# Climate Change Impact Assessment on the Temporary Transport Infrastructure

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## Abstract

Global warming is already impacting the activities of many sectors of the economy. We studied this influence on forestry, particularly, temporary road infrastructure used for logging in winter. The goal of the paper is to investigate the relationship between the wood removal volumes and timing of operations temporary infrastructure in the different climate zones. We tested hypotheses for the dependence of wood removal on: a) annual allowable cut; b) road density; c) road density except wetlands.This paper used the data covers 1999-2009 and the territory of the Republic of Karelia. We examined two types of winter temporary road (ice roads and snow-ice roads) and two versions of their lifetime (earlier and later construction). The investigation made use of panel model with the fixed effects. Also we used one-way analysis of variance (ANOWA) to explain the territorial effects. Our main findings are that the volume depends on the type and lifetime versions of winter roads. One day winter road operation increases monthly volume of wood removal by 1485-1746 m3. We have determined the territory that is the most vulnerable to climate warming. This approach is suitable for identifying areas where should be increase road density to avoid deforestation. It can be applied to justify the state co-financing of forest road construction and to develop adaptation measures for forestry and forest industry of to climate warming.

**Keywords:** climate change, logging, wood removal, winter roads, forest roads, modeling.

## Introduction

Currently there is a lot of evidence of changes in the planetary climate. The discussion on this topic has long gone beyond the scientific community and become part of meetings the heads of leading countries of the world. In 2017 the President of the United States stats the withdrawal from the Paris agreement under the UN framework Convention on climate change. The subsequent reaction of the world community reaffirmed that the problem of climate change is global.

The opinions of experts differ in their forecasts of climate change, and effects of anthropogenic factors. Most of the (Cook, 2016) accept the hypothesis of the presence of anthropogenic impact on the climate, according to its the increase in emissions of carbon dioxide provokes global warming (Anderson et all, 2016), (Hulme, 1999), (Kjellstrom, 2016), (Love,2010), (Maibach, 2015), (Zhang, 2015). A number of international organizations follow this hypothesis (Shaw,2015)]. There are studies that deny this hypothesis (Kegwin, 1996), for certain areas of the Earth predicted cold snap. The existence of diametrically opposed views on climate change emphasizes the shortcomings of the current climate models (Larminat, 2016). However, variety views contributes to elaboration of different scenarios of weather regimes, which allows to assess the consequences of climate change for the national economies in specific regions. In this regard, studies on the relation between weather conditions and the results of economic activities different types are critically important and relevant.

## Climate Change and Transportation Infrastructure

The most visible form of climate change impact on transport infrastructure is the increase the frequency and intensity of extreme weather events (Love, 2010), (Travis, 2014), leading to economic losses (Porfiriev, 2015). The large scale flooding in the Russian Far East in 2013 resulted in damage to transport infrastructure amounted about 30 billion rubles. A less visible consequence of climate change for transport infrastructure is a gradual change of the environment, which impact is dual nature. On the one hand, for some objects of transport infrastructure appear additional opportunities for territorial expansion or prolongation of the season of use. Climate warming in the Arctic and the North sea route opens prospects for the navigation of Arc7 class ships without icebreaker escort (Komkov, 2016). On the other hand for other objects of transport infrastructure appear completely opposite effects. Warming in the Arctic leads to decrease bearing capacity of permafrost (Stern), which leads to deformation of the foundations of houses, railways roads, gas pipelines and oil pipelines.

Temporary transport infrastructure is used because of the specificity of the geographical position and economic activities carried out in separate regions. It makes it possible to work in remote areas, where air transportation is the only alternative. In some cases there is no alternatives. It is obvious that the infrastructure functioning only in certain weather conditions, more susceptible to the effects of climate change. In this study, we focused on snow-ice and ice roads (winter roads), which is widespread in Russia, Canada and USA (Alaska).

The impact of winter roads on the Russian economy remains understudied issue. By contrast, in Canada the winter roads volume of traffic is one of the basic indicators, which is necessary to adequately estimate of the impacts of climate change on the local economy (Lonergan et all, 1993). For example, winter road Tibbit – Contwoyto to service the diamond mines annually moves goods worth $ 500 million [18]. The Northern Canada experience shows that reducing the usual time of winter roads operation leads to higher production costs, the rising cost of basic commodities, reduced availability of services and increasing social tensions. Canadian researchers note that the scientific literature on the estimates of these effects are not vastly and most of the necessary information provided in the reports of consultants, local self-government or the media (Prowse, 2009). For example, halving the time of winter roads operation in Northern Manitoba in winter of 1998 led to additional government expenditures on fuel and food of more than 15-18 million dollars. At that time, roads could not be built to 12 settlements. These expenditures should also be added to the part of seasonal incomes which were lose. Were no wages for the roads construction, were no opportunities to realize the products of hunting and trapping at more profitable prices in the South of the province. In 2006, the communication of the winter road Tibbit – Contwoyto was interrupted for almost a month. According to the diamond Corporation Rio Tinto these natural anomalies forced to use air transport to deliver more than 24 thousand tons of cargo and fuel, which led to additional expenditures in the tens of millions of dollars.

More frequent cases of warm winters require a transformation from temporary to permanent infrastructure. This is important even given the fact that operating costs of maintaining roads in permafrost areas in North America 10 times more than the cost than the costs for similar roads in the southern regions. The state in Canada took steps to increase adaptive capacity of winter roads. The main measures of modernization were the transportation of roads away from areas of reservoirs and rivers, to explore possibilities of construction of land routes (to save on air transport, reducing construction difficulties).

## Seasonal Transport Infrastructure in the Forest Sector in the Climate Change Context

In the regard with the above the comparison of transport road networks in the forest sector for two similar territories like the Republic of Karelia (one of the subjects of the Russian Federation) and the Republic of Finland clearly shows the different. Both territories have the same natural and climatic conditions, but Finland has a high density of forest roads, which provides year-round access to forest resources in all areas, and also allows promptly to suppress forest fires. In Karelia and in other forest subjects of the Russian Federation loggers due to low density roads of year-round use have to get to hard to reach areas of the forests in the winter and depend on favorable weather conditions. During a warm December in 2006, 2007 and 2011, the loggers were not able to build the roads. This situation had led woodworking enterprises of Karelia which did not provide production lines by raw materials in the proper amount.

The idea of reducing the season of use winter roads in the forest sector under global warming has been presented in several publications (Goltsev, 2013), (Chugunkova, 2016). In particular was studied the relationship between weather conditions and load-carrying capacity of different types of roads. With the help of GIS-technologies were identified the forests which are available only in the winter period. Next on the basis of characteristics of forests were calculated the timber stock and volume of allowable annual removal (Chugunkova, 2016).

There are different views on the question of suitable conditions for winter road functioning. Goltsev V. and Lopatin E. assumed that the roads start to use after the temperature drops below -5°C and maintaining that temperature more than 5 days. End of using comes when the air temperature exceeds 0°C over 5 consecutive days (Goltsev, 2013). The study in the other subjects of the Russian Federation (Krasnoyarsk region and Irkutsk region) suggested to subtract from the obtained period 7 days, because, according to the author, building of forest winter roads needs this time period (Chugunkova, 2016). In this work the technical parameters for starting of the winter road functioning are included a presence of snow cover height of 10 cm and the sum of temperatures after transition through 0°C should reach the range from -100 to -130°C. The authors to exclude days with extreme weather conditions (low temperatures, high wind speeds) from the terms of loggers working. In addition, type of winter road determines the temperature regime for timber removal stop. For the roads with snow coating the critical temperature is from -4.5 to -4°C; for ice-and-snow coating is from -2,7 to -1,8°C; for ice coating is from +1 to +2°C (Shhegoleva, 2008).

We're proposing to identify the dependency of logging sector to weather conditions. So, the aim of our study is evaluation the relationship between the actual volume of timber removals and the timing of the operation of the winter roads. The realization and quantification of this dependence allows to evaluate the significance and strength of this relationship and to highlight areas more or less resilient to climate change.

## Data and Methods

The first task was to divide the territory of the Republic of Karelia into several parts or zones. It was critical to have the necessary data for all zones. The climatic zones were formed taking into account the administrative boundaries (tab. 1).

**Table 1: The Climatic Zones**

| Name (in the models) | Municipal district | The weather station | Area, sq.km. | The share of wetlands, % | Calculated cutting area, thsd m3 |
|---|---|---|---|---|---|
| North (Nor) | Louhi, Kalevala, Kostomuksha | Kalevala | 39858 | 19 | 1397,9 – 2266,9 |
| Center (Cen) | Muezerskiy, Belomorsk, Segezha, Medvezhiegorsk | Padani | 54875 | 24 | 2052,8 – 2421,8 |
| Southeast (SE) | Pudozh, Kondopoga, Prionezhsky, Pryazhinsky, Olencki, Petrozavodsk | Petrozavodsk | 33667 | 12 | 3181,4 – 3356,5 |
| Southwest Ladoga Region (SWL) | Sortavala, Lahdenpohja, Pitkyaranta | Sortavala | 6655 | 5 | 680,3 – 733,7 |
| Southwest Suoyarvi Region (SWS) | Suojarvi | Tohmajarvi, (Finland) | 13739 | 20 | 817,1 – 873,4 |

Source: Statistical data

To transform climate data into the number of days of the winter road operation we used the technical parameters proposed by Shhegoleva, L.V. et al [22]. First we determined the start date of the winter road functioning then the date of the winter road destruction. And for each month counted the number of days of the winter road functioning. The work is carried out on all the public holidays except New Year. In addition, it is no timber logging in the days with extreme weather conditions. So were excluded days with average temperature below -30°C. The last assumption is due to thaws. The road does not disappear but ceases to be operated.

To estimation the model of panel data with fixed effects data grouped by season. In northern territories the climatic parameters reflecting the onset of winter can already appear in November. So the data generated starting November 1999 (the first timber logging season), and ending October 2000, as the result was formed 10 timber logging seasons.

With the help of the EViews program was estimate the following models to answer the question about influence of weather conditions on the removal:

$$V_{ij} = A_1 + C_j + B_1 \times IR\_el_{ij}, \qquad (1)$$

$$V_{ij} = A_2 + C_j + B_2 \times IR\_la_{ij}, \qquad (2)$$

$$V_{ij} = A_3 + C_j + B_3 \times ISR\_el_{ij}, \qquad (3)$$

$$V_{ij} = A_4 + C_j + B_4 \times ISR\_la_{ij}, \qquad (4)$$

Where Vij – the volume of timber removal for the i-th month in j-th zone; A1, A2, A3, A4 – general constants; Cj – are the constants that express the effect for the j-th zone; B1, B2, B3, B4 – coefficients show the significance of day operating of winter road; IR_elij, IR_laij, ISR_elij, ISR_laij – the number of days of usable in the i-month for ice (IR) and snow-ice (ISR) roads (the end _el shows early buildings of the roads (reaching -100°C after the transition through 0°C), the end _la – later buildings of the roads (reaching -130°C after crossing 0°C) in j-zone.

Every model as the source data used 5 series (number of climatic zones) for 120 observations (monthly data on the transportation and weather conditions from November 1999 to October 2009), the total number of observations is 600.

To explain the influence of factors which were not considered explicitly, but impact on the fluctuation of removal (coefficients A) arose the need to include in the models additional variables. A lot of indicators are not available in territorial aspect, so we were limited in the choice of methods of analysis and variety of factors. However, there were tested several hypotheses about the impact on the removal volume the following factors: 1) the availability of forest resources; 2) density of roads and swamped of the territories. These data have a different structure that is not suitable for inclusion in the model of panel data, therefore, to test these hypothesis we used methods of mathematical and nonparametric statistics.

The first hypothesis suggests a significant influence in the removal forests resources the volume of it stocks. As indicator of the availability of forest resources, was selected level of forest cutting approved by the state. With help by Statistica program was conducted the analysis of variance. The indicator of level of forest cutting was factor of clusterization (one-way ANOVA). For implementation of ANOVA in each period (month) separately data has been ranked. Depending on the level of the annual forest cutting each zones had gotten a rank: 1 – the highest level of the annual forest cutting, 5 – the lowest level of the annual forest cutting. The procedure was repeated for each period (120 periods) thus was formed a new data set, where the removal in each period was ranked based on the level of the annual forest cutting particular zone.

Similarly we checked the hypothesis about the impact of the conditions of transportation on the timber removal. We focused on density of regular roads, which enables logging regardless of climate conditions and seasonal transport infrastructure. The density were presented as density for all territory and as density for territory excluding swamped.

In the case of confirmation of the hypothesis about the significant influence of the cluster factor (the cutting level and density of roads) is assumed to estimate the strength and direction of the relationship through Spearman correlation coefficient. Thus, we find that the timber removal has a ranks from 1 to 496; the density of roads from 1 to 52; density of roads excluding swamped – from 1 to 52, the level of cutting is 1 to 70.

## Results and Discussion

According to the analytical data of the leading Business Insider news portal, the world Bank has made a The results of the estimation of depending for the volume of removal and the number of days of ice and snow-ice roads operation in terms of early and late onset of their operation are presented in table 2.

**Table 2: the results of estimations for models of panel data with fixed effects**

| The parameters of models | A variant of regressors | | | |
|---|---|---|---|---|
| | *IR_el* | *IR_la* | *ISR_el* | *ISR_la* |
| Constant A | 62.366 | 62.721 | 64.148 | 64.389 |
| Coefficient B | 1.485 | 1.522 | 1.723 | 1.746 |
| $C_{Nor}$ | -21.698 | -21.894 | -22.349 | -22.365 |
| $C_{Cen}$ | 29.999 | 30.152 | 29.728 | 29.794 |
| $C_{SE}$ | 55.346 | 55.097 | 55.499 | 55.463 |
| $C_{SWL}$ | -44.751 | -44.808 | -44.522 | -44.522 |
| $C_{SWS}$ | -18.897 | -18.547 | -18.356 | -18.371 |
| $R^2$ | *0.757* | *0.758* | *0.738* | *0.740* |
| *F-stat* | *369.186* | *376.134* | *338.790* | *342.273* |

Source: Authoring

For all models, coefficients and the constant are statistically significant. The value of the coefficient of determination shows acceptable explanatory capacity of models. The obtained results demonstrate that a single day operation of snow and ice winter road in the terms of late building adds to daily removal of 1746 m3, while for early building one day adds 1485 m3. This does not mean that snow-ice roads increased transportation of wood, in contrary, reduction the terms of its operation forces the loggers to increase the intensity of its use. It is important to note the fact that for the zones North (C_Nor), Southwest Ladoga region (C_SWL) and Southwest Suoyarvi region (C_SWS) are unaccounted in the model factors that reduce the timber removal. For zones Centre (C_Cen) and Southeast (C_SE), in contrast, are specific factors that lead to the excess of the timber removal over the value expressed in the coefficient A.

The results one-way ANOVA allow us to reject the null hypothesis that factors of clusterization: road density (dens_TR) and density of roads excluding swamped (no_swamp_dens_TR) and the level of cutting (Lecu), have no effect on the timber removal (Vij). We have a significant difference for the variables, since the estimated F-stat (dens_TR)=240.7, F-stat (no_swamp_dens_TR)=225.3, F-stat (Lecu)=155.6 exceeds the critical value of F-stat (4;∞)=2.37 (table. 3, 4, 5).

**Table 3: the results of one-way ANOVA for density of roads**

| The parameters | SS | df | MS | F | p |
|---|---|---|---|---|---|
| Free member of equation | 3354631 | 1 | 3354631 | 3850.540 | 0.00 |
| Dens_TR | 838761 | 4 | 209690 | 240.688 | 0.00 |
| Error | 518370 | 595 | 871 | - | - |

Source: Authoring

**Table 4: the results of one-way ANOVA for density of roads excluding swamped**

| The parameters | SS | df | MS | F | p |
|---|---|---|---|---|---|
| Free member of equation | 3354631 | 1 | 3354631 | 3698.116 | 0.00 |
| No_swamp_dens_TR | 817396 | 4 | 204349 | 225.273 | 0.00 |
| Error | 539736 | 595 | 907 | - | - |

Source: Authoring

**Table 5: the results of one-way ANOVA for the level of cutting**

| The parameters | SS | df | MS | F | p |
|---|---|---|---|---|---|
| Free member of equation | 3357476 | 1 | 3357476 | 3011.982 | 0.00 |
| Lecu | 693881 | 4 | 173470 | 155.620 | 0.00 |
| Error | 663250 | 595 | 1115 | - | - |

Source: Authoring

Relationship (according to the Spearman coefficient) between the removals and the acceptable level of cutting is strong, positive and statistically significant (the Spearman coefficient was 0.770). ANOVA discovered the relationship between of the acceptable cutting level and zonal coefficients estimated in the model panel data (table. 2). The smallest cutting level in three zones lead to the negative effect for zone and negative signs in model. Two zones are the most forest resourced have large absolute value and positive signs in model. Note that transport availability of the forests also influence hard.

For density of roads coefficient amounted to -0.388, for the for density of roads excluding swamped is -0.376. The relationship is moderate, moreover is negative. That is, the road density increasing parallel there is a reduction in removals. The obtained results are the consequence of the transition of the national market. When Russia rejected the planned economy then the forests close to existing transport infrastructure are proved to be the most commercially attractive and began to develop firstly. Subsequently this situation led to exhaustion. To confirm this opinion we can show the dynamics of achieve percentage of approved by the state level of cutting. During the study period in Karelia this indicator was at the level of 60-70%. And in recent years (2008-2009) the percentage dropped to 50% despite the fact that the state level of cutting increased. Apparently, the formal expansion of the resource base had not become a stimulus for increasing removal of timber. It may be that new forests were allocated in a distance from communication. In the result, we found zones which are having limitations due to insufficiency of roads.

In the Southwest Ladoga zone, where was the highest density road network (in Karelia) and the lowest percentage of wetlands, in 1995-1999, a small acceptable level of cutting is processed almost completely. Therefore, acceptable level of cutting is no limit factor for removal of this zone and increasing density of roads can no contribute to removal growth. Thus, one month of winter in this zone allows you to increase the volume of timber removal in 2,5 times.

In the Southwest Suoyarvi zone the achieve percentage was more than 85% only in 2007 began its decline. As the Ladoga this zone has a high density road network and a relatively small approved by state level of cutting at the same time has ample wetlands. One month of winter road operation allows to double the results of timber removal compared to a summer month. A similar effect is in North zone, which have lower density of the road network. Since in the North zone the average life of ice roads was

17 days longer than in Suoyarvi. This allows to conclude that in the case of climate warming, the greatest falling of timber removal will happen in this zone.

The Center and the Southeast zones was the least affected by climatic influence. The Center permanently does not reach the acceptable level of cutting (is the most swamped and penultimate in roads density but with a large cutting area). We can assume that in case of increasing the of roads density its rate of logging (the amount of the regional coefficient C_Cen) would be even greater. As in the case of Southeast zone, where the density of roads was higher due to less swamped (the highest regional coefficient C_SE). However, it should be noted that the main wood processing companies of Karelia are located in these zones, including ones having the financial capacity to maintain and develop the network of forest roads, purchase of modern logging equipment. This could contribute to an increase in regional factors, thereby reducing dependence on climatic factors.

## Conclusion

On data from 1999-2009 proved the existence of a positive relationship between the volume of timber removal and weather conditions suitable for operation of winter roads. The type of winter road determines the daily growth well of timber removal in the range from 1485 to 1746 m3. However, using of snow-ice roads less resistant to warming involves increasing the intensity of their use, and thus increase the costs of labor, maintenance of roads, to the repair of equipment and the reduction of the TBO (time between overhauls).

North zone was the most exposed to climate change, where due swamped and low density of the road network, one month of winter road operation allows to Karelian loggers to double the output of timber removal in comparison with the same period in the summer.

The global warming will reduce the time of operation of winter roads. And opportunities for intensive exploitation of forests close to existing transport infrastructure are largely exhausted. So for stable operation of the forest sector in Karelia and other territories it is necessary to find ways to invest in the development of year-round road infrastructure.

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