remote sensing imagery, Oak Ridge National Laboratory (ORNL) has prepared a population dataset named LandScan (Rose et al., 2018) that provides information about population across the globe. LandScan is considered a reliable data for mapping population distributions (Calka and Bielecka, 2019). The data is generated at 30 arcsecond (approximately 1km) resolution. Unlike typical census tables, LandScan has spatial information that helps in understanding geographic heterogeneity.

4.1.2. Land cover data from Landsat**:** To identify land use change we use multispectral images of Landsat 5 and 7 acquired from the USGS Earth Explorer (Explorer, 2019). The images were selected to minimize the cloud cover. The selected images were composited in GIS software. They were classified by applying the maximum likelihood method of supervised classification technique whereby the spatial analyst's *a priori* knowledge is used to place pixels in relevant categories. Classes were identified on each image that were relevant for land use/land cover change identification.

4.1.3. Road density from Global Roads Inventory Project: The Global Roads Inventory Project is a harmonized global and geospatial dataset on road infrastructure. The dataset was generated to integrate existing national road data into a consistent global dataset. The data sources used to create the inventory include publicly available national and supranational datasets from governments, research organizations, and crowdsource initiatives (Meijer et al., 2018). The raster layers for road density, which is defined as road length per unit of land area, are produced at a resolution of 5x5 arcminutes which is approximately 8×8km. This dataset is split into five road types: highway, primary, secondary, tertiary, and local.

4.1.4. Potential for the agriculture and mining industries from SEDAC: SEDAC is a data archive in the Earth Observing System Data and Information System (EOSDIS) of the US National Aeronautics and Space Administration. From the available datasets, we use the Global Development Potential Index (2016) that provides from spatial data a ranking of land suitability for the development potential of 13 sectors including fossil fuels, mining, and agriculture (Oakleaf et al., 2019). This data is used to identify locations where agriculture-based or mineral-based raw materials are available for use by industries set up in proximity.

4.1.5. Nighttime light data: Nighttime light data used here is the latest one titled Visible Infrared Imaging Radiometer Suite (VIIRS) obtained from satellite captures compiled and gathered by the DMSP. The algorithm for the final dataset is developed by the NGDC of the NOAA. It comprises lights that are stable over time. The algorithm returns reliable data by removing disturbances created by sunlight, glare, moonlight, aurora, and observations obstructed by cloud cover. VIIRS is considered more reliable spatially (for example, Chen and Nordhaus, 2015) to be used as a proxy for population density and economic activity. It has a pixel footprint of 0.742km x 0.742km. The VIIRS light units are nanoWatts/cm^2/sr where pixel values vary in the range of -1.4011 to 32641.72. Negative values result from calibration, but only a very small fraction of cells show negative values.

4.2. Methodology

To measure the economic impact and compare the transformation process of transport corridors, we need a globally consistent method. As typically the performance measures used to evaluate these achievements hugely depend upon national datasets, it is often difficult to compare them across countries or regions. Our objective in this study is to use indicators against which we can obtain data from repositories whose source is globally available satellite imagery instead of national or regional agencies. Similarly, this analysis aims at finding common denominators of urban development and corridor areas identified as broad corridors in our literature review.

The following steps for the spatial analysis were followed:

1) Use GIS software to map the geo-referenced CAREC transport corridors passing through China (XUAR), Tajikistan, and Pakistan. The relevant corridors for our study are CAREC corridors 5 and 6.
2) Using the Srivastava (2011) framework, empirical studies such as Mukhopadhyay (2018), and inference from nightlight imagery we assume a 50km influence zone on either side of the transport corridor. Accordingly, we define an influence zone on both sides adjacent to the corridor. This is the region where we expect transport investment spillovers to take place and where we hypothesize that we will observe new urban development. Further, we intend to find optimal locations for SEZs within this influence region.
3) To determine the change in land use over time, population density, local road networks, and the level of economic activity, we use spatial data for these attributes from the data sources mentioned in the data section. This data indicates new urban settlements and points towards spillover effects/local use of the transport corridors.
4) We use data from SEDAC as indicated in the data section to find a spatial development potential index for crops, metallic mining, and fossil fuels. These, along with population density, which we employ as proxy for labor force availability, are used to determine optimal locations for SEZs using the MCDA approach given in detail below.

4.2.1. Analysis techniques using GIS and spatial data

Using spatial data from GIS, our analysis is based on attributive (tabular) data and nonparametric techniques. In our analysis we employ these techniques to understand spatiotemporal variations and to study the impact of transport networks. The spatial data layers are used to quantify changes over time and also as input information in the MCDA mentioned in the literature review section for solving the optimal location choice problem for SEZs. For application of the MCDA method in the location choice model of GIS, the input is geo-referenced data that is used to assess multiple available alternatives, each of which is weighted according to value judgments by the decision-makers. The role of GIS is to incorporate criteria and constraints to generate suitability maps according to the results from an MCDA. There are two types of criteria employed by the spatial analyst: factors and constraints. A factor is a determinant that can either enhance or lower the suitability of a specific alternative for optimizing the location choice problem. A constraint, on the other hand, enforces certain limitations imposed on the choices under evaluation. In many cases, constraints will be expressed in the form of a binary choice: areas excluded from consideration being coded with a 0 and those open for consideration being coded with a 1. To sum up this discussion, MCDA can be considered as a process that combines and converts given spatial data (input) into a decision outcome (output) according to the assigned weights.

5. Results and discussion

In this section we focus on our findings and discuss five main areas. Mostly our emphasis is on the use of spatial data within the influence region of the transport corridor. We intend to highlight changes in population density and growth, use of spatial techniques to determine the optimal location of SEZs, changes in the level of economic activity, local and national investments around the corridor, and the spatial footprint of transport networks.

5.1. Population density

The LandScan data has approximately 1km resolution (30 inches x 30 inches) and it provides the number of people in a spatial cell. We use this data and calculate the area of the cell by a method proposed in the GICHD[4] document. This way we obtain the spatial distribution of population density within the transport corridor influence zone for 2000 and 2018.

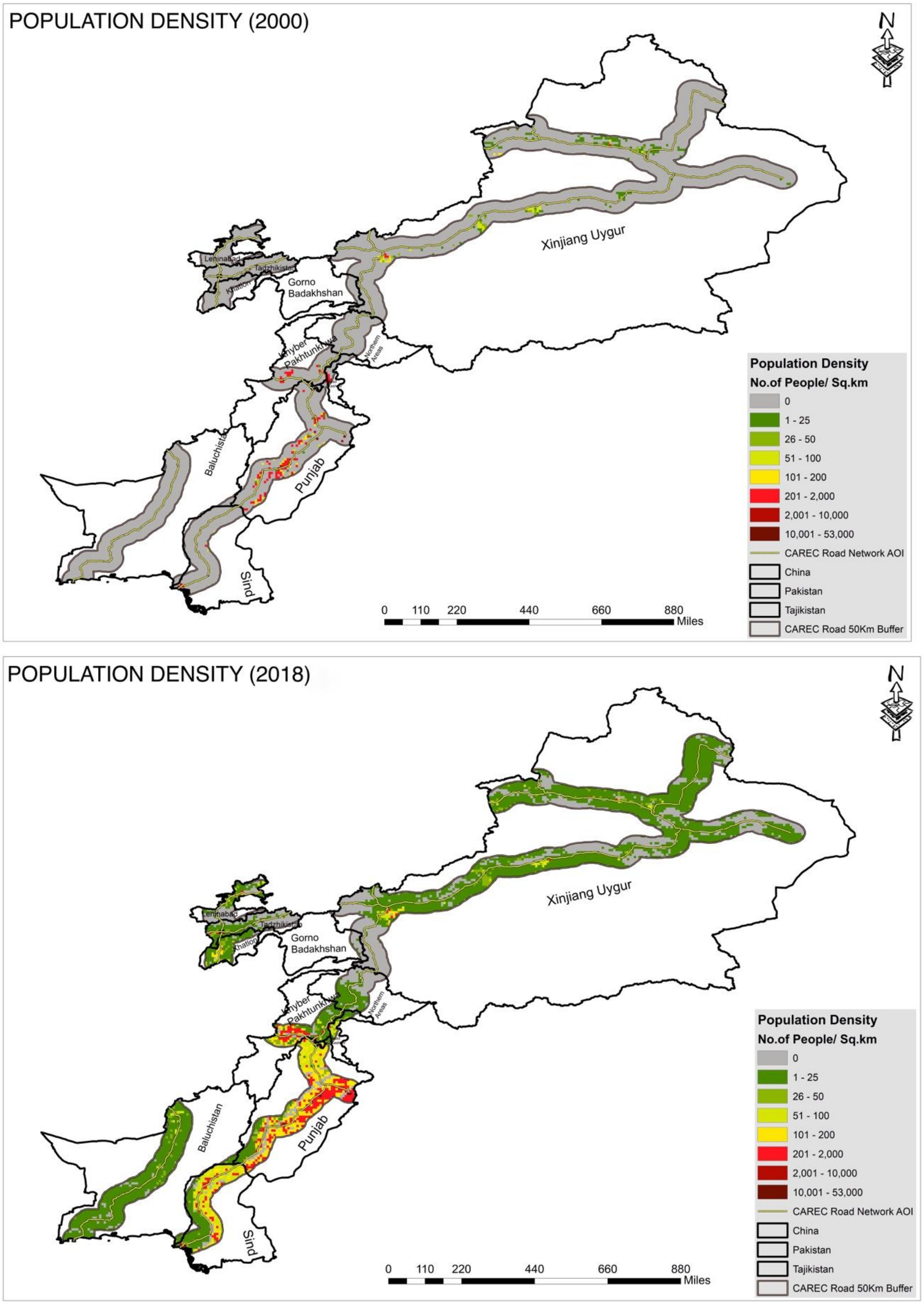
Table 2: Annual population growth rate (2000-2018)

Country	Population growth rate within corridor influence area (LandScan)	Population growth rate—national figures
China (XUAR)	2.70	1.83[5]
Pakistan	2.87	2.4[6]
Tajikistan	1.82	2.5[7]

Source: Author's estimation

4. https://kars.ku.edu/landmines/publications/FactSheets/FactSheetPopulation.pdf
5. *The Statistical Yearbook of Xinjiang Uyghur Autonomous Region 2016*.
6. www.pbs.gov.pk
7. https://databank.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG/1ff4a498/Popular-Indicators

Figure 6: Population density within corridor influence zone for 2000 and 2018



Source: Author's estimation using LandScan data

The combined maps for the three countries are shown in Figure 6. Using LandScan data we observe heterogeneity in the population growth rate within the corridor influence area in comparison with the national population growth rates. In the case of Pakistan and XUAR (China), the growth rate in proximity to the corridor is higher than the national average; however, this is the opposite in Tajikistan where we observe lower population density growth nearby the transport corridor. Although this variation in numbers may be driven by several other reasons, such as rural-urban migration or suitability of terrain for human settlement, this does point to the actual or potential transformation of the transport corridor to an economic corridor. The contrasting trend in the case of Tajikistan, as opposed to Pakistan and (XUAR) China, can be explained in terms of large-scale labor migration to the Russian Federation and other countries in search of employment opportunities (Yoshino, 2014). The same report indicates a high contribution, about 44% in 2012, of foreign remittances to the Tajikistan GDP. Although this figure has recently dropped to 29% (WDI dataset) it indicates a low rate of labor force participation locally. Besides, Yoshino (2014) also indicates issues around financial sector development as only 3% of the population aged over 15 held an account with a formal financial institution in 2013. The financial market penetration level points out likely constraints in the optimal use of infrastructure investments.

5.2. Optimal location for SEZs

One of the objectives of the study is to identify potential sites for successful SEZs. A recent World Bank report (Wong and Buba, 2017) highlights the internal and external factors that are potentially beneficial for the success of SEZs. Here in this study we focus on the external factors, namely: (i) labor availability, which we proxy through population density, (ii) raw material availability, for which we use SEDAC data for crop and mining potential, and (iii) energy accessibility, which we proxy from the SEDAC spatial data on fossil fuel availability. Our focus is within the 50km buffer of the transport corridor so we can safely assume that all such sites can be easily connected through a grand highway network. We then employ the MCDA through the GIS software to obtain a range of suitable locations.

To obtain optimal locations for SEZs we work through two alternate choices: one in which our focus is on industries that use agricultural produce as inputs and the other in which the industries use mining (metallic) output as raw material. Figure 7 indicates the potential sites within the influence zone for agricultural and metallic mining. Assuming labor as one factor of production, we assume that high population density locations can have more supply options. We perform the MCDA for two types of industry: one using agricultural produce and the other metallic minerals as raw materials. The results for the two configurations are shown in Figures 8 and 9. The lower panels in these figures indicate individual towns, cities, or countries identified as optimal locations based on the assigned criteria (see Table 3 for some mid-range/highly suitable sites). Interestingly, most of these sites have not seen much development despite their inherent natural advantage so the transport corridor can be instrumental in stimulating local economic growth only if supported by adequate policy measures.

Table 3: Suitable locations for SEZs

Country	Agriculture-based locations	Mining-based locations
China (XUAR)	Bole (Bortala), Yining (Gulja)	-
Pakistan	Chakwal, Khushab, Jhelum, Attock, Nowshera	Charsadda, Mardan, Khyber, Mohmand, Chakwal, Khushab
Tajikistan	Qabodiyon, Jilikul, Vakhsh, Qumsangir, Kolkhozobod	Yovon, Khuroson, Jomi, Danghara, Vahdat, Asht, Ghafurov, Matchin, Istaravshan

Source: MCDA by author

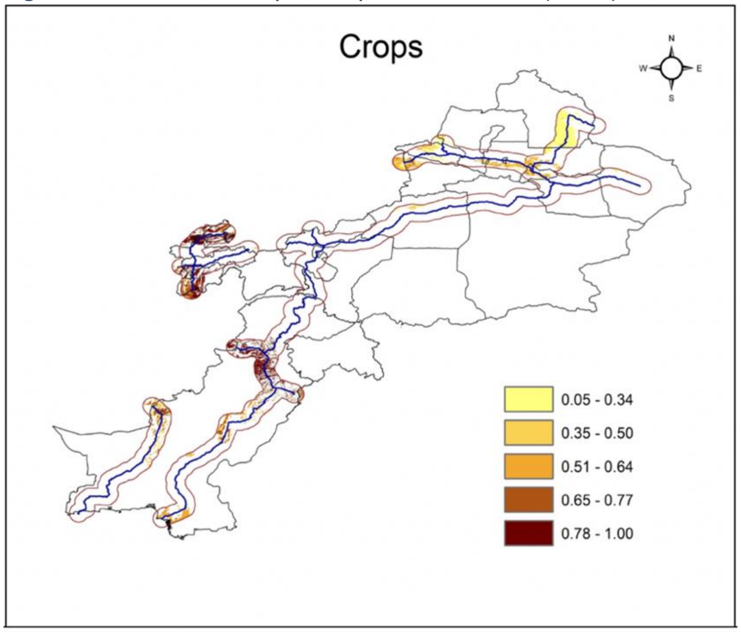
As this is an exercise based on limited information, we propose that it might be validated further by making the criteria more objective—for example, by using micro-level data on industry.

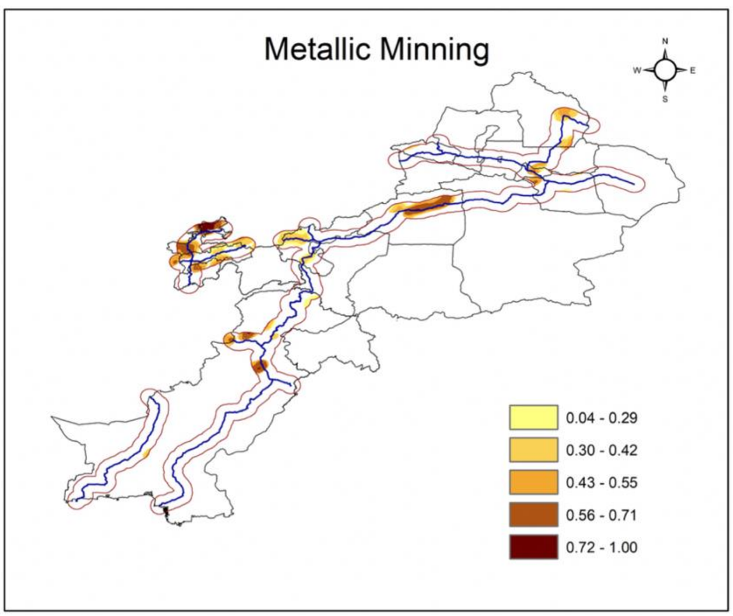
5.3. Economic impact of corridors

As CAREC is a regional project it involves multiple countries; hence, intercountry comparisons of impact on income or GDP based on national data are subject to uncertainty owing to procedural differences and measurement errors related to the data collection process as highlighted by Deaton and Heston (2010). As such, we follow the method of Henderson et al. (2012) by using nightlight data to measure income growth and human economic activity. Using nightlights as a proxy for economic activity and income growth ensures that this data is available for all locations and over time as well as with high frequency. The main question we intend to answer here is whether the locations within the influence zone of the corridor grow faster and whether we observe new urban settlements within these zones.

The country-level nightlight imagery is shown in Figures A1 and A2 in the Appendix. These images are for 2012 and 2019 and clearly indicate higher luminosity within the corridor influence zone. Zoomed-in images for three locations, one for each country of analysis, are shown in Figures 10 to 12. In the case of Tajikistan, the results within the corridor influence zone or in proximity to major urban agglomerations are in contrast to national level findings of a weak or negative correlation of lights with GDP or population mentioned in Elvidge (2014). It seems that the corridor impact has successfully offset the state's inability to provide the population with an appropriate level of electricity, a reason mentioned by Elvidge to explain the weak correlations.

Figure 7: Global development potential index (2016)





Source: SEDAC

Figure 8: MCDA for agriculture-based industry location (lower panels show zoomed-in maps)

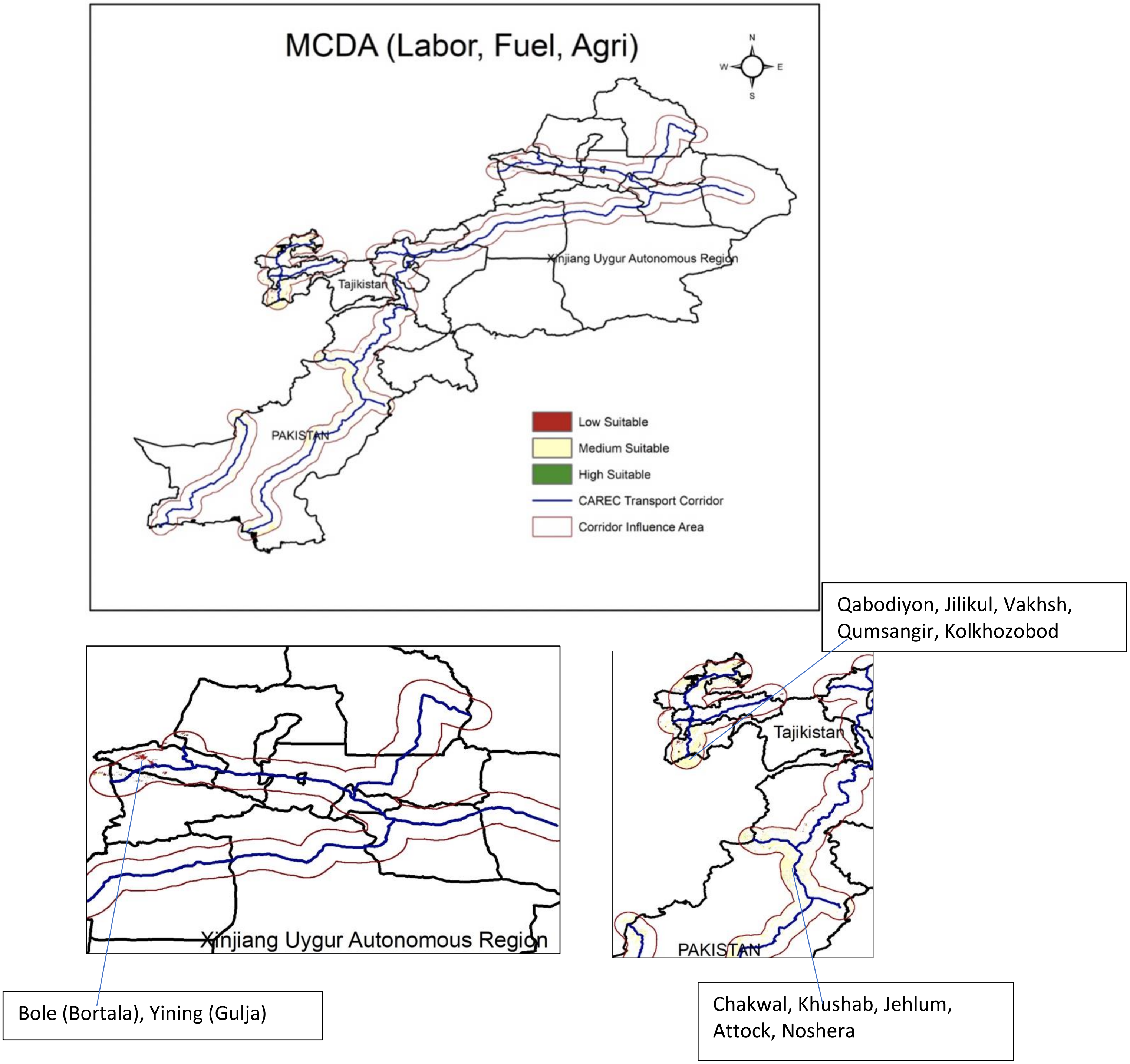


Figure 8: MCDA for mining-based industry location (lower panels show zoomed-in maps)

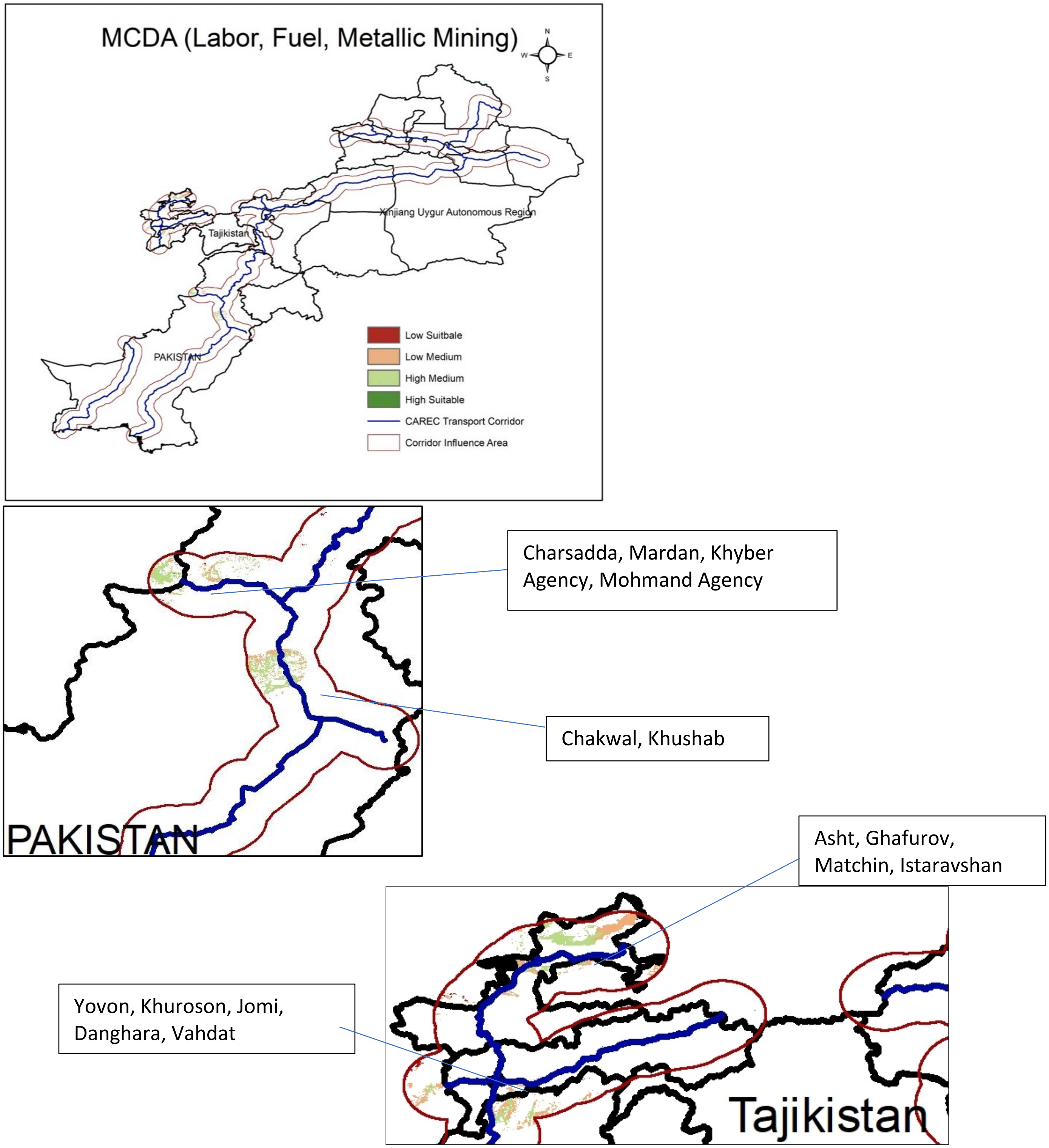


Figure 9: Nighttime light plot for XUAR (China) for 2012 and 2019

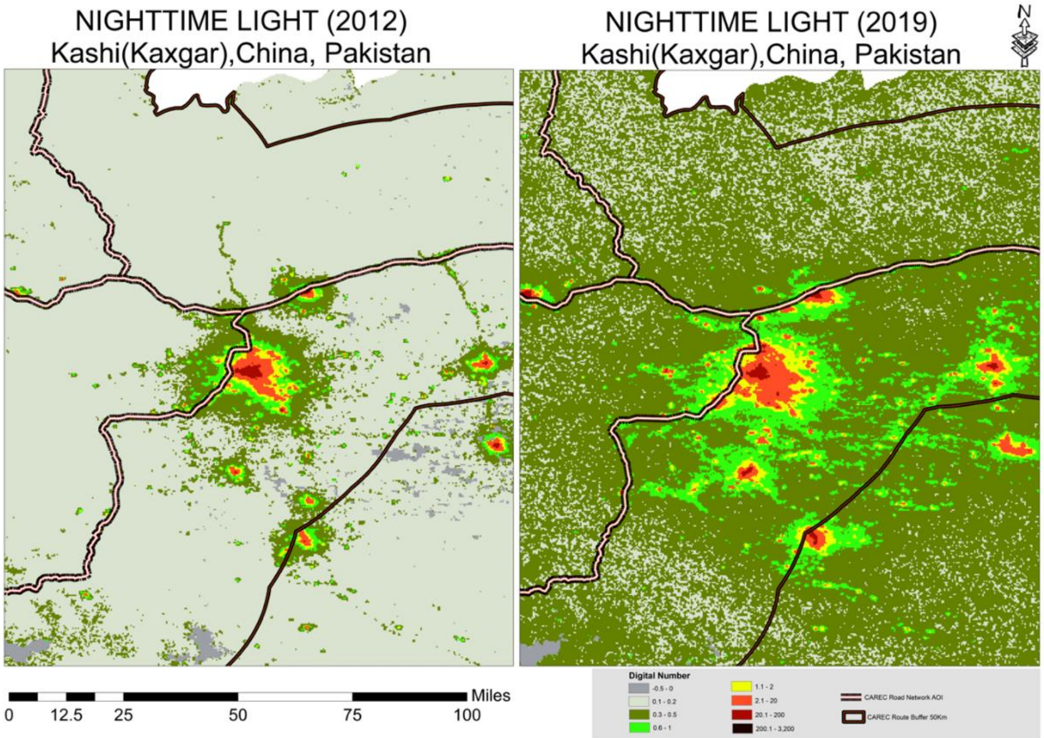


Figure 10: Nighttime light plot for Tajikistan for 2012 and 2019

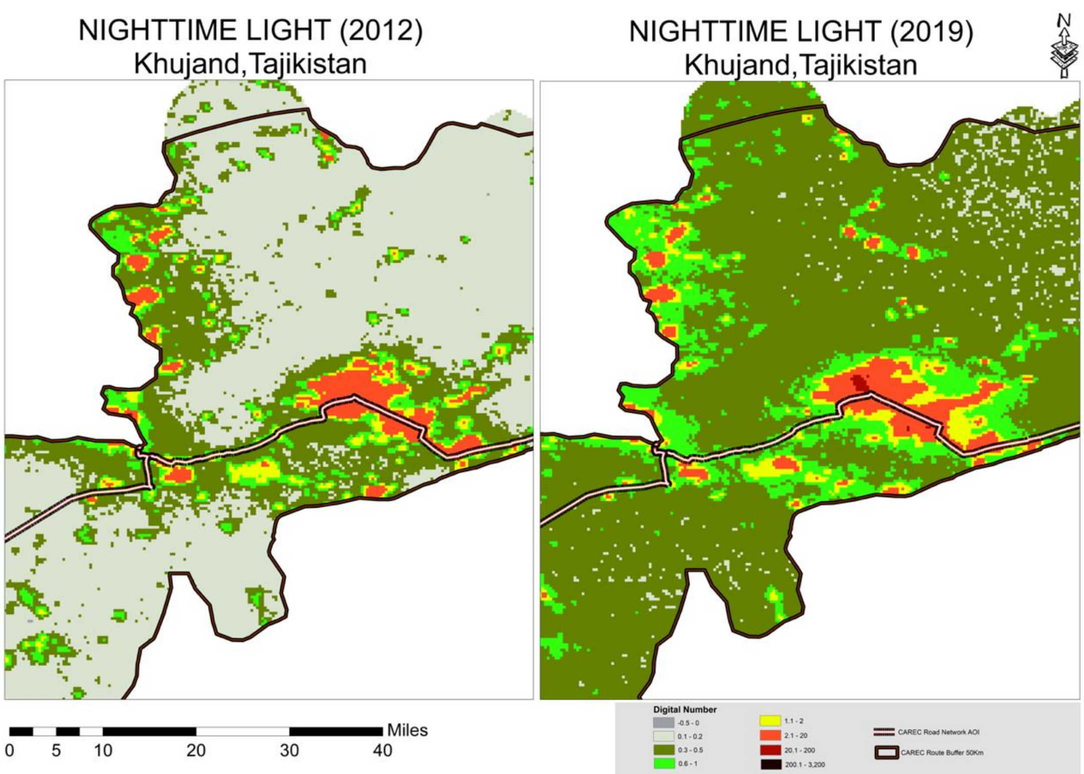
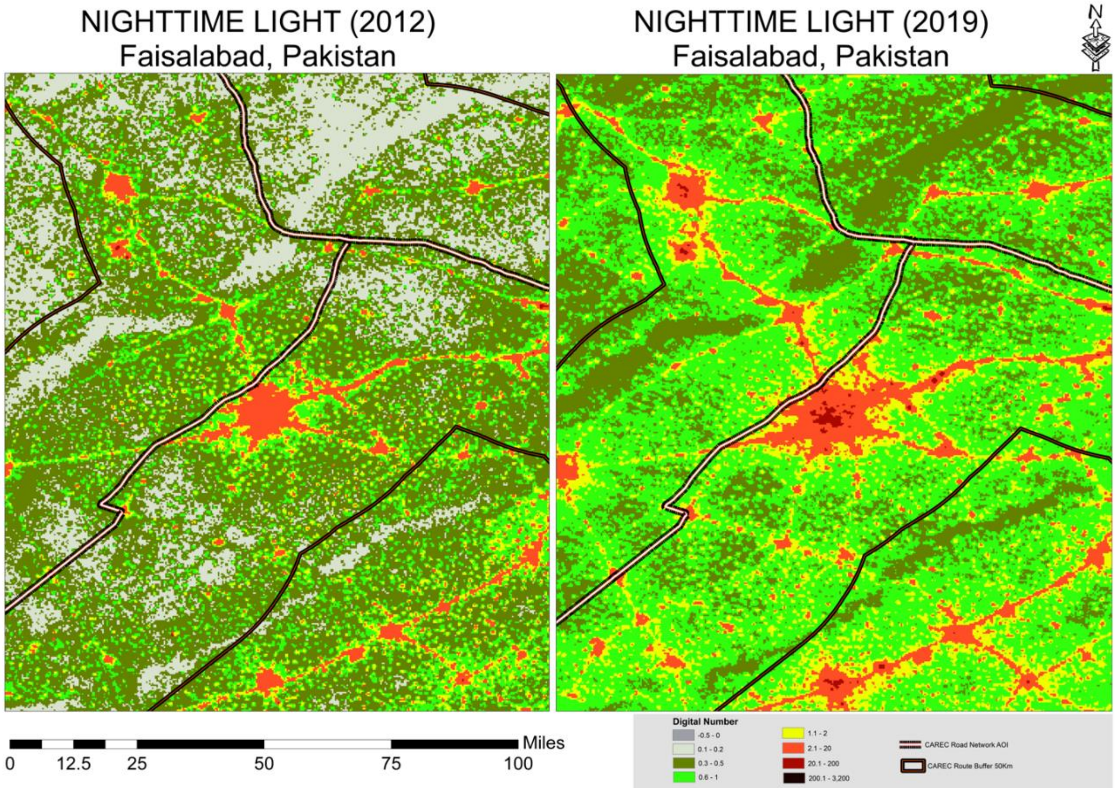


Figure 11: Nighttime light plot for Pakistan for 2012 and 2019



5.4. Benefits of corridors for the local economy

To observe the utility of the corridor for the local economy we map the primary and secondary road density for the three countries. Although the definition of primary and secondary roads may differ on the basis of allowable speed and asset ownership, we rely on the classification commonly mentioned in building codes.

Primary roads provide routes for the movement between high-density human settlements and economic centers on a national and provincial level. On the other hand, secondary road networks give transport access to routes from primary roads to those leading to residential locations.

The presence of primary and secondary roads in the proximity of corridors is an indicator of the local connectivity usage. The development of primary and secondary roads for freight and passenger traffic is also an indicator of the corridor's influence on the local transport route choices and, hence, improved local accessibility options through the highways, as mentioned in the discussion on Srivastava (2011). As we were not able to find data for the road network inventory over time, we rely on a one-time snapshot from the Global Road Inventory Project. This data is helpful in observing road density both inside and outside the corridor influence zone.

The primary road network appears to be more developed in XUAR (China), but the secondary network is denser in the case of Pakistan along the CAREC corridor 5, as shown in Figure 13. Road density of all categories is shown in the Appendix in Figure A3.

5.5. Land use/land cover change

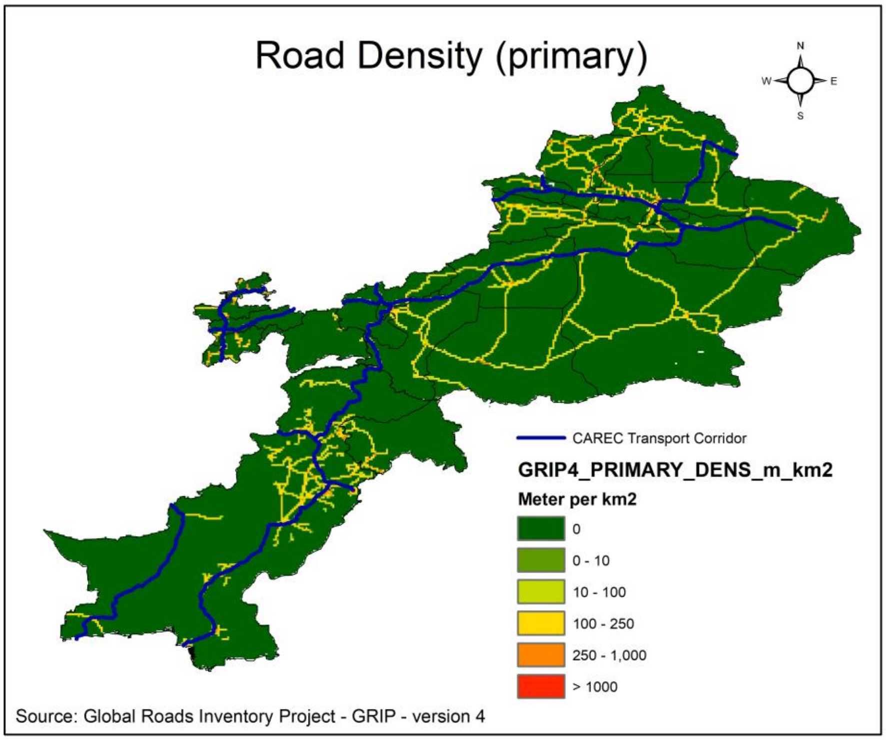
The land use/land cover (LULC) change for the countries under focus are shown in Figures 14 to 16. These images have been developed using Landsat data for 2001 and 2020. Visible land cover change towards urban use can be observed particularly for Tajikistan and the XUAR; this can be used to identify new settlements as well as increase the size of existing ones. Interestingly, the LULC data points at annualized growth of the urban built-up area in China by 16.5%, Tajikistan by 10.2%, and Pakistan by 8.2%. These numbers are considerably larger than national growth rates or urbanization trends, and therefore point to a certain extent to the potential impact of the nearby transport corridor (Table 4).

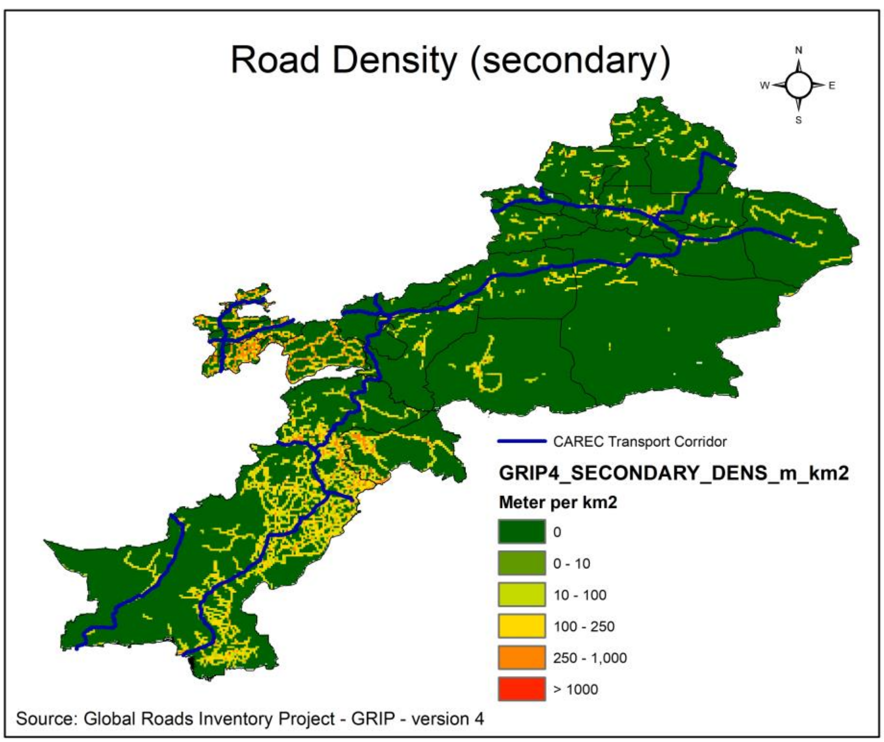
Table 4: Comparison of urban growth

Country	**Annual urbanization rate (national statistics)**	**Annual urban[8] land use within corridor influence zone (built-up area increase)**
China (XUAR)	~1%[9]	15.2%
Pakistan	3%[10]	7.9 %
Tajikistan	2.7%[11]	9.7%

8. Author's calculation using method of Puyravaud, JP (2003). 'Standardizing the calculation of the annual rate of deforestation.' *Forest ecology and management*, 177(1-3), 593-596.
9. Annual Statistical Communiqué of XUAR on the National Economic and Social Development.
10. www.pbs.gov.pk
11. https://databank.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG/1ff4a498/Popular-Indicators

Figure 12: Road density map (primary and secondary types)

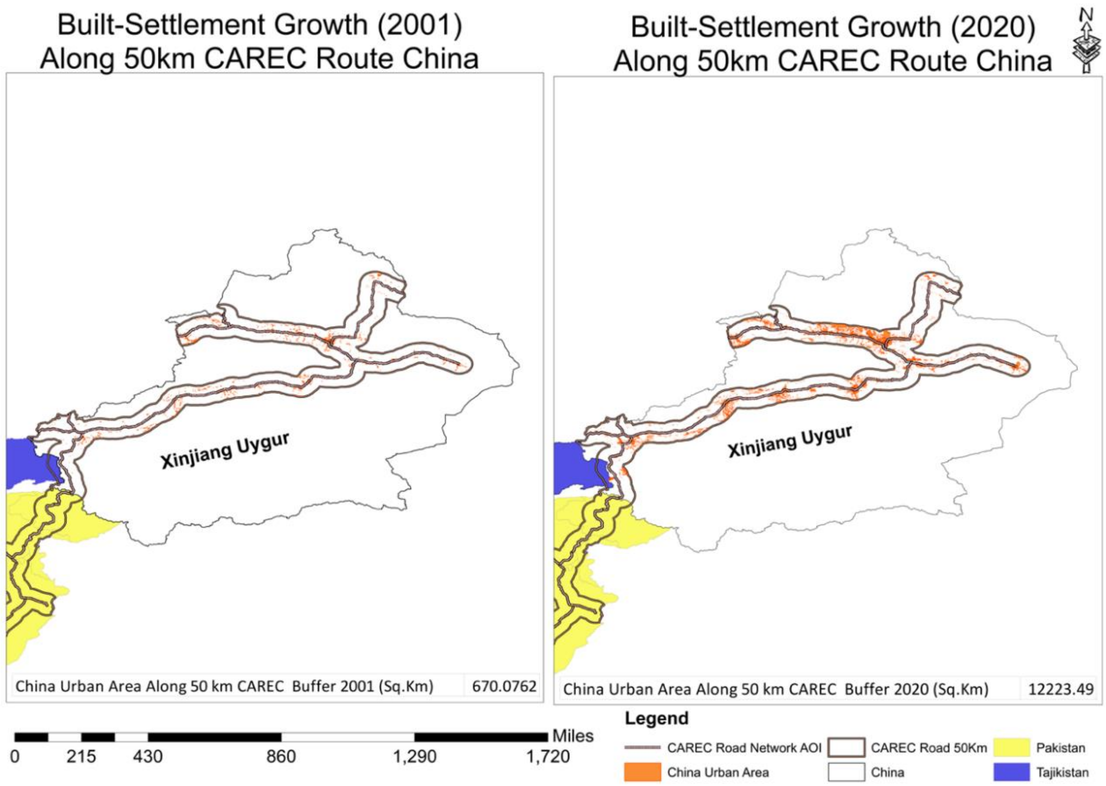




Source: GRIP

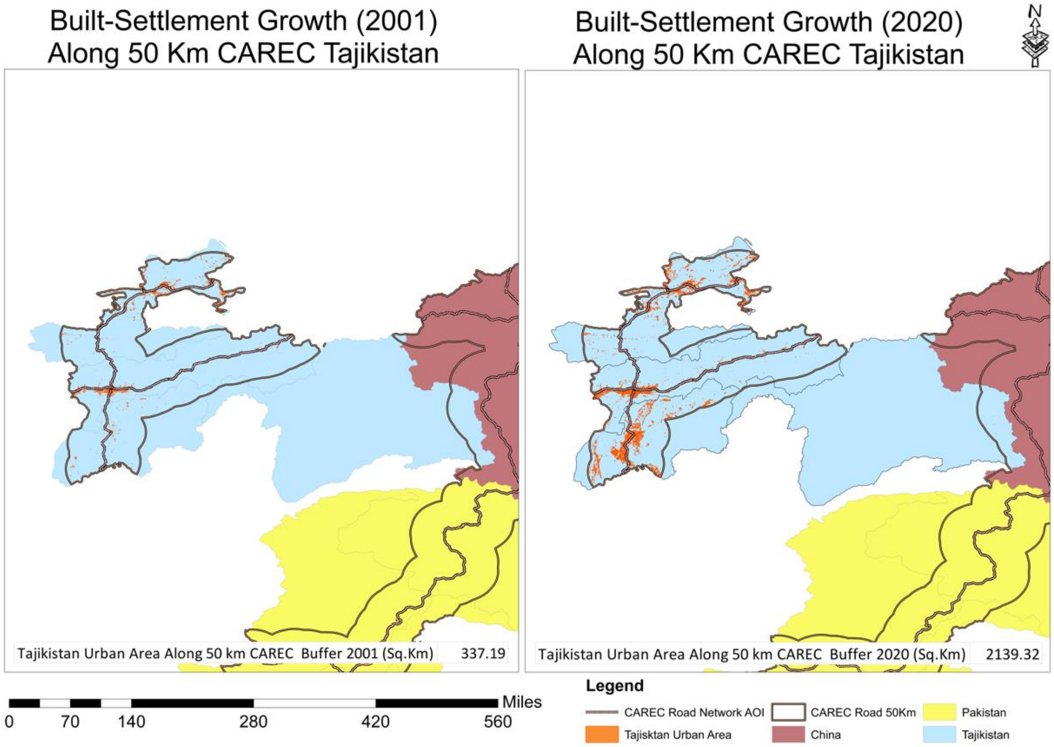
To calculate the increase in the built-up area at city level, we use pixel values larger than zero for the three locations shown in Figures 10 to 12. We find that for Khujand (Tajikistan) the annual increase is 5%. For Kashi (China) and Faisalabad (Pakistan) the increase is 20% and 22%, respectively. These values are much larger than the annual increase figures calculated using the projected growth method as we included all locations where the pixel values are larger than zero, which shows the extreme case.

Figure 13: Urbanization trend along the corridor XUAR (China) for 2001 and 2020



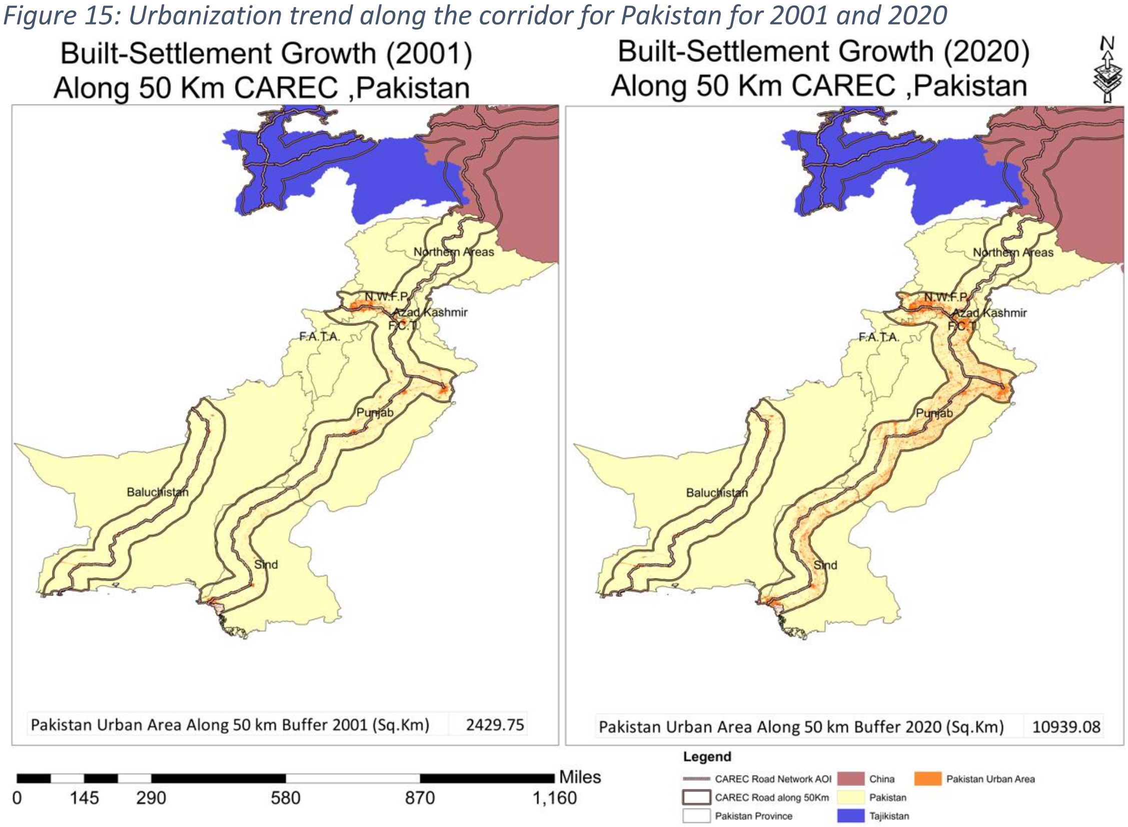
Source: USGS

Figure 14: Urbanization trend along the corridor for Tajikistan for 2001 and 2020



Source: USGS

Figure 15: Urbanization trend along the corridor for Pakistan for 2001 and 2020



Source: USGS

5.6. Discussion of the case of Tajikistan

The above analysis points out variations in the impact of CAREC investments across countries. Such differences may arise on account of inherent heterogeneity and this is evident in Tajikistan where the impact of improvement in the transport infrastructure is relatively less distinct. This highlights the need for further analysis of the Tajikistan case to determine the constraints for development. A related aspect is to identify the potential for economic growth based on existing resources. Here we briefly cover both of these interconnected scenarios.

Using the World Bank's Logistics Performance Index (LPI), Asadov (2012) shows that except for the indicator of timeliness Tajikistan's 2010 LPI score is below that of its neighbors (Afghanistan, China, Kyrgyzstan, Uzbekistan) and Kazakhstan. Among the indicators determining the LPI, the ones that matter most in terms of structural reforms are (i) improving customs efficiency, (ii) quality of logistics services, (iii) tracking consignments, and (iv) ease of arranging economically priced shipments.

The results obtained in this study indicate that Tajikistan needs massive interventions to truly reap the benefits of its strategic location whereby it serves as a bridge for the transit of goods and services between China, Central Asia, South Asia, and the Middle East. Its road infrastructure comprising three Asian highways (AH7, AH65, and AH66) and four of the six CAREC transit corridors (2, 3, 5, and 6) provides the country with an unmatchable potential to act as a major transportation hub in the hub and spoke model, which provides greater flexibility within the transport system through a concentration of flows. In this model, transport companies collect cargo from its point of origin, which can be assumed to be the tip of the spoke, and ship it to a central processing facility, which is the hub. The consignment is then combined with other shipments and transported to its destination, which is the tip of another spoke. Studies indicate that hubs can benefit from economies of scale by offering a high frequency of services and economies of scope in the use of shared trans-shipment facilities. To assume the role of a transportation hub it is imperative to attain a significant improvement in the indicators determining the LPI. This approach will soon reap benefits from its transportation infrastructure by improving systems and procedures regulating transit goods and hence be a reasonable strategy for Tajikistan.

6. Conclusion

Following investments in the transport and energy sectors, the CAREC countries have become more closely connected through new infrastructure. However, to reap the true benefits of these initial interventions there is an evolving need to cooperate at a broader economic level and to focus on 'linking markets, ideas, and people'. Economic corridors can play a key role in integrating economies across a region (Vickerman 2002). This study on the spatial aspects of economic activity highlights the crucial role of transport infrastructure to achieve the goal of economic corridor development, which is closely connected with the spatial organization of economic activities. This paper analyzed spatial data from remote sensing imagery to capture the extent of spillovers from the CAREC regional transport corridor. The spatial analysis reveals that across a multitude of indicators, such as population growth, economic activity variation, road density differences, and land use change, the values within the influence zone of the corridor are heterogenous across countries, but significantly higher (Tajikistan being an exception in population growth variable) in comparison to the countrywide averages determined from national statistics. Brief analysis in the case of Tajikistan indicates that structural weaknesses obstruct the returns on infrastructure investment and hence highlight the need for adequate reforms and targeted interventions.

The spatial analysis conducted in this study is useful to generate regionwide and country-specific policy recommendations. The proximity of CPEC and CAREC demands a holistic approach to fully utilize the potential of the connectivity network being generated by the two mega projects. Besides, learning from the monitoring and planning experiences of the two ventures, such as formulating CPMM indicators in the case of CAREC and defining optimal locations for the development of SEZs along the CPEC, could be mutually beneficial for the two corridor planners. The case of Tajikistan indicates the need to focus on improvements beyond the transport infrastructure to spur local economic impact. For Pakistan and (XUAR) China, the analysis reveals a need to regulate urban growth and the rapid increase in the built-up areas in the periphery of urban centers. The identification of potential locations for farm-based and mineral-based industrial zones in the three countries has important policy implications at local and national levels. This information is not only useful for designing national industrial policies but could also be utilized to identify local human capital development needs to achieve efficient labor market outcomes through spatially optimal skill matching.

In the NEG model, the success of policy interventions aimed at enhancing economic growth, such as the development of SEZs, depends upon factors beyond infrastructure, such as the local stock of human capital, market linkages, and trade costs (transportation included). This study is a first step to map these factors spatially for the CAREC region. The maps indicate the current pattern of growth and will be helpful to determine the future course of action for sustainable growth in the region as envisaged under the CAREC 2030 strategic framework.

7. Limitations

The use of geographic information is helpful in bridging data gaps and identifying the spatial pattern of urbanization and development trends. However, for optimal policy design, such information needs to be used to complement national census and survey datasets conducted by national statistical agencies. Nonetheless, the study highlights the usefulness of spatial data analysis in showing the local economic impact of regional interventions as well as the importance of further research using spatial data.

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Appendix: nightlight and road density maps

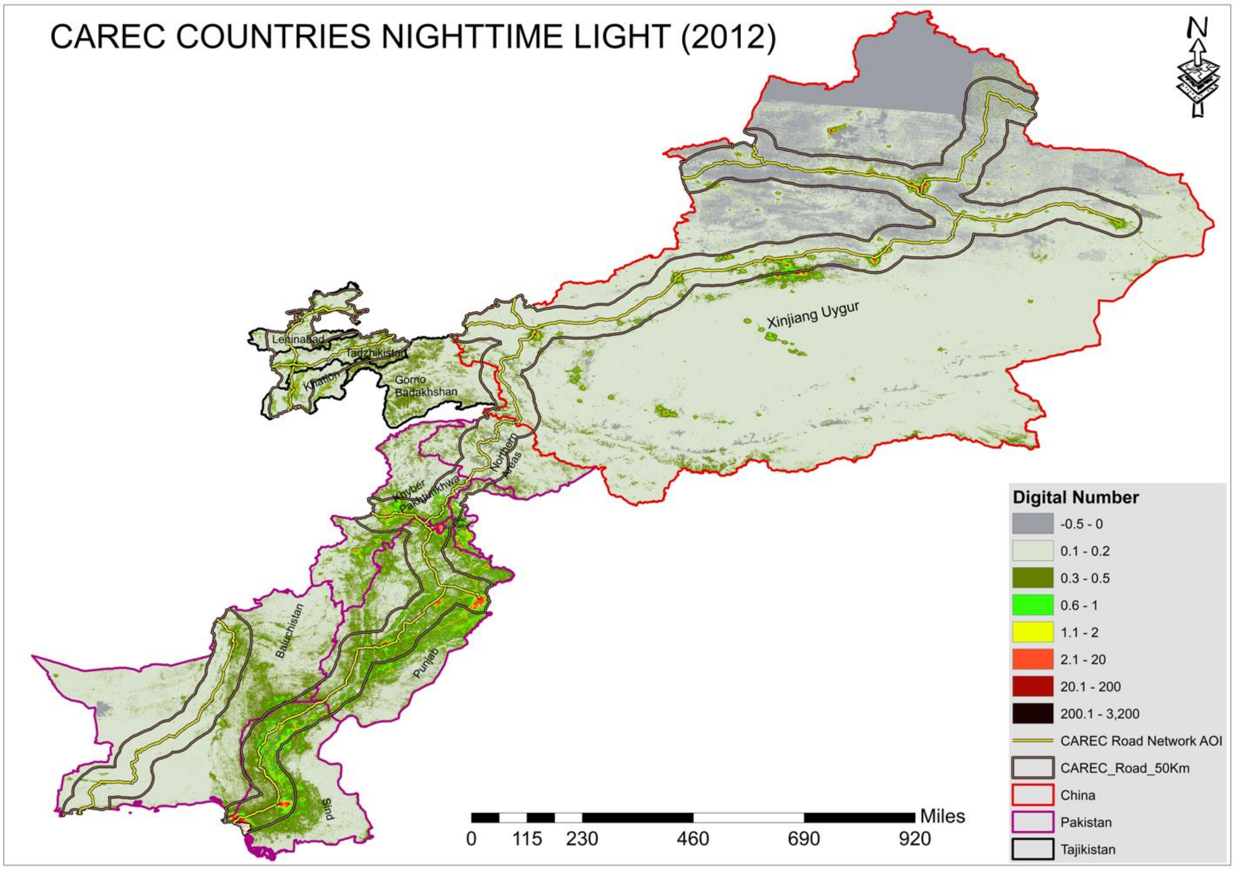

Figure A-16 CAREC Countries Nighttime Light Map for XUAR (China), Pakistan, Tajikistan

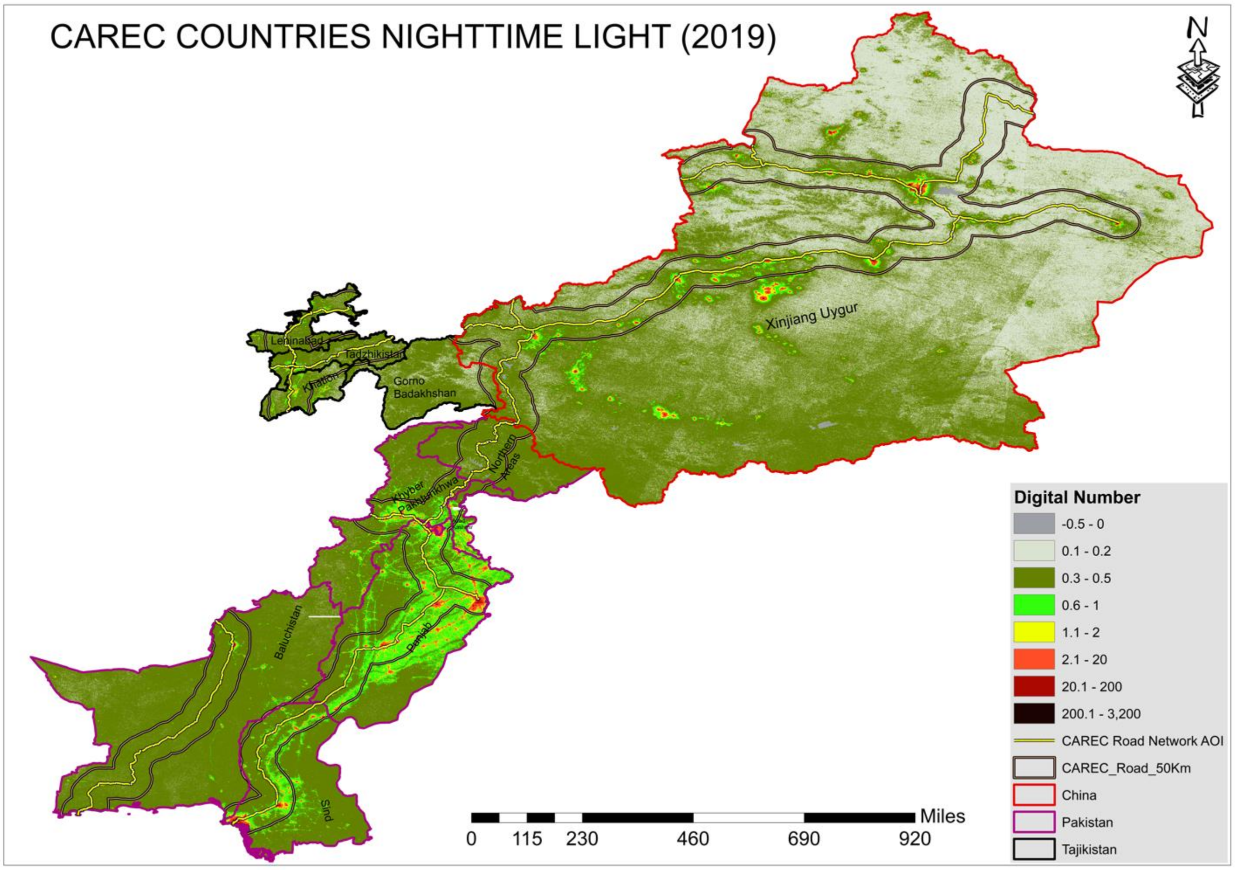

Figure A-17 CAREC Countries Nighttime Light Map for XUAR (China), Pakistan, Tajikistan

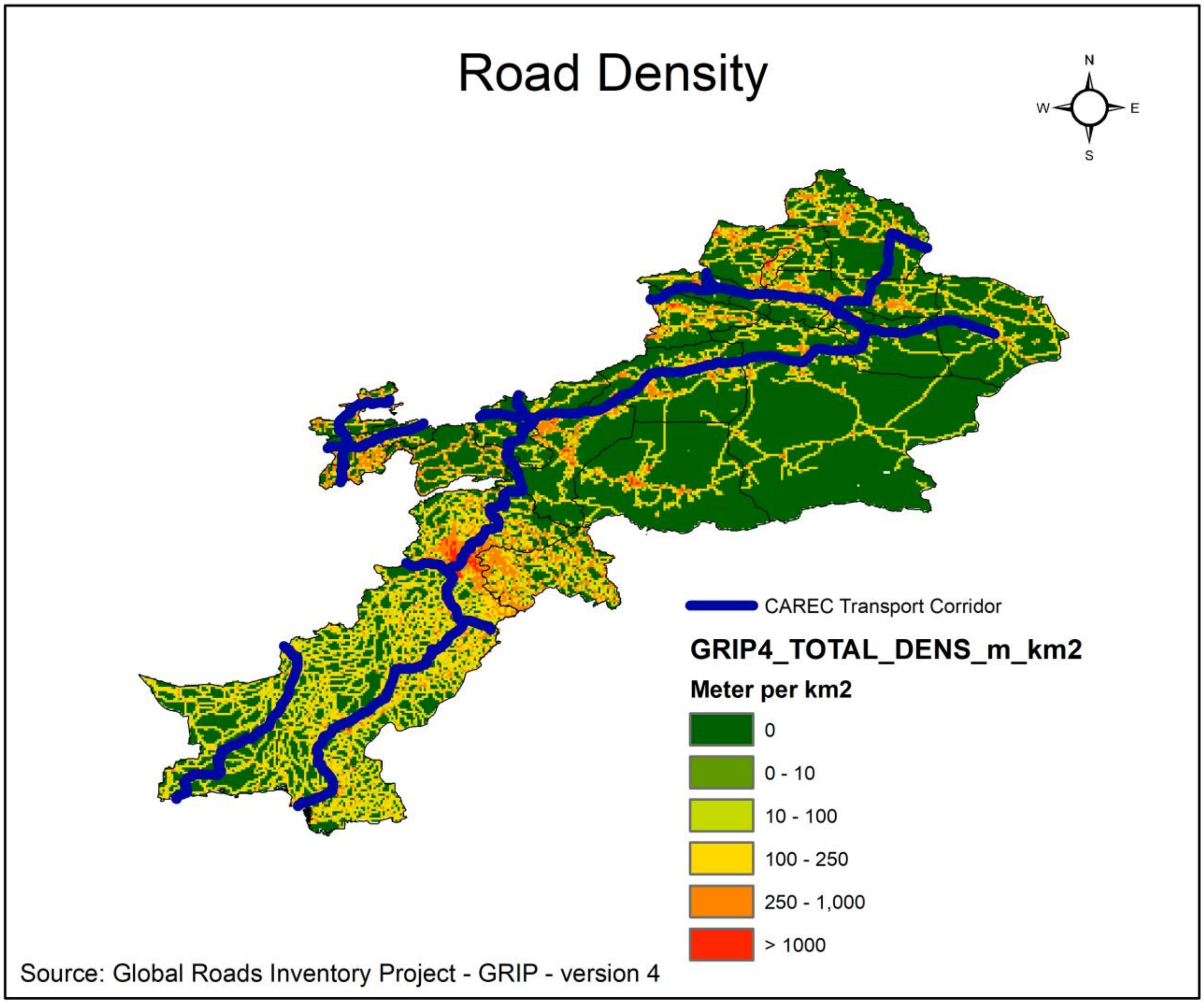

Figure A-18 CAREC Countries Road Density Map for XUAR (China), Pakistan, Tajikistan