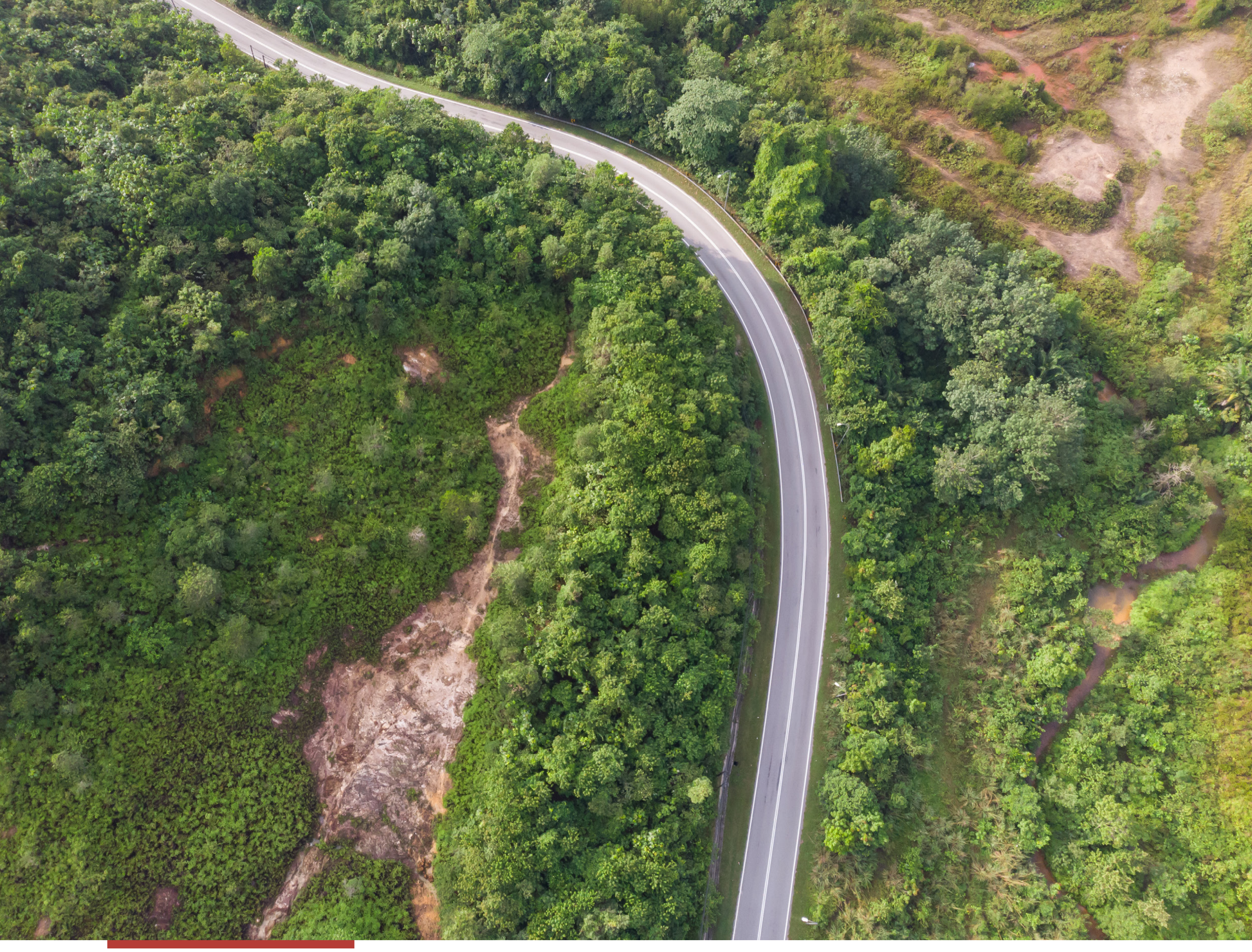

Guidelines to Assess the Direct and Indirect Area of Influence of Transportation Infrastructure Projects

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CLIMATE POLICY INITIATIVE

PUC RIO

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ABOUT CPI

Climate Policy Initiative (CPI) is an analysis and advisory organization with deep expertise in finance and policy. Our mission is to help governments, businesses, and financial institutions drive economic growth while addressing climate change. CPI has six offices around the world in Brazil, India, Indonesia, Kenya, the United Kingdom, and the United States.

KEYWORDS

Deforestation, Market Acess, Transportation Infrastructure

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LIST OF FIGURES

CONTENTS

INTRODUCTION

Climate Policy Initiative/PUC-Rio in partnership with BNDES and the state of Pará has developed and applied a market access methodology to quantify the direct and indirect impacts of infrastructure development on deforestation in Brazil (Araujo, Bragança, and Assunção 2022; Araujo, Assunção, and Bragança 2020; Bragança et al. 2021; Chiavari et al. 2022). The application of this methodology allows stakeholders to draw more precise scenarios of the impacts of infrastructure, leading to a more accurate assessment of costs and benefits of individual projects.

Mapping the areas that will be affected by a change in transportation infrastructure is crucial to assess costs and benefits. The correct mapping of the area of influence allows the identification of peoples that will be affected, the natural habitats that will be converted to agricultural use, and of emissions associated with deforestation. Areas at a greater risk of deforestation should guide mitigation efforts, with the possibility of having the development of targeted policies – such as, command and control efforts, implementation of the forest code, and the implementation of payment for ecosystem services (PES) schemes -- as a condition to attract investments.

This document provides a set of guidelines for assessing the direct and indirect area of influence for transportation infrastructure projects that can be used by environmental agencies, investors, and civil society.

The next sections present a blueprint of all the steps necessary to apply the market access methodology. It begins with an overview of the methodology and moves on to build each of the components of the model: transportation cost, market size, and deforestation. These three components are then combined into a statistical model to estimate the deforestation footprint of projects. Deforestation is not the only outcome that can be computed with the methodology though. A section on how to compute the carbon footprint of projects closes the blueprint. Additionally, a simplified example is developed from scratch.

THE MARKET ACCESS METHODOLOGY

Usually, the delineation of the area of influence is determined by a geographical distance to the outline of the project: the closer it is, the higher is the impact, with the impact beyond a predefined threshold set to be zero. This methodology alone is not optimal because it doesn't consider the social and economic dynamics inherent to changes in infrastructure, especially for large projects. To capture these important social and economic dynamics a shift from using the geographical distance to the project to changes in access to markets caused by the project is a necessary step. In this document, CPI's researchers present a blueprint to develop an application to assess the direct and indirect area of influence of transportation infrastructure projects accounting for social and economic factors.

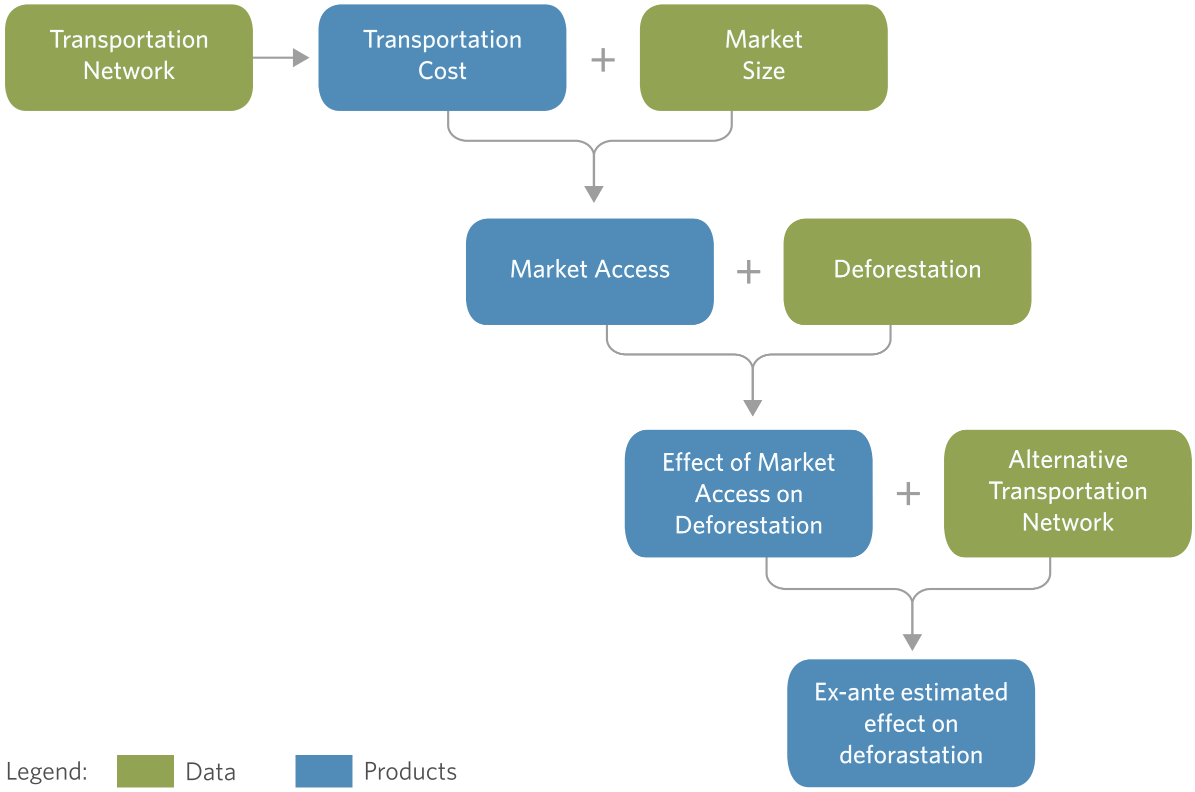
To capture social and economic factors, the change in transportation infrastructure should be translated into changes of access to markets. The **market access** methodology described in this study explores the fact that what is relevant is not the outline of the project per se, but how and what the project connects. For example, a road connecting a region to a port with access to international markets would result in more deforestation than if the same road structure were used to connect the region to a small city.

It is important to highlight that the market access approach is not proposed as the sole method to determine the area of influence. Rather, it is a method suitable to estimate impacts via social and economic factors that can be composed with other methods to create a more credible estimate of the area of influence.

The key components of the market access methodology are: the **cost of connecting markets** – represented by the transportation cost of goods between markets – the **economic size of the markets** – represented by either its population or its production value – and **land conversion** – represented by measures of deforestation. The combination of these three components allows for a flexible specification of **how land use is affected by transportation infrastructure.**

The steps for a full analysis are shown in Figure 1. In this figure, the green boxes indicate the necessary data for the analysis and the blue boxes indicate the outputs of the analysis. We start with data on the available transportation network that is used to compute the transportation cost among markets. The transportation cost and market size are combined to create the market access measure, which is further explained in the next section. The market access measure is combined with deforestation data to estimate the statistical relation between market access and deforestation. The final step is to create an alternative transportation network -- a new road for example -- recompute the market access and use the statistical model of market access on deforestation to estimate an ex-ante deforestation impact of the change in the transportation network.

Figure 1. Step by Step for Environmental Impact Analysis



Note: *This figure describes the steps for a full analysis of the deforestation footprint of an infrastructure project.*
Source: *CPI/PUC-Rio, 2023*

To combine **transportation cost** and **market size** in a single interpretable number, the economics literature of international trade has developed the market access measure (Eaton and Kortum 2002). To build this measure, each market is seen as connected to a range of different markets and each connection is subject to a different transportation cost. This rich set of information is then summarized as a weighted average, where the **market access of each region depends on the market size of its trade partners** inversely weighted by the cost to access it.

Figure 2 illustrates the concept, where each Brazilian state represents a market and the transportation network is composed only by the infrastructure of roads. In Figure 2a, the size of each market is represented by the size of the circle and the cost to travel between two markets is represented by the size of the line connecting them. Additionally, in Figure 2b, the size of each circle represents the market access. It differs from the size of each market because the market access is determined not only by the market size of a region but also by the market size of the other regions and on how easy it is to access these other markets. The market in São Paulo for example, is not only the market with the biggest size, but also the one that has good connections with other markets. This is why it has the highest market access. Changes in transportation infrastructure – the lines in Figure 2 - will change the transportation network, affecting the market access.

Figure 2. Graph Size of Market and Market Access

Figure 2a. Marke Size

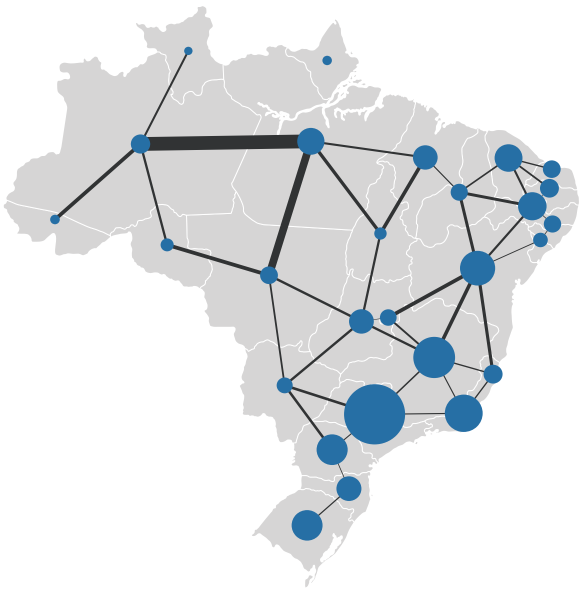
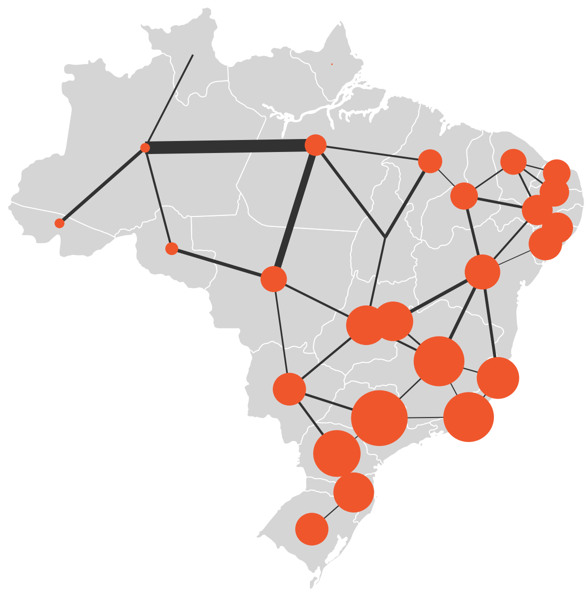


Figure 2b. Market Access



● **Markets** (the size of each market is represented by the size of the circle)

— **Connections between markets** (the stroke line indicates the cost of transport between markets: the thicker the line, more expensive is the transport)

● **Markets** (the size of each circle represents the market access)

— **Connections between markets** (the stroke line indicates the cost of transport between markets: the thicker the line, more expensive is the transport)

Note: *This figure shows the market size (2a) and the market access (2b) in a scenario where each state represents a market and trade can only happen through roads, which are shown as black lines. The area of the black lines represents the cost of transportation.*

Source: *CPI/PUC-Rio with data from Censo IBGE (2010) and Ministry of Transportation, 2023*

BUILDING THE MARKET ACCESS AND MEASURING DEFORESTATION

To study the impact of individual infrastructure projects, the first step is to build the market access measure, which requires data on market size (the size of the circles in Figure 2) and the ability to compute transportation costs (the area of the black lines in Figure 2) for any given infrastructure network. The next sections describe in detail each of these components.

COMPUTING TRANSPORTATION COSTS

There is a range of applications used in a day-to-day basis that computes transportation costs between a given origin and destination, with the cost of transport usually being expressed in terms of estimated travel time. Nonetheless, these applications do not allow their users to change the infrastructure network – building a new road, for example – thus it is necessary to build this application.

The data requirements to build such program are georeferenced data of the transportation infrastructure: **roads, railroads, waterways, railroad stations, ports and other modes of transportation**. The better the data, the more precise the computation of the transportation costs will be. For example, with data on the condition of roads – paved or not paved, average velocity of the traffic, average freight cost per km – it is possible to assign different transportation costs for the use of each type of road. The same reasoning applies to the other modes of transportation. For example, data on loading fees for using a port or of the delay of the loading process can also be included in the transportation cost measure.

Table 1 presents possible data sources for the transportation network in Brazil that can be used to build the transportation cost data.

Table 1. Transportation Model Data

Content	Source	Coverage
Federal roads with data on roads condition	Ministry of Infrastructure	Decennial from 1980 to 2020
State roads with data on roads condition	DNIT	One year: 2020
Federal, state, and municipal roads with data on roads condition	Open Street Maps	Only the current year
Freight data	SIFRECA ESALQ USP	Yearly from 2014 to 2018
Waterway and Railroads	Ministry of Infrastructure	Decennial from 1980 to 2020
Railroads Stations	Ministry of Infrastructure	One Year: 2020
Ports	Ministry of Infrastructure	Only the current year
Year of ports construction	ANTAQ	Since 1970

Note: *This table shows potential data sources to build the infrastructure network.*
Source: *CPI/PUC-Rio, 2023*

To understand the flexibility allowed in this type of application, it helps to know the underlying data structure. These data on the transportation network are transformed into a network data (a graph) in which a standard optimal path algorithm can be applied. The algorithm is responsible for finding the least cost path and the cost of that path between a given origin and destination.

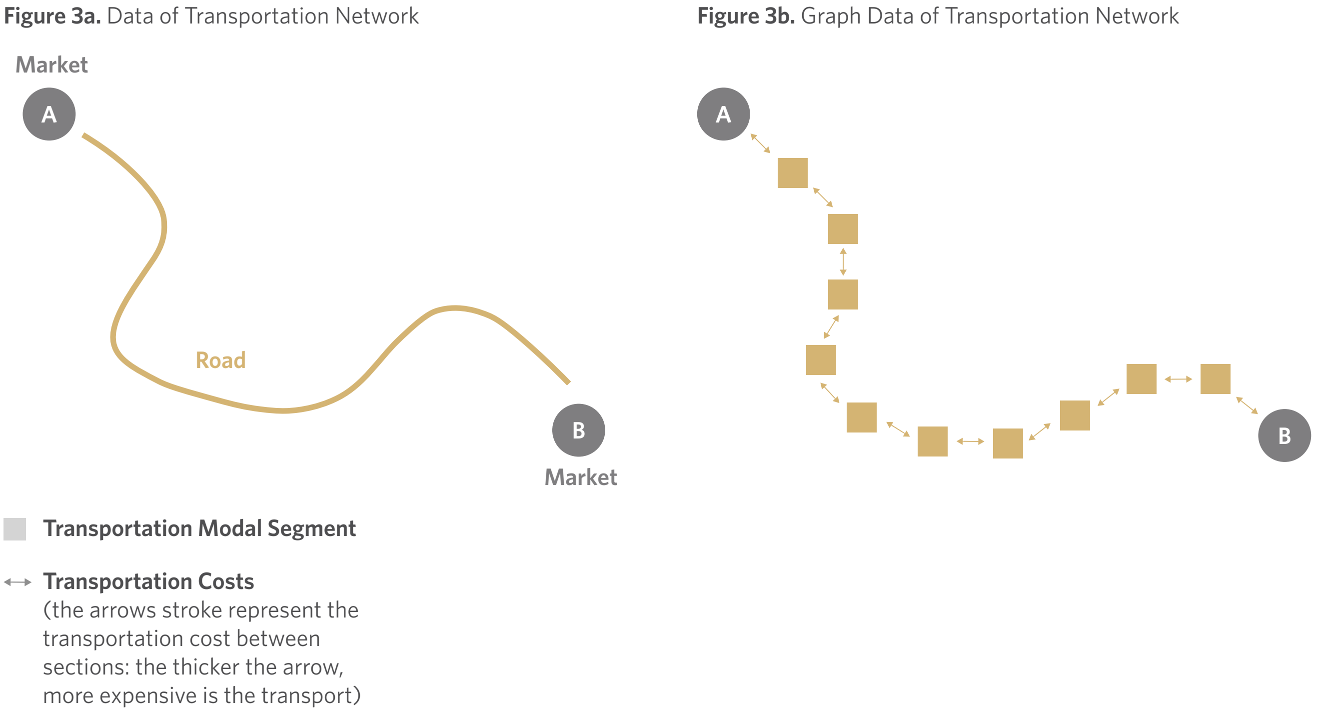
This graph data divides the infrastructure network of interest in a range of small pieces (nodes) and determines: which node is connected to which – for example, the node representing a port is connected to a node representing a waterway – and the cost to move from one node to another – for example, the fee of using a port to access a waterway. Any data on how those nodes are connected and on how much it costs to move from a node to another can be included in the application.

The next examples describe some cases to show the flexibility of this data structure.

ROADS, PORTS, AND WATERWAYS

Figures 3 illustrates this data structure. In Figure 3a, there is data of a simple transportation network connecting two markets: A and B. Only one road is available. To compute the cost to travel from A to B, Figure 3b illustrates a possible configuration of the graph data, with the arrows (edges) representing the allowed direction and the size of the arrows representing the cost of moving from one node to another.

Figure 3. Exemplo of How a Computer See a Road



Note: *This figure presents two markets – A and B – connect by a single road (3a). This road is converted to a graph (3b) where the arrows represent the cost of moving from one pixel (node) to another.*
Source: *CPI/PUC-Rio, 2023*

It is possible to add many more features in this simple infrastructure network. Figure 4 changes the network by adding a waterway, two ports, and small roads that allow access to the ports. The small roads are costlier to travel by, therefore their arrows are larger. To access the waterway, one must necessarily use a port and pay a loading fee, represented by the thick yellow arrow.

Figure 4. Adding More Elements in Transportation Model

Figure 4a. Data of Transportation Network

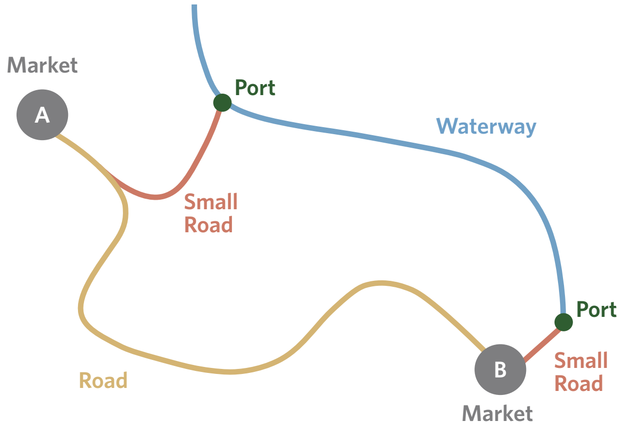
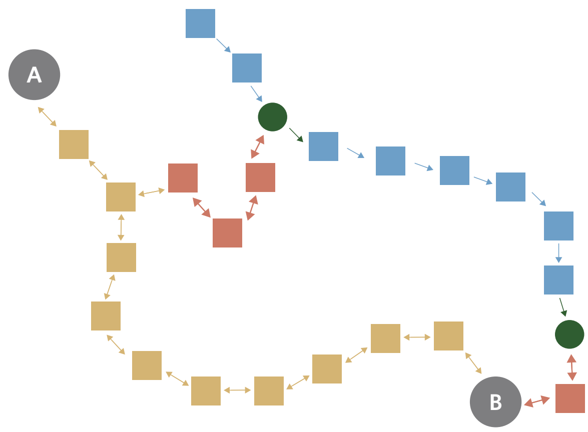


Figure 4b. Graph Data of Transportation Network



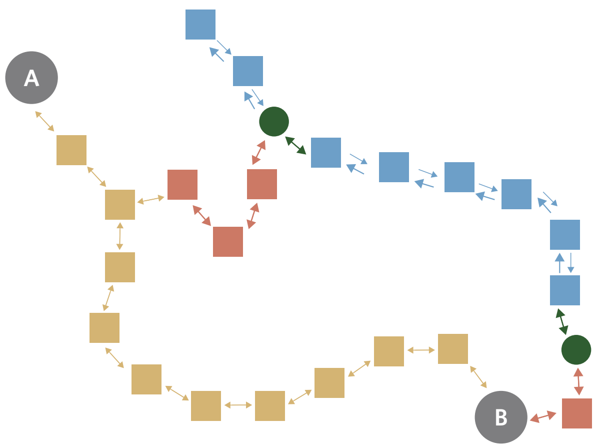
Transportation Modal Segment

Transportation Costs (the arrows stroke represent the transportation cost between sections: the thicker the arrow, more expensive is the transport). The color of the arrow represent the type of transportation.

Note: *This figure presents two markets – A and B – connect by a road and a water way (4a). This transportation network is converted to a graph (4b). Notice that the cost of moving from a port to a waterway is different then the other costs (the yellow line), representing the flexibility of the application in incorporating different loading fees data on the transportation cost model.*
Source: *CPI/PUC-Rio, 2023*

Notice that in this specific configuration, it is only allowed to travel downriver. If there is available data on heterogeneous costs of travelling up and down the river, it can be added to the data structure, as in Figure 5, where the blue arrows pointing upriver are thicker than the ones pointing downriver.

Figure 5. Adding More Elements in Transportation Model



Waterway

Small Road

Market

Port

Transportation Modal Segment

Transportation Costs
(the arrows stroke represent the transportation cost between sections: the thicker the arrow, more expensive is the transport). The color of the arrow represent the type of transportation.

Note: *This figure represents the same transportation network of Figure 4, except that the cost of travelling upriver is added, with this cost being higher than the cost of travelling downriver.*
Source: *CPI/PUC-Rio, 2023*

The same way that a waterway and two ports were added, it is possible to add railroads, airports, subways, and other types of infrastructure. It is possible to upgrade existing projects by lowering the cost (downsizing the arrows). This allows the methodology of market access to be employed not only to assess the area of influence of the construction of projects, but also the area that will be affected by regulatory changes, such as subsidies or a price cap. All that is needed is the outline of the project and data to assign the cost of travelling by the project.

BRIDGE: A COMPARISON OF TWO METHODOLOGIES

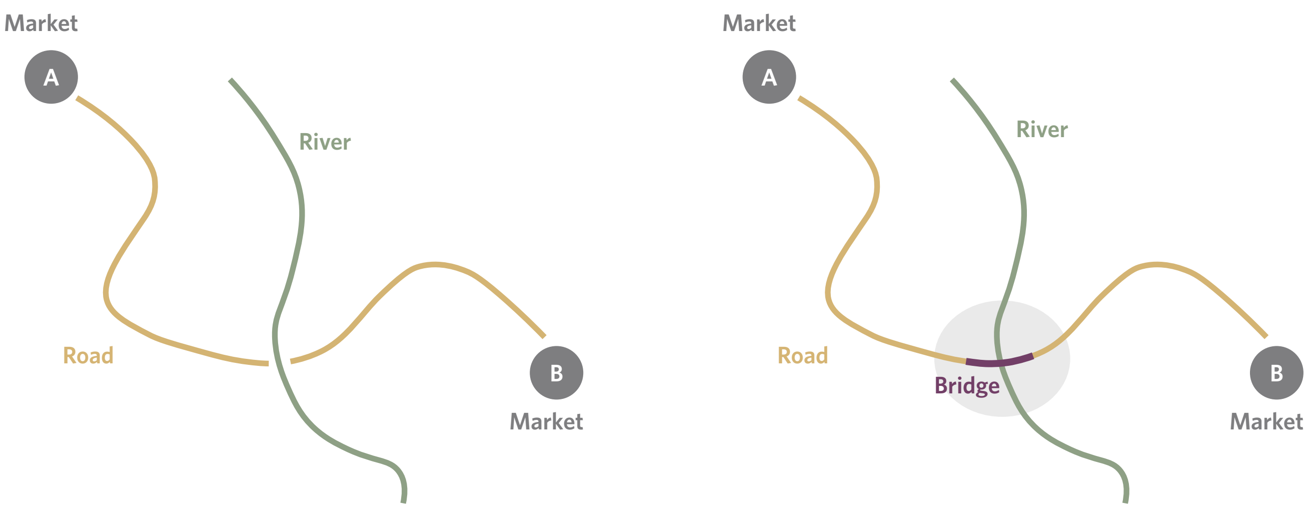
The example of the construction of a bridge clarifies the difference between using buffers and thresholds to determine the area of influence and using the market access approach. In the market access methodology, a bridge is just another structure to affect transportation cost. If a small bridge has a huge impact on transportation cost, it will have a huge impact on market access and therefore on land use. In a mechanical methodology where the outline of the project is the relevant feature, a small bridge will always have a small impact on land use.

Consider the example of Figure 6, where markets A and B are not connected due to the presence of a river. In that case, the road depicted is useless for the trade between markets A and B. Nonetheless, if a bridge is built, A and B are instantly connected. An area of influence determined only by the geographical distance to the new project, of the bridge, as in Figure 6B, may fail to account for the fact that all the path between A and B will be affected by the newly constructed bridge. The bridge will effectively change the market access of A and B, causing changes in the land use of both regions.

Figure 6. Restricted Area Restrita for Bridge

Figure 6a. Unconnected Markets

Figure 6b. Markets Connected by a River

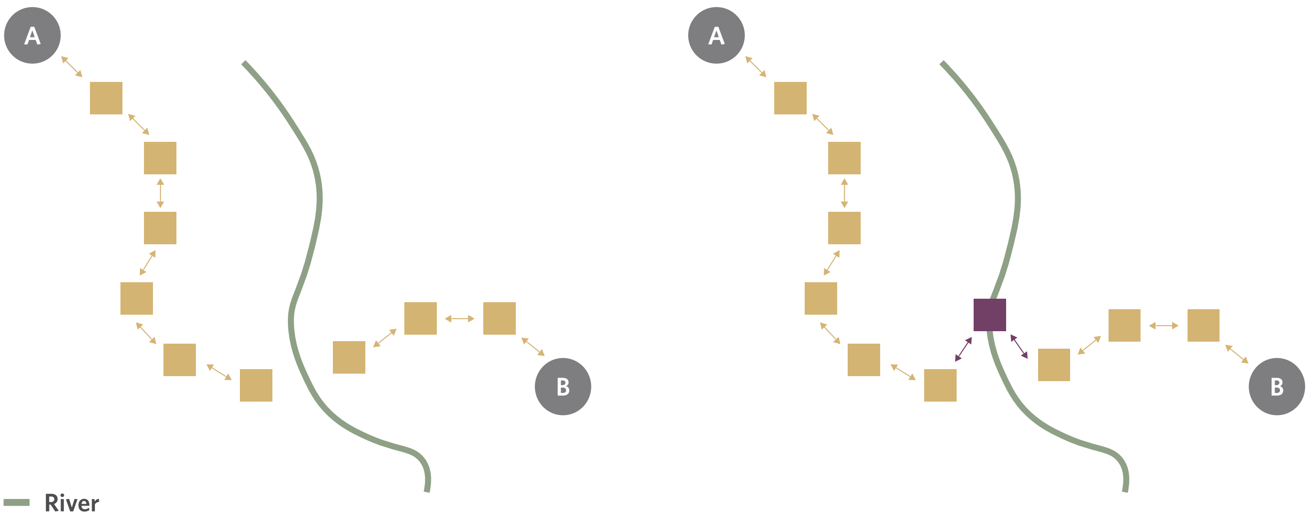


Note: *This figure shows two markets – A and B – that are not connected, due to a river (6a). The construction of a bridge (6b) allows for the connection of both markets. A methodology for delimiting the area of influence that only accounts for the outline of the new project could draw an influence area as in (6b), ignoring that the entire road connecting markets A and B will be affected by the construction of the new bridge.*
Source: *CPI/PUC-Rio, 2023*

Figures 7 illustrate how a bridge can be incorporated into the network. It is even possible to model a toll, by assign a different cost for moving across the node representing the bridge.

Figure 7. Building a Area of Influence for a Bridge

Figure 7a. Unconnected Markets (Graph) **Figure 7b.** Markets Connected by a River (Graph)



River

Bridge

Transportation Modal Segment

Transportation Costs
(the arrows stroke represent the transportation cost between sections: the thicker the arrow, more expensive is the transport).

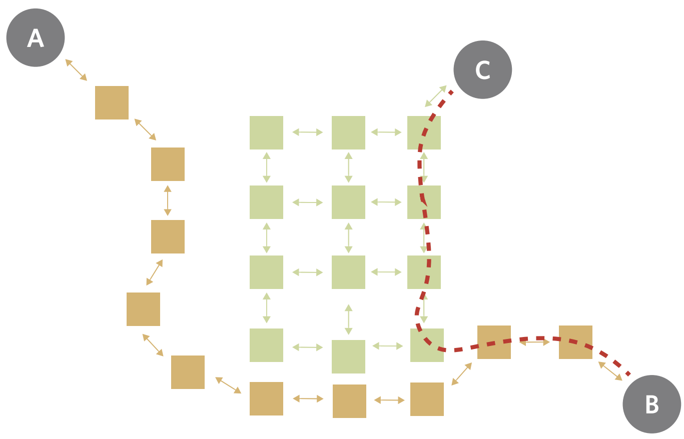
Note: *This figure shows how a bridge would be added to the graph (network) data. Notice that the arrows (edges) connecting the bridge to the roads have a different color, representing that it can be modeled an specific cost for the use of the bridge, as with a toll for example.*
Source: *CPI/PUC-Rio, 2023*

FISHBONE PATTERN

In the literature, the fishbone pattern refers to roads (legal or illegal) that are created as a result of the arrival of a new road. The crucial aspect determining the presence of this pattern is whether the surrounding regions of a new arrived road has access to that road. The access of surrounding regions may depend on a range of factors: law enforcement, topography, and characteristics of the project. Figure 8 shows this distinction. Suppose the construction of a road happens to be near a protected area, represented by market C. The crucial question is: can this area access and be accessed by the road? If it can in some points, due to lack of oversight for example, then these pixels of the protected area will be part of a possible minimizing cost path and part of the markets as well, effectively creating new paths which can be interpreted as roads.

In Figure 8 the dashed red line represents a path that leverages the presence of the road to connect markets, effectively inaugurating a path that would not exist without the road.

Figure 8. Fishbone



Protected Area

Markets

Transportation Modal Segment

Transportation Costs (the arrows stroke represent the transportation cost between sections: the thicker the arrow, more expensive is the transport).

"New" Road (the dashed red line represents a path that leverages the presence of the road to connect markets, effectively inaugurating a path that would not exist without the road.

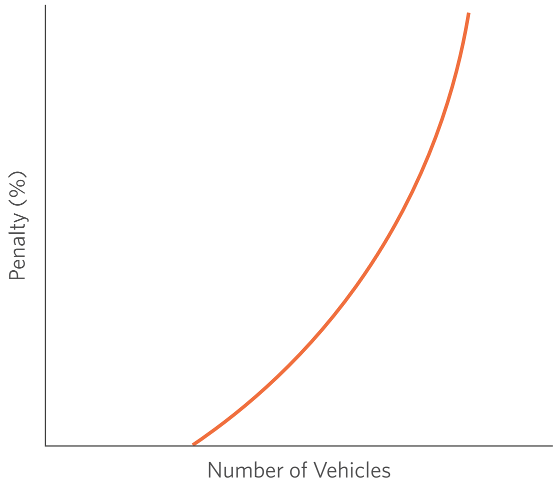
Note: *This figure shows how a new path (the dashed red line) may appear as the result of the construcition of a road connecting markets A and B. This is a representation of the mechanism that creates the fishbone pattern.*
Source: *CPI/PUC-Rio, 2023*

A NOTE ON CONGESTION

An application that allows for congestion costs would require considerably more data and computation capacity. In a model with congestion, the cost of moving across a road, for example, depends on how much the path is being used. To do this, two steps are necessary.

First, it is necessary to have a function – estimated or calibrated – that connects a measure of how much the path is being used with a penalty on the cost to traverse the pixel. Figure 9 shows an example, where there is no congestion cost up to a threshold of vehicles, from which the penalty is exponential. Second, the penalty affects how much the path is being used (the number of vehicles) which affects the penalty back. Thus, this relation needs to be considered in equilibrium. This is done using an iterative procedure: start without a penalty and measure the use of the path, apply the penalty function on the pixels, and measure again the use of the path. Repeat this process of measuring and applying the penalty until convergence. This will give the equilibrium state of optimal paths in a setting with congestion.

Figure 9. Congestion Cost



***Note:** This figure illustrate a possible penalty function for congestion in transportation infrastrcuture. After a threshold of vehicles using the structure, the cost increases exponentially with the number of vehicles.*
***Source:** CPI/PUC-Rio, 2023*

MARKET SIZE

To build the market access variable the size of each market can be represented in a variety of ways, such as population, income, or production. It is also possible to use proxies of economic activity, such as nighttime lights (Addison and Stewart 2015).

Table 2 presents possible data sources for the market size variable.

Table 2. Market Size Data

Content	Source	Coverage	Spatial Level
Population	IBGE Demographic Census	Decennial from 1980 a 2010	Municipality
Production	IBGE Municipal GDP	Yearly 2002 - 2019	Municipality
Nighttime lights	Zhao, Chenchen; Xin Cao, Xuehong Chen, and Xihong Cui. A Consistent and Corrected Nighttime Light dataset. (CCNL 1992–2013) from DMSP-OLS data". *Scientific Data* (2022). bit.ly/NighttimeLight.	Yearly 1992 - 2013	Pixel of 1km
Nighttime lights	Mills, Stephen; Stephanie Weiss e Calvin Liang. "VIIRS day/night band (DNB) stray light characterization and correction". In: Butler, James J., Xiaoxiong (Jack) Xiong, and Xingfa Gu. *Earth Observing Systems XVIII*, vol. 8866, 549-566. San Diego: SPIE, 2013.	Yearly 2014 - 2022	Pixel of 460m

***Note:**This table shows potential data sources to build the market size measure.*
***Source:** CPI/PUC-Rio, 2023*

The market size data is usually available from decennial Census data at the municipal level. Satellite data on nighttime lights can give more granular data both at the spatial and temporal dimensions. The granularity of the data for the market size will determine the granularity in which the area of influence can be built. For example, with data of population at the municipal level, the impact of an infrastructure project in deforestation will be computed at the municipal level.

Nonetheless, more granularity is not necessarily desired. The market size variable should reflect a market, that is, a region with buyers and sellers. For example, a plot of land is rarely a market and therefore using data at the plot level may result in unnecessary complexity. An aggregation of information at the state level (as in figure 2) can be seen as a group of multiple markets and therefore this level of aggregation may discard useful information.

MARKET ACCESS

With the computed transportation cost and market size data, the market access can be measured as (Donaldson and Hornbeck 2016)

$$MA_m = \sum_{m'} \frac{N_{m'}}{(\tau_{mm'})^{\theta}}$$

Where MA_m denotes the market access of market m, $N_{m'}$ denotes the market size of market m', $\tau_{mm'}$ denotes the transportation cost between markets m and m', and θ is a scale parameter. This measure has been extensively applied in economics (Eaton and Kortum 2002; Redding and Venables 2004) to study welfare and production impacts of trade and infrastructure.

The interpretation is that all markets exert an economic force on each specific market, but this force is diminished the higher is the cost to access that specific market. It is also commonly referred to as a **gravity model**, in analogy with models in physics where each body is affected by the gravity generated by all other bodies, but this force is diminished by distance.

The θ is a scale parameter commonly known as the trade elasticity, which captures how strongly a market is penalized by the cost to be accessed. This value can be calibrated with estimates found in the literature. Table 3 describes some values estimated in the economics literature.

Table 3. Values for Exchange Elasticity

Reference	Preferred (θ)
Eaton, Jonathan and Samuel Kortum. "Technology, geography, and trade." *Econometrica* 70, no. 5 (2002): 1741-1779.	8.28
Donaldson, Dave and Richard Hornbeck. "Railroads and American economic growth: A "market access" approach." *The Quarterly Journal of Economics* 131, no. 2 (2016): 799-858.	8.22
Caliendo, Lorenzo and Fernando Parro. "Estimates of the Trade and Welfare Effects of NAFTA." *The Review of Economic Studies* 82, no. 1 (2015): 1-44.	8.64
Costinot, Arnaud, Dave Donaldson, and Ivana Komunjer. "What goods do countries trade? A quantitative exploration of Ricardo's ideas." *The Review of economic studies* 79, no. 2 (2012): 581-608.	6.53
Simonovska, Ina and Michael E. Waugh. "The elasticity of trade: Estimates and evidence." *Journal of international Economics* 92, nº 1 (2014): 34-50.	4.10
Head, Keith and Thierry Mayer. "Gravity Equations: Workhorse, Toolkit, Cookbook". In: Gopinath, Gita, Elhanan Helpman, and Kenneth Rogoff. *Handbook of International Economics*, vol. 4. Amsterdam: North-Holland, 2014.	6.74

Note: *This table summarizes estimated values for the trade elasticity (θ) in the economics literature.*
Source: *CPI/PUC-Rio, 2023*

DEFORESTATION

One of the key benefit of this model is that it allows decision makers to better understand the potential environmental impacts of infrastructure development beyond the trajectory of the project itself. In other words, incorporating deforestation data allows us to understand the broader deforestation impact that comes from expanding markets.

Once the market access is built, the next step is to connect it with deforestation data. This is done by estimating a statistical relation between the market access variable and land use conversion. The deforestation data needs to be aggregated at the same level of the market access variable, that is, if the market access is at the municipality level then the deforestation data needs to measure the deforestation of each municipality.

Table 4 presents possible data sources for the deforestation variable.

Table 4. Deforestation Data

Source	Coverage
INPE Prodes	Yearly 1988 - 2021
MAPBIOMAS	Yearly 1985 - 2021
IBGE Agricultural Census	Decennial 1980-2020
Hansen - Global Forest Change	Yearly 2000 - 2020

Note: *This table shows potential data sources to build the deforestation measure.*
Source: CPI/PUC-Rio, 2023

ESTIMATING THE RELATION BETWEEN MARKET ACCESS AND DEFORESTATION

The objective is to understand the impact that an increase in market access has on deforestation. To do that, it is necessary to estimate a statistical model linking both variables. This statistical model depends on the data available. The spatial level of the data – municipal or census tract data for example – determines the granularity in which deforestation can be predicted. The temporal dimension – whether there is more than one year of observed market access and deforestation – allows for a more sophisticated model where specific characteristics of each market can be considered.

One simple statistical model is a log-linear model connecting the cumulative deforestation to the market access

$$\boldsymbol{log\,Defo_m} = \alpha + \boldsymbol{\beta}\ \boldsymbol{logMarketAccess_m} + \boldsymbol{erro_m}$$

The estimated $\boldsymbol{\beta}$ coefficient gives the percentage effect that a 1% increase in market access has on deforestation.

With the estimated $\boldsymbol{\beta}$ parameter, any change in the transportation infrastructure can be translated into deforestation. If a new road, for example, generates a change in market access of $\%\Delta\boldsymbol{MarketAccess_m}$ in each market $\boldsymbol{m}$, then the deforestation change can be computed as:

$$\%\Delta\boldsymbol{Defo_m} \triangleq \boldsymbol{\beta}\ \%\Delta\boldsymbol{MarketAccess_m}$$

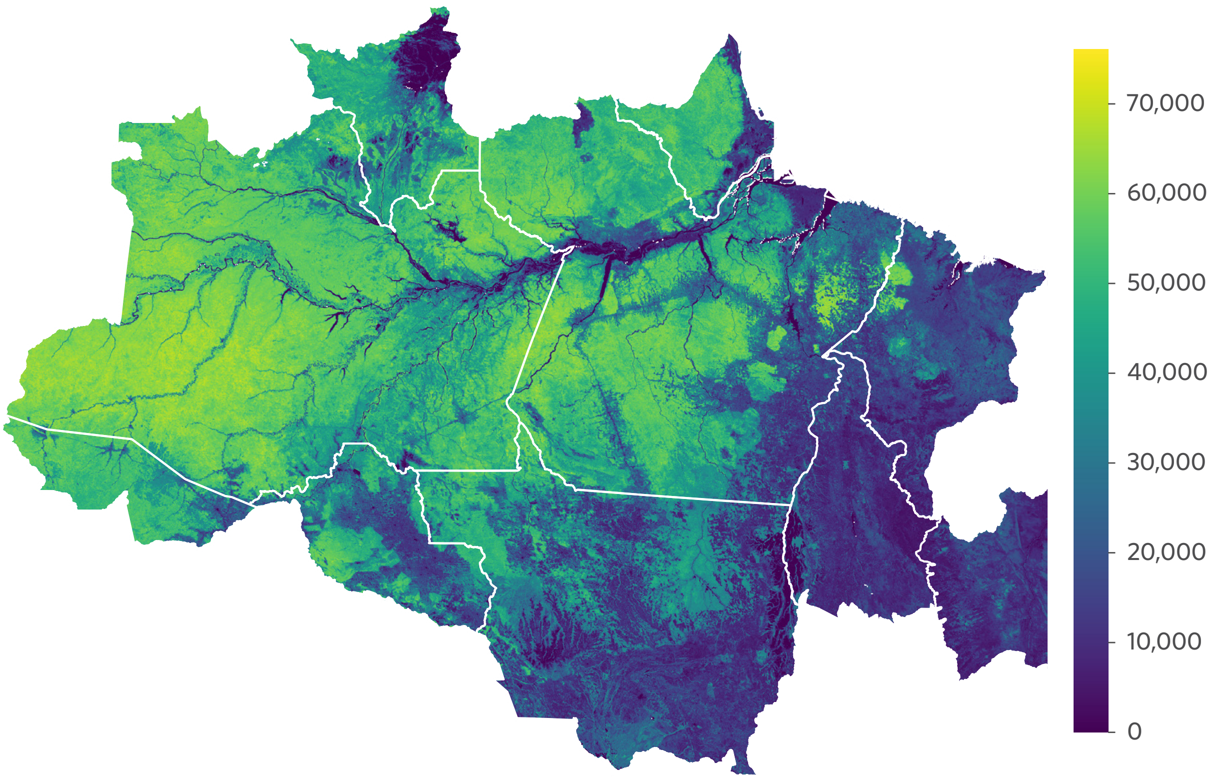
CARBON FOOTPRINT

Once the deforestation footprint is assessed, it possible to overlap the deforestation data with carbon stock data to measure the carbon footprint of the project.

A simple method is to multiply the deforestation area by an average carbon stock in the Amazon. For example, the Amazon Fund (technical note nº 2093/2018-MMA) defines a potential CO_2 emission of 48,510 per km^2.

A more detailed analysis can overlap a map of deforestation areas with a map of carbon stock. Figure 10 shows a carbon density map (Baccini et al. 2012) , measured as potential CO_2 release per km^2. With a carbon density map, each deforested area will present a different carbon footprint, which allows for a better comparison of the environmental cost of different infrastructure projects.

Figure 10. Carbon Stock in the Amazon



Note: *This figure shows a map of CO2 density measured as potential CO2 release per km^2.*
Source: *CPI/PUC-Rio with data from Baccini et al. (2012), 2023*

APPLYING THE METHODOLOGY

This section presents a simplified example of how to go through all the steps presented in Figure 1. To keep it easy to visualize, the Brazilian state of Amapá and its infrastructure of roads are chosen as an illustrative example. Figure 11a shows the municipalities of Amapá – which represents the markets in this example – and the roads infrastructure. The example computes the deforestation footprint of a fictional road – the red line in Figure 11b. For more realistic case studies see the previous publications by CPI/PUC-RIO (Bragança et al. 2021; Araujo, Assunção, and Bragança 2020).

The first step described in Figure 1 is to compute bilateral trade costs between all the markets, in this case, between all municipalities of Amapá. To compute this transportation cost, data of state and federal roads as of 2010 is collected from the Ministry of Transportation.

The data in Figure 11a is converted to a graph, where the cost to traverse a node of road is set to be one and the cost to traverse a node outside a road is set to be 100. This choice of values may be seen as if it were allowed for agents to travel by foot by paying a significantly high cost. For an optimal path algorithm, the magnitude is not relevant, but rather the proportion among different costs. The transportation cost is then normalized so that the average transportation cost is 10%, reflecting an average logistical cost of agricultural costs in Amapá. The result is shown in Figure 11c, where for each municipality (row) there is data for the transportation cost for all other municipalities (columns).

Figure 11. Transportation Cost in Different Scenarios

Figure 11a. Amapá Roads

Figure 11b. A New Road in Amapá

Figure 11c. Bilateral Cost

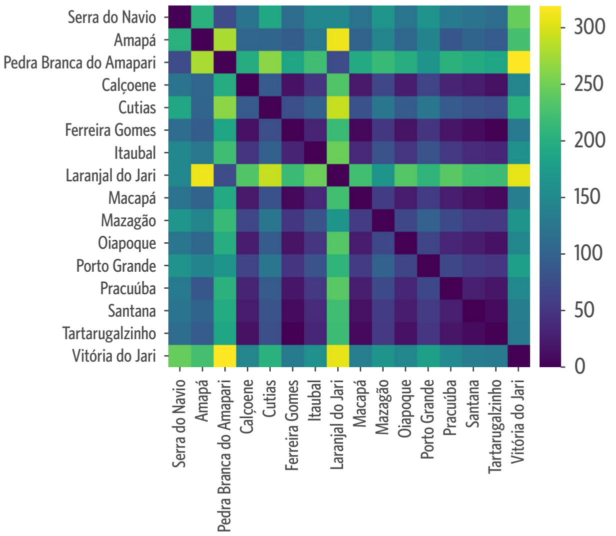
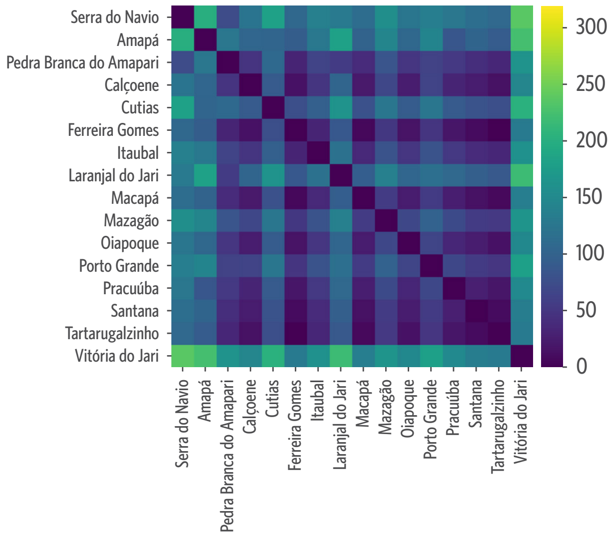


Figure 11d. Bilateral Cost with New Road



Note: *This figure shows the municipalities of the state of Amapá – the markets in this example – and the state infrastructure of roads (11a); a counterfactual road is built, shown as the red line on the map (11b); the bilateral trade cost among all municipalities in Amapá is shown in (11c), where the pair (row, column) denotes the transportation cost of going from municipality row to municipality column; the new road changes the transportation cost, generating a new matrix of bilateral trade costs (11d).*
Source: *CPI/PUC-Rio with data from Censo IBGE (2010) and Ministry of Transportation, 2023*

The second step described in Figure 1 is to gather data on the market size and compute the market access. In this example population data is from the 2010 demographic census, described in Figure 11a. With the market size data, the market access can be computed by simply multiplying the matrix of Figure 10c and the population data. The result is shown in Figure 11b. Here, the market access is normalized, so that the highest value is set to one.

The third step is to gather data on deforestation and to estimate a statistical model of deforestation and market access. Deforestation data is the accumulated deforestation of each municipality in the state until 2010 calculated by the MAPBIOMAS project. Figure 12c shows the data. The simple model of expression 1 is estimated. Figure 12d shows a correlation plot of the log of deforestation and market access, with the line showing the fitted model. An increase of 1% in the market access is associated with an increase of 0.7% in the accumulated deforestation.

Figure 12. Market Access and Deforestation

Figure 12a. Population

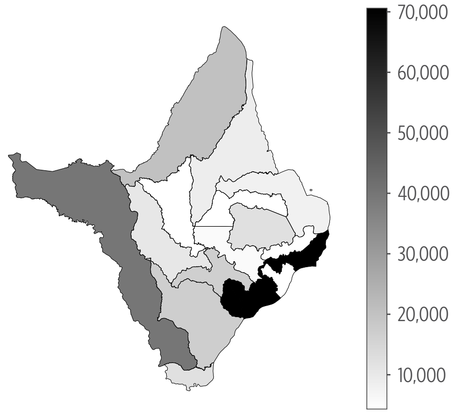


Figure 12b. Market Access

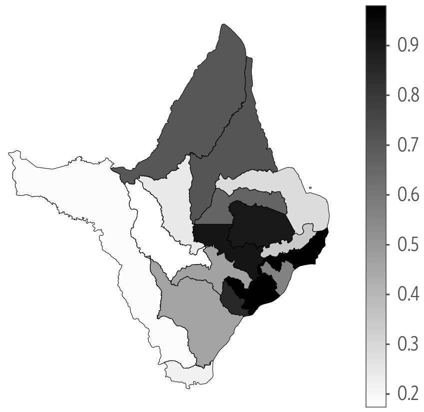


Figure 12c. Deforestation

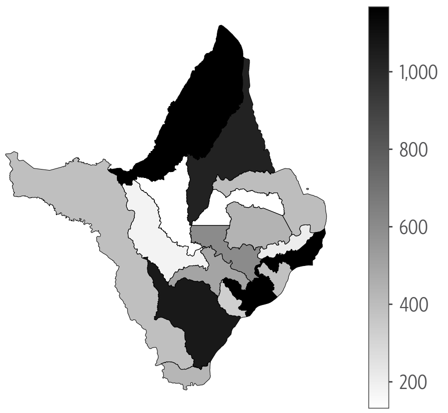
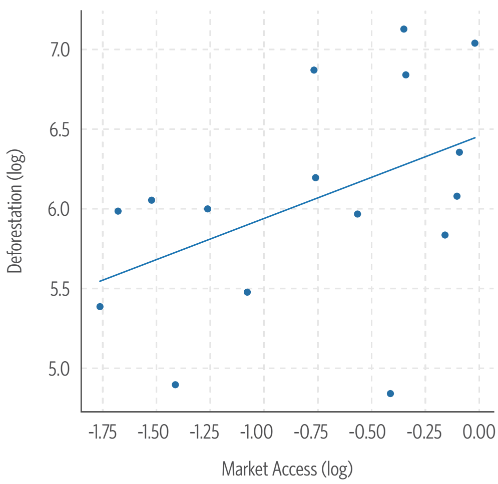


Figure 12d. Market Access and Deforestation



Note: *This Figure shows the population distribution, the market size in this example (12a); the calculated market access (12b); accumulated deforestation (12c); the relation between (log of) market access and (log of) deforestation (12d).*
Source: *CPI/PUC-Rio with data from Censo IBGE (2010) and Ministry of Transportation, 2023*

The final step is to propose a change in the infrastructure network. In this example, a new road is created, shown as the red line in Figure 11b. With this new road, a new matrix of bilateral costs is computed, shown in Figure 10d. The new road significantly lowers the transportation cost in the state, as seen by comparing Figures 11c and 11d.

With the new bilateral cost matrix and the market size data, a new market access is computed, shown in Figure 13a. Finally, the estimated model of Figure 12d can be applied to predict the deforestation caused by this change in market access, as shown in Figure 13b.

Figure 13. Impact of a New Road

Figure 13a. Market Access

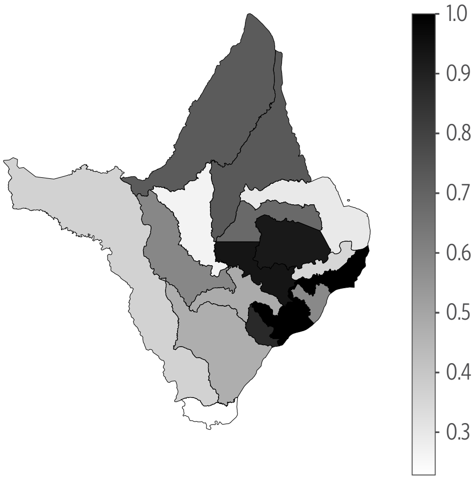
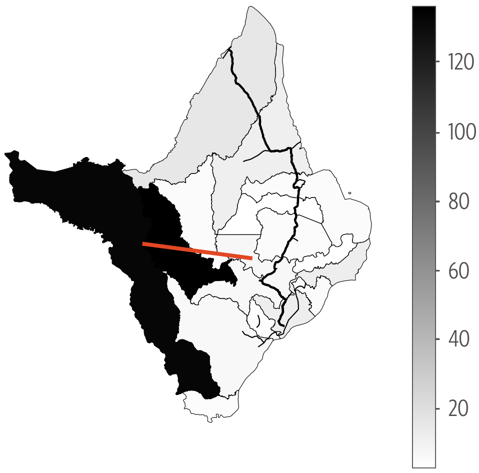


Figure 13b. Deforestation



Note: *This Figure shows the market access after the construction of the new road (13a) and the estimated deforestation (13b).*
Source: *CPI/PUC-Rio with data from Censo IBGE (2010), Ministry of Transportation and MAPBIOMAS, 2023*

In this example, the road is associated with a deforestation footprint of 368 km2, approximately 2.2 km2 of deforestation for each km of road.

Using the measure of potential CO_2 emission of 48,510 per km2, the project is estimated to release 17 million tons of CO_2.

CONCLUSION

This document compiled information from different sources in order to build a blueprint of how to assess the environmental footprint of infrastructure projects. The market access methodology considers the economic and social dynamics when drawing the impacted area. This methodology can be employed together with different methodologies to delimit a more precise area of influence.

The market access methodology requires measuring three components: transportation costs, market size, and deforestation. Market size and deforestation can be readily accessed in the data sources provided in tables 2 and 4. The transportation cost data, on the other hand, needs to be built with data on the transportation network. Converting the transportation network into a graph allows for a flexible specification of different modes of transportation and different interventions that may affect transportation cost, such as, roads pavement condition, tolls, and loading fees.

With these three components, a statistical model recovers the effect that an increase in market access has on deforestation. The final step is to propose a change in the infrastructure network, compute the market access in this counterfactual scenario, and apply the statistical model to estimate the area of influence of the proposed change.

The application of this methodology allows the government, civil society, and private sector to estimate ex-ante the impact of transportation infrastructure, allowing for a better assessment of cost and benefits and ranking of the portfolio of available projects, identifying those that will be affected and designing policies of compensation and mitigation.

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