# THE ECONOMIC BENEFIT OF HEADROOM IN THE ICELANDIC POWER NETWORK

## Study for Landsnet

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# CONTENTS

# EXECUTIVE SUMMARY

When estimating the net-present value ("NPV") of publicly funded projects all resulting costs and benefits should theoretically be accounted for. For example, a project that is designed to increase network capacity should account for all the direct, measurable, costs of the project (such as cost of construction, maintenance, etc.) Ideally a NPV calculation should not only include the easily measurable, but also things of real value that are harder to measure. That includes uncertain, but conceivable, future costs. If any cost item is ignored then the NPV is overstated, which would risk investing in projects that are not worthwhile.

The same holds true for benefits. If a project is known to result in certain monetizable social benefits (e.g. by facilitating a private sector investment, which raises employment and wages), then all such benefits need to be counted for in order to reduce the risk of rejecting net-beneficial projects.

One key challenge in this context is how to deal with uncertainty, i.e. potential benefits which might potentially arise in the future as a consequence of an investment but are not guaranteed. This is particularly relevant when assessing the economic value that can be derived from having secure supply of electricity, beyond the predicted minimum ("headroom"). By providing headroom of electricity entrepreneurs can take advantage of the headroom and set up new, or expand current, businesses. Both stimulate economic activity and have the potential to increase employment and wages.

In this report we look at the current state of headroom in a number of localities[1] in Iceland and analyse the potential option-value of headroom. We find that:

- headroom has steadily declined since the early 1990's and today headroom is at historically low levels;
- there is good theoretical basis for thinking that headroom is associated with significant positive option-value; and
- economic data supports our theory that headroom is associated with real option-value.

Since headroom is at such low levels today – and correlation analysis suggests that headroom could lead to real future economic value – it seems appropriate for Landsnet to include the option-value of headroom as an indicator in future NDPs. This would reduce the risk of rejecting economically beneficial project in the future.

In summary, we suggest that Landsnet:

- include option-value of headroom as an indicator in future NDPs; and
- adbot as a rule-of-thumb: particularly prioritise investments in headroom capacity in localities where the ratio of headroom to peak-load demand falls below 1.

[1] Throughout this report we refer to municipalities and groups of municipalities as "localities". Because, some municipalities had to be grouped is explained in Annex A. The final list of localities is provided in Annex B.

# 1 BACKGROUND AND OBJECTIVE

Electricity is a key input into almost all modern production processes. Guaranteed availability of electricity – or security of supply – plays an important role in long-term economic development, growth and wellbeing.

Network capacity operators have an enabling function: by investing in enough delivery capacity, network operators can ensure that sufficient secure supply of energy exists in order to allow for new investments, which in turn might facilitate long-term economic growth and wellbeing.

Construction and maintenance of network capacity comes at a cost, such as investment and operation cost. Balancing the costs and benefits, to arrive at an efficient level of network capacity, is a constant challenge for network operators.

In this report we show that the provision of some level of spare capacity ("headroom"), at local delivery points ("localities"), increases the likelihood of future economic activity taking place in those localities. The existence of headroom increases the probability of future economic value being generated, and the expected future value can be quantified as option-value. The nature of option-value is such that option-value will exist, even if no investment takes place, simply through the enabling function of the option to provide opportunities. Omitting option-values in analysis of network-investment risks undervaluing the expected socio-economic benefit that is attached to network investment.

Option-value of headroom is relevant for the socio-economic analysis carried out by Landsnet, as a part of their network development plan ("NDP"). By not accounting for option-value in their cost-benefit analysis, Landsnet risks underestimating the benefit of investment in network capacity. Which could constrain economic development.

While the option-value of headroom can be expected to apply to a variety of essential infrastructure, it is particularly relevant for the power grid in Iceland compared to other geographies, for at least two reasons:

- the island network in Iceland is significantly less interconnected than the power grid in other countries and therefore are network constraints much more localised than in integrated system with the option for loop flows; and
- economic development in Iceland is highly dynamic with significant increases in power demand over relatively short periods of time.

In this report we investigate the current state of headroom in different localities in Iceland and set out a model for how option-value can be derived from headroom. Finally we combine the power data with local income data and find that the economic data adds support to our approach.

The rest of this report is organised in the following way.

- Section 2 looks at the current state of headroom, by different localities, and explores the potential consequences of the tight local headroom today.
- Section 3 starts by briefly setting out real option-value theory, in the context of headroom. It then progresses to set out a pragmatic model which explains how headroom could lead to increased long-term economic growth.
- Section 4 provides economic evidence in support of our theory.
- Section 5 provides a summary of the report, as well as it points out the key policy implications of our research.

# 2 STATE OF HEADROOM AT LOCALITIES

Since 1992 peak power demand has steadily risen across almost all localities in Iceland. Over the same period, new capacity has been added, but at a significantly lower rate than demand has been growing. The consequence of demand outpacing capacity has not been outages and price increases. Instead the headroom (electricity delivery availability beyond peak-demand) that existed in the 1990s has largely been exhausted. Majority of the localities that we looked at have significantly lower headroom today than they did in the 1990s. Headroom has reached such a low point in many localities today that it could constrain demand growth and limit economic development, in localities across the country.

In this chapter we provide descriptive analysis of peak-load demand and headroom across 18 localities, covering more than 85% of the population of Iceland, from 1992 to 2016.[2]

## 2.1 Data sources

To analyse historic development of peak-load demand and headroom Landsnet provided us with network data ("Landsnet data") for up to 69 substations across the country, describing:

- peak-load demand during the busiest hour of the year at each substation, individually ("local peak-load");
- peak-load demand during the busiest hour of the network as a whole ("system peak-load"); and
- estimated headroom, on the substation level.[3]

As we are concerned with the development of headroom within a geographical economic zone ("locality"), we aggregated and adjusted the data such that we could look at both peak-load/headroom development and economic indicators on a meaningful geographic level (see Annex A). In some cases, a single substation is connected to multiple municipalities, in other cases multiple municipalities are connected to a single substation and in a few cases multiple substations are connected to multiple municipalities. Once these issues had been addressed, the Landsnet data aggregated, checked and cleaned 18 localities were available for our analysis. These 18 localities account for more than 85% of the population of Iceland (see Annex A for detail).

## 2.2 Development of peak-load demand since 1992

Since 1992, peak-load demand has been on the rise in almost all localities in Iceland. The rise in local peak-load was likely driven by growing population and increasing demand for electricity to support a growing economy. Across all

2 For data quality reasons we could not include all localities. See Annex A and Annex B for detail.

3 The Landsnet data was provided on substation basis for 69 substations. Headroom data was only provided for 56 substations, as some substations didn't allow for meaningful analysis (for example when they were dedicated to single industry-customers or because they couldn't be mapped to single localities).

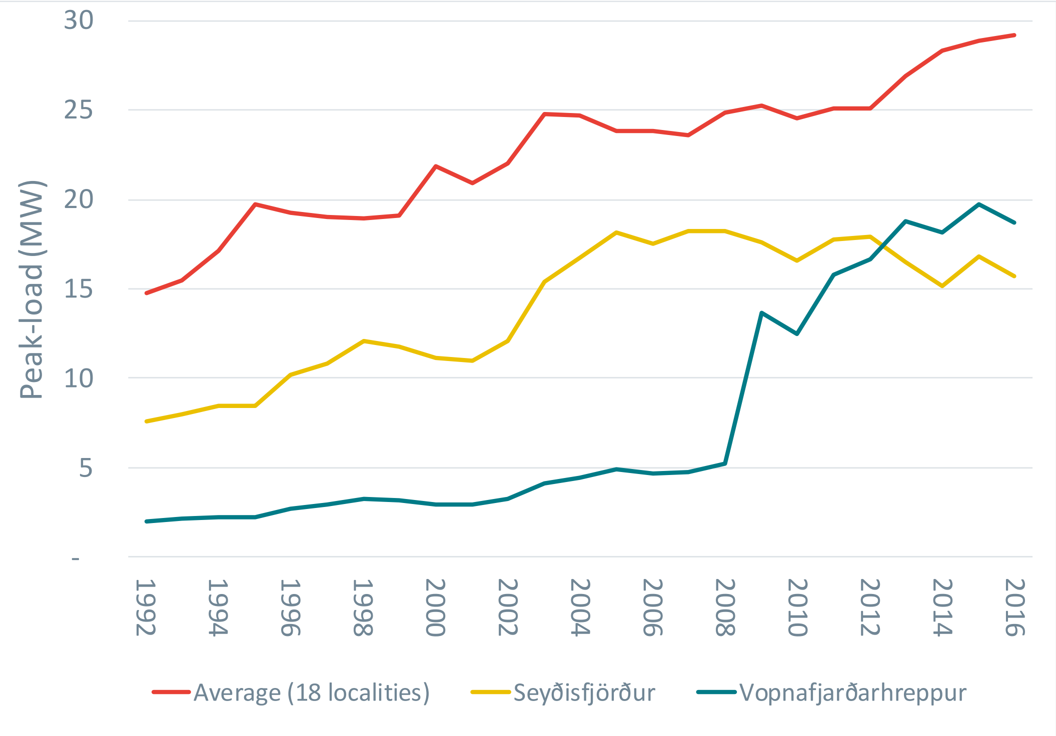
localities we analysed, peak-load demand increased around 3.6% per annum[4]. On average local peak-load demand increased in every locality we analysed and in 7 out of the 18 localities peak-demand more than doubled.

Figure 1 below shows the development of average peak-load (red line) across the 18 localities in our data. The figure shows that, on average, peak-load has doubled since 1992. Although informative, as it shows the steady increase in peak-load across localities, on its own the straight average can only tell a limited story of an increase across the board of localities. Somewhat more interesting is to look at the development of individual localities. Which is why we have provided the development of peak-load demand for two typical towns: Seyðisfjörður (yellow line) and Vopnafjarðarhreppur blue line).

Seyðisfjörður follows roughly the same path as the average, until 2002. From 2002 to 2005 peak-load demand increased sharply (in absolute figures from 12 MW to 18 MW), in which range it has remained since. In Vopnafjarðarhreppur the development was different. Peak-load demand at Vopnafjarðarhreppur grew slowly, but steadily, from 1992 to 2008. In 2008 peak-load demand was estimated to be around 5 MW. In 2009 it jumped to 14 MW and kept rising, reaching 19 MW in 2016.

While the average peak-load demand across all localities shows a steady trend of growing peak-load demand, the examples of Seyðisfjörður and Vopnafjarðarhreppur show that in individual regions peak-load demand is sensitive, and tends to increase suddenly. Obviously, this creates special challenges in network planning and development in specific areas.

**Figure 1 Absolute peak-load demand (MW) , 1992 – 2016**




*Source: Landsnet data and Frontier calculations.*

[4] Annual growth rate averages are geometric averages.

## 2.3 Development of absolute headroom since 1992

Last section showed the steady increase of peak-load demand in Iceland since 1992 and a volatile stepwise increase in individual localities. Such additional peak-load demand could either remedied through:

- the creation of additional network capacities; or
- better utilisation of existing infrastructure (i.e. using already existing headroom).

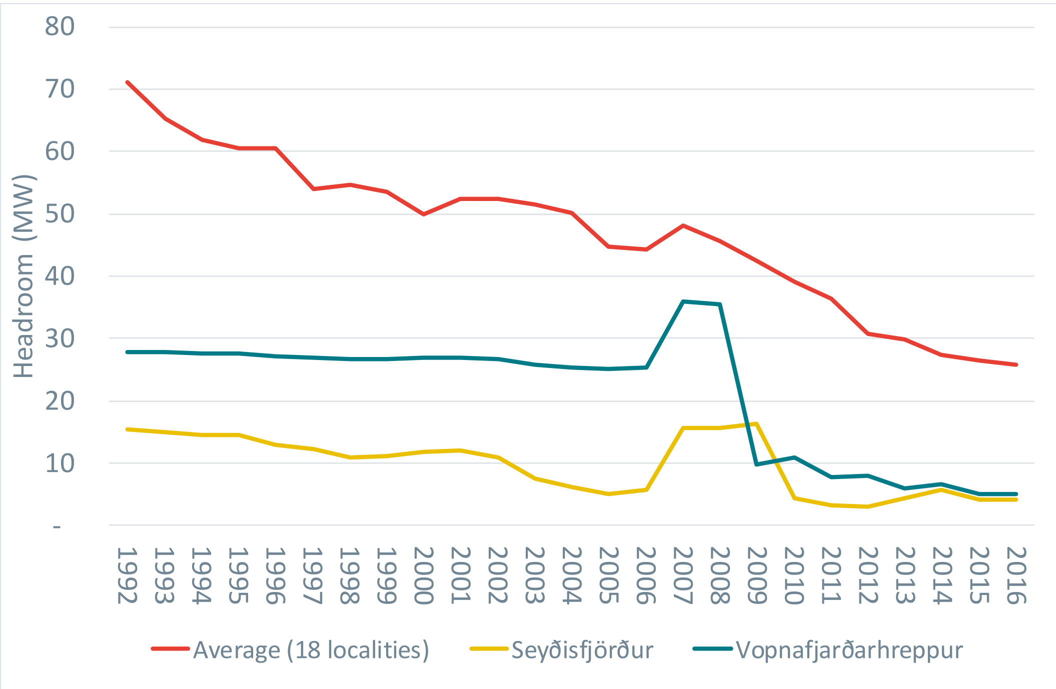
To analyse the development of headroom, we asked Landsnet to provide us with headroom estimates per substation. Such data was however not systematically available as the availability of headroom at a specific location depends on the status of the network in other regions. Landsnet therefore carried out a substantial exercise – which involved re-running network models going back to 1992 – in order to estimate the available headroom at various points in time at various substations.

Out of the 18 localities, in our database, 16 experienced a reduction in absolute level of headroom over the period 1992 – 2016. In 1992, average total headroom available was 68 MW. In 2016, average headroom available was 26 MW.

Figure 2 below shows in red the development of headroom, on average, across all 18 localities. There is a significant difference in headroom development across the localities in our sample. To illustrate that we have added Seyðisfjörður and Vopnafjarðarhreppur to the chart. In 1992, Vopnafjarðarhreppur and Seyðisfjörður had headroom of 28 MW and 15 MW, respectively. In 2011 both localities had less than 10 MW and in 2016 headroom was measured at around 5 MW.

In conclusion: the observed rise in peak-load demand over time has to a significant degree been facilitated by the use of excess capacity (headroom) available across the networks.

**Figure 2 Absolute headroom (MW) , 1992 – 2016**




*Source: Landsnet data and Frontier calculations*

## 2.4 The current state of headroom

From the analysis above it is clear that increasing demand has absorbed much of the historically abundant headroom, across all localities. In some localities headroom is reaching a critically low level.

So far, we have focused on peak-load demand and headroom in absolute terms. Since peak-demand tends to develop in line with local resources (i.e. working population), local endowment (i.e. current infrastructure and current composition of the local economy) and current demand the absolute level of demand and headroom is not directly comparable across various regions.

For example, the Greater Reykjavík area accounts for more than two thirds of all inhabitants and economic activity in Iceland. In contrast, Grundarfjarðarbær accounts for less than 1% of the population and economic activity in Iceland. Absolute headroom in Reykjavík in 2016 was around 220 MW, whereas Grundarfjarðarbær had a headroom of around 5 MW. During the busiest hour of the year, the peak-load for the Greater Reykjavik area was around 195 MW, whereas the peak-load at Grundarfjarðarbær was 4.3 MW. Meaning, although in absolute terms Reykjavík has much greater headroom than Grundarfjarðarbær, the two localities have a similar headroom buffer in relative terms. In both regions a doubling of current peak-load demand would eat up most of the remaining headroom.

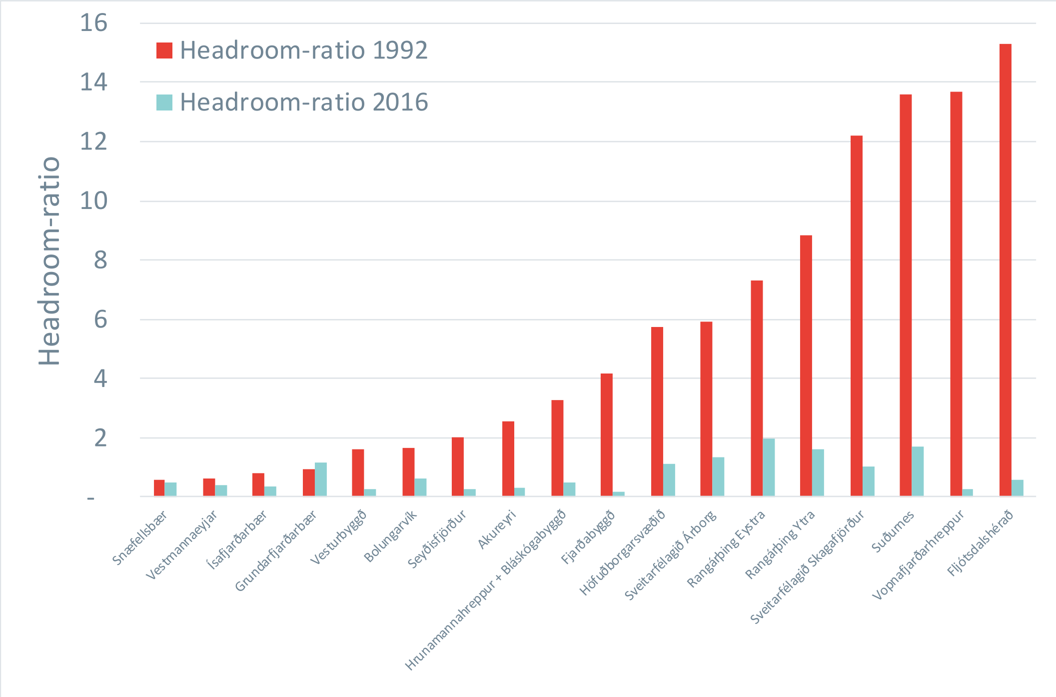
We therefore developed a comparable metric of headroom by dividing absolute headroom with the peak-load demand (from here on we refer to the metric as „headroom-ratio“). If the potential of economic activity is relative to the local resource capacity, as one would expect, then the headroom-ratio produces a comparable measure of headroom across localities of different characteristics.

The main advantage of looking at headroom-ratio, rather than absolute headroom, is that the headroom-ratio makes different localities (with heterogenous resources) comparable. Another benefit of the headroom-ratio is that it has a clear, simple and meaningful interpretation. The headroom-ratio describes the additional capacity available beyond peak-load. For example, a headroom-ratio of 1 indicates that the network can cover the busiest hour of the year twice. A headroom-ratio of 2 means that three times the peak-demand could be served. A ratio of zero would indicate that there is no flexibility left during the busiest hour of the year and if only one more MW was required the network would not be able to deliver.

Our calculations show that in 1992 the average headroom-ratio across all 18 localities was 5.6. This ratio varied significantly, from 15.3 at Fljótsdalshérað to 0.6 at Snæfellsbær.

In 2016 the average headroom-ratio was down to 0.8. The headroom-ratio was highest in Rangárþing Eystra (2) and lowest in Fjarðabyggð (0.2). **Figure 3** below shows the headroom-ratio for all 18 localities, in 1992 and 2016.

**Figure 3 Headroom-ratio in all 18 localities, in 1992 and 2016**




*Source: Landsnet and Frontier calculations.*

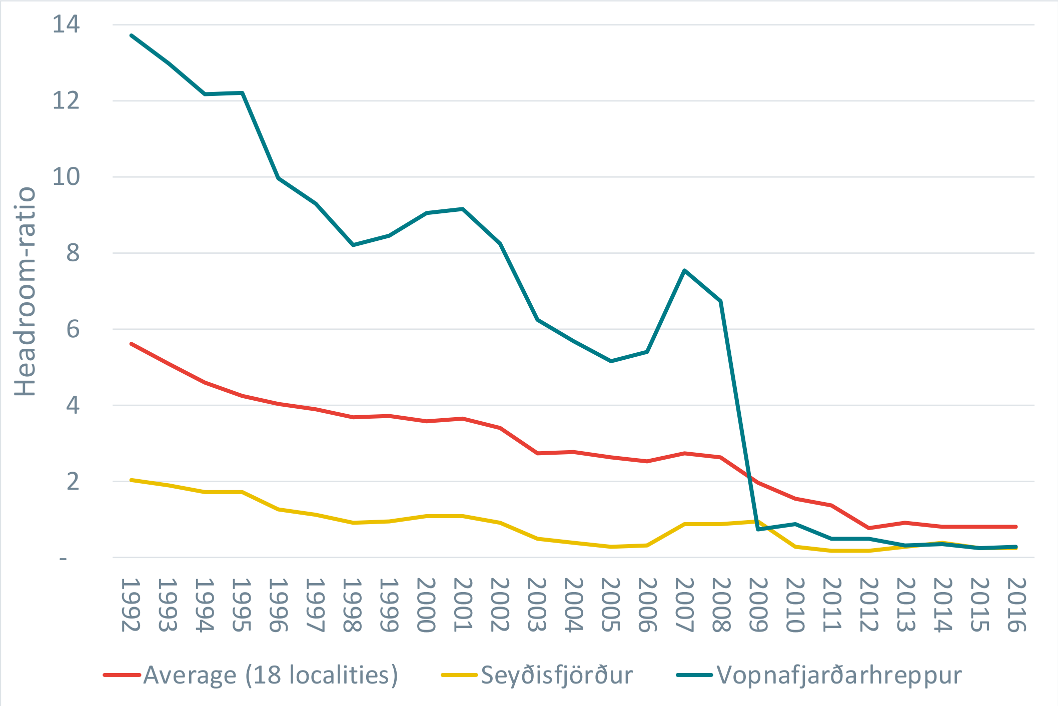
*Note: Headroom-ratio is calculated by dividing the headroom (MW) with peak-load (MW).*

This significant drop in headroom-ratio did however not happen overnight. The headroom-ratio steadily declined across most localities. Figure 4 below shows the development of the average headroom-ratio (across all 18 localities) and for Seyðisfjörður and Vopnafjarðarhreppur. The figure shows the steady decline of the average headroom-ratio (red line), where it went from 5.6 to 0.8 in 24 years.

In Seyðisfjörður headroom could cover three times peak-load demand in 1992, but only 1.3 times the peak-load in 2016. In Vopnarjarðarhrepppur there was excess of headroom in 1992, where the peak-demand could have been covered 13.7 times. However, in 2016 peak-load demand could only have been covered 1.3 times.

In 1992, only four out of 18 localities in our sample had a headroom-ratio of less than 1. In 2016, 11 localities had a headroom-ratio of less than 1. In 1992, 12 of 18 localities enjoyed a headroom-ratio above 2. In 2016, not a single locality had such buffer.

**Figure 4 Headroom-ratio, 1992 – 2016**




*Source: Landsnet and Frontier calculations*

*Note: Headroom-ratio is calculated by dividing the headroom (MW) with peak-load (MW).*

As there is a good reason to believe that, on the margin, headroom matters for long term economic development, it is clear that the network is now reaching a point where headroom might constrain long-term economic development.

# 3 THE OPTION-VALUE OF HEADROOM

In this chapter we develop an economic framework describing headroom as an enabler of long-term local economic development. The framework describes the option-value of headroom and how headroom is associated with real economic value, even if the option is not taken advantage of, as headroom creates additional opportunities.

In some cases, headroom will be irrelevant. For example, aluminium smelters in Iceland almost always rely on new capacity being exclusively built for it to be possible to install and operate a smelter. However, in many other cases – such as a medium or small-scale expansion of a local factory or an installation of a cloud-computing services – developments might depend on the availability of network capacity. Without headroom, the development (e.g. an investment) might either be transferred to another locality, delayed or cancelled all together.

In this chapter we interpret the provision of headroom as a real option for future development. The chapter starts with a brief overview of the concept of option-value and how headroom can theoretically generate option-value. Thereafter we proceed to develop a simple model of option-value of headroom.

## 3.1 Real option-value and headroom

In a classic cost-benefit analysis, network investment would be assessed by comparing up-front investment costs with future benefits that usage of the network will likely produce. In monetary terms such a comparison is typically expressed using indicators, such as net present value (“NPV”). A positive NPV signals that the accrued benefits outweigh the costs of network investment, in which case the project being analysed should go ahead.

Cost-benefit models systematically ignore uncertainties and the value of future information. Even an investment which future usage cannot be fully guaranteed, might prove valuable. Because, the network expansion provides an option of accommodating potential future usage. Therefore, a decision to invest in a project might be optimal, if the probability-weighted value of any potential future usage is sufficiently high.[5]

Option pricing theory is well known and understood from the field of finance, where the theory has contributed to the pricing of the option of future purchase (or sale) of financial assets. Real option theory can also be applied to investments in real assets (such as power network capacities), in order to factor in option-values in investment decision making.[6]

[5] See Fujii and Ishikawa (2013): Arrow-Fisher-Hanemann-Henry and Dixit Pindyck Option Values Under Strategic Interactions

[6] Option-value theory developed in environmental and resource economics independently and is based on the same principles. For more see Traeger’s discussion in his paper: “On Option Values in Environmental and Resource Economics

In simple terms, the value of any option can be broken into three components.

- **Duration of the option –** the longer the option is available more likely it is that it can be used ("executed").
- **Probability of option being executed** – the less we know about the future, the more likely it is that we need to account for something that might happen.
- **The value of the action that the option represents** – if the value of the unknown future usage of the option provided is high, the value of the option will also be high.

There is a clear analytical framework for how to measure option-value of financial assets, where the value and volatility of the underlying (e.g. a company stock) can easily be observed (see Black-Scholes, for example). However, regarding network capacity investments much less is known about the future.

All that can be known at the cost-benefit analysis stage is roughly the true duration of the option, which is the lifetime of the investments (e.g. a couple of decades for a network capacity extension). Much less known is:

- the probability of the option being executed (or the likelihood, when and where additional demand for network capacity will occur); and
- the value of future economic activity that the availability of additional network capacity might stimulate.

The nature of real options is such that the true value of an investment in options can only be assessed after the fact. However, just because option-value is hard to measure does not mean it doesn't exist. In fact, option-value of headroom could be substantial and ignoring it on the basis that it is hard to measure will lead to sub-optimal investment in network capacity, long-term.

## 3.2 Illustrative example (option-value of headroom)

For illustrative purposes one can think of a local economic activity (e.g. a fish processing factory), which is dependent on the secure supply of electricity. If today the network operator makes investment decisions based on current need (and/or foreseeable growth) the network operator will build just enough capacity to cover secure supply of current operation. In a world where network operators possess perfect foresight, such cost-benefit analysis would be the correct one.

However, network operators, just like all other economic agents, do not have perfect foresight. Which means, if new information and opportunities emerge in the future and entrepreneur/s would like to expand current business – or set up a new one – there would not be enough capacity for the expansion. Imagine, for example, that at some point in the future an unexpected opportunity for expansion turn up (e.g. local fishery receives an additional fishing quota). A potential investment in additional local processing capacity would depend on secured access to electricity.

Since the network operator will only know opportunity after the fact, they cannot immediately expand capacity to accommodate the fish factory expansion. The lack of headroom at the time of desired fish factory expansion would therefore result in one of the following:

- a delay in the fish factory investment;
- relocation of the factory to another locality with headroom; or
- cancelation of the investment all together.[7]

All three options would result in lower economic growth than if headroom had existed. Meaning that had the network operator built capacity above the minimum required, before the investment opportunity was known, the investors could have gone ahead with the factory expansion.

## 3.3 A pragmatic framework for estimating the option-value of headroom

It is highly likely that spare capacity in a network (headroom) contains positive economic value, as it provides a real-option that can be executed in the future. What is missing from the economic literature is a clear framework showing how option-value of network headroom is generated, as well as how it could be quantified.

As a part of our research we have developed a pragmatic framework which shows how option-value of headroom could be generated. This framework should provide a methodological framework for including option-value of headroom in future socio-economic analysis, such as the one carried out by Landsnet as a part of their NDP and investment options analysis.

In our framework we model the option-value of headroom by looking at how headroom has the potential to add to long-term regional economic wellbeing, by setting the local economy on a permanently higher growth path. We assume a stylised situation of a municipality, where the network operator has two options:

- invest in the **minimum capacity** that secures the supply of electricity in line with their own expectation of future demand; or
- invest in **additional headroom** (i.e. more capacity than the minimum required), leaving sufficient headroom for entrepreneurs to execute investments, if they desire.

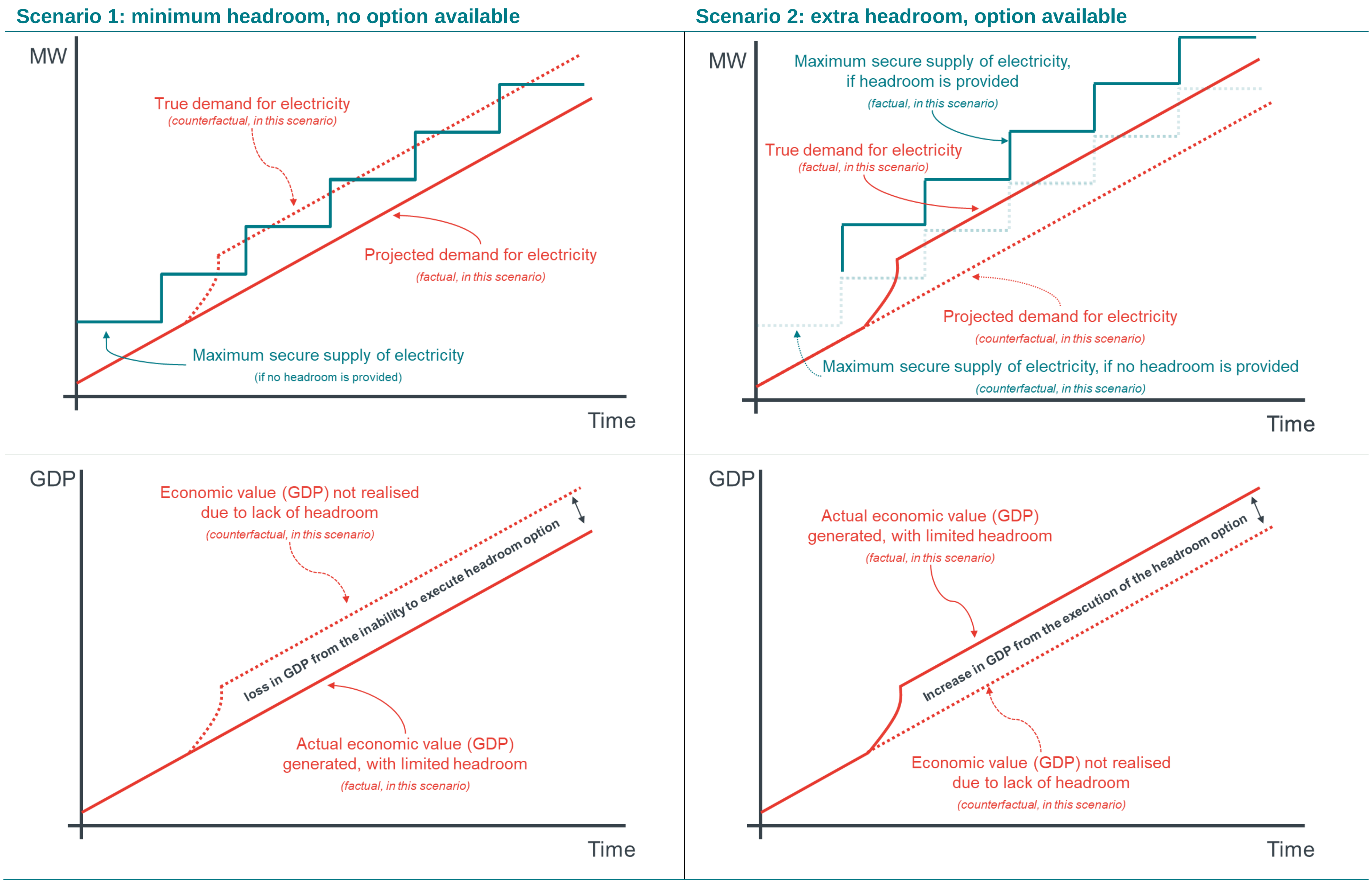
Figure 5 shows a stylised graphical example of the model. The graphic has two columns, each with an identical hypothetical locality. Scenario 1 (first column) represents a locality with no headroom investment and scenario 2 (second column) represents a locality which receives investment in headroom in the first network investment period.

[7] Even if, in the long-run, capacity was added to accommodate the fish factory, the owners of the capital face opportunity cost. At certain point it would be more profitable for the capital owners to simply invest outside of the locality – or even outside of Iceland – which would result in less economic development then had headroom been available.

In scenario 1 a network operator invests the minimum amount necessary at each investment stage. In this case, if an entrepreneur wants to invest in a project, which requires electricity beyond the minimum secure supply (blue kinky line), the entrepreneur will not be able to do so as there is not enough secure supply of electricity for her to safely make the investment and keep her business going. As a result, she will either move to another locality, where there is spare capacity, or not invest at all. The non-materialised increase in local GDP is then represented by the second chart in the first column. The difference between the dotted and solid lines can be thought of as the economic loss from not having headroom.

In scenario 2 (second column in Figure 5) a network operator initially invests more than the minimum amount necessary, in the first investment period (and he bears the higher costs of doing so). Thereafter the network operator invests the same amount in the network as it did in scenario 1. The difference between the solid blue line (factual) and the dotted blue line (counterfactual) represents the additional headroom. In this scenario the same entrepreneur can go ahead with the investment, because she can be sure that there is sufficient secure supply of electricity. In this case, the economic gain can be seen in the second chart of the second column, where the economic gain is the difference between the two lines.

**Figure 5 Stylised example – simple model of the value of headroom**




*Source: Frontier Economics*

The model presented in this chapter offers a clear framework for quantifying option-value of headroom, for individual network expansion projects. On the back of this framework, economic benefit could be calculated using readily sociodemographic and economic data. In particular, the option-value of headroom could be calculated using only information on changes in growth rates (of say GDP or income) and headroom. In Annex C we provide a simple example of how such calculation can be carried out**.**

# 4 THE HISTORIC RELATIONSHIP BETWEEN HEADROOM AND GROWTH

In section 3 of this report we set out the theoretical reasoning for option-value of headroom. We also explained how a pragmatic approach, using assumptions about economic growth, rather than theoretical probabilities and values of unknown future investments, could be used to quantify the option-value of headroom.

In section 2 we showed that headroom declined significantly in recent years. In 2016 headroom was at its lowest point, since at least 1992. If headroom constitutes a real option-value, as our theory suggests, then the Icelandic network is today likely at a point where increases to headroom, on the margin, could generate significant option-value.

In this chapter we combine local income data with the Landsnet power data (from the chapter 2, in order to investigate the association between average headroom levels and long-term income growth rates.

## 4.1 Income data

We approximate regional GDP (sometimes referred to as GRP) – which are not directly available – using income data obtained from the Icelandic Statistics office (“Hagstofa”).The data is based on tax returns and is aggregated by municipality and year (see Annex Annex D for a detailed description on the metrics used).

As discussed in section 3 of this report (and Annex A), the municipality data and the network data do not match one-to-one. In some cases, a single municipality is connected to more than one substation, in other cases one substation is connected to multiple municipalities, and in few cases multiple substations are connected with multiple municipalities. We overcome this issue by matching and aggregating substations and municipalities.[8]

All income and GDP figures presented in this chapter are in per-capita terms and have been adjusted for inflation using consumer price index (“CPI”), also obtained from Hagstofa. Income and GDP figures are all reported at 2018 prices.

## 4.2 Headroom is associated with marginally higher long-term income growth rates

As we are concerned with long-term economic development and how that might be correlated with headroom, we started our research by calculating the average growth rate for all 18 localities, for the entire period in which we had power data for (1992 - 2016).[9] Next we calculated the average headroom-ratio for the same set of localities. Finally, we looked at the correlation of the two. Figure 6 below shows

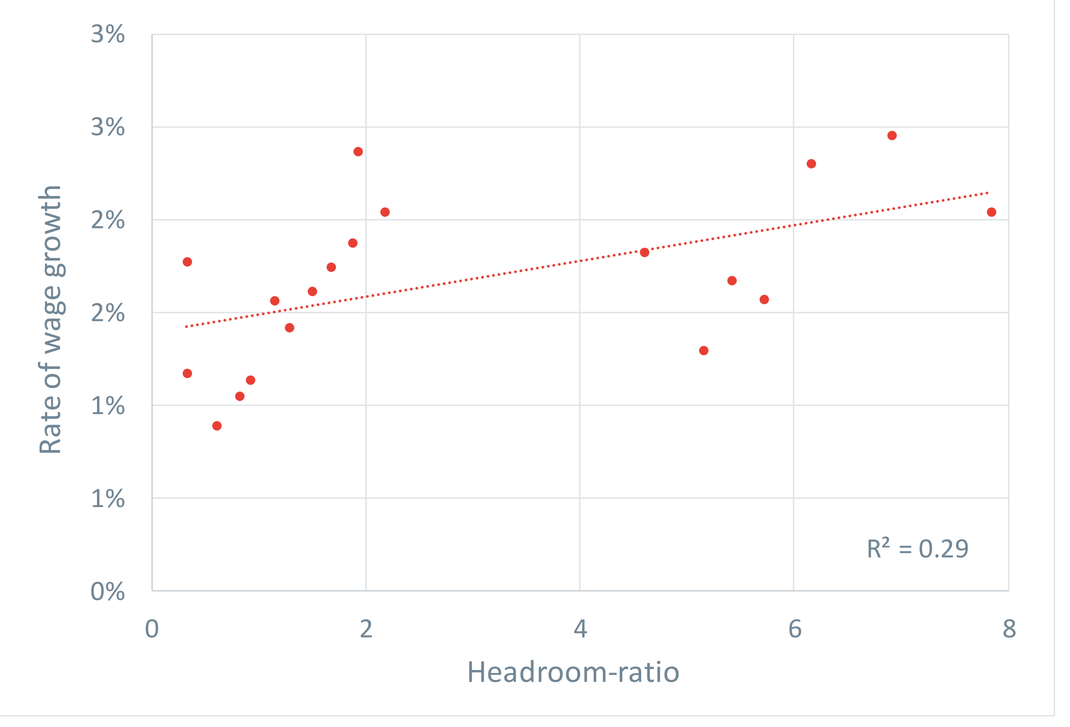
[8] A full discussion of our approach and the final aggregation of substations and municipalities is provided in Annex A and Annex B, respectively.

[9] We calculated the geometric mean, as is the norm when looking at long-term average growth rates.

the correlation between wage-income growth rates (Y-axis) and average headroom-ratio (X-axis). The figure tells us three things:

- Historically, localities with higher headroom-ratio have enjoyed higher wage average growth;
- at the lower end (where headroom-ratio is less than 2), a strong correlation exists between long-term income growth rates and available headroom; and
- the correlation between income growth and headroom-ratio is not strong in localities with overall high level of headroom (this might signal a saturation effect, which implies that once sufficient headroom has been reached, more headroom doesn't provide additional benefit).

**Figure 6 Average (geometric) wage-income growth rate and average headroom-ratio, all 18 localities, 1992-2016**



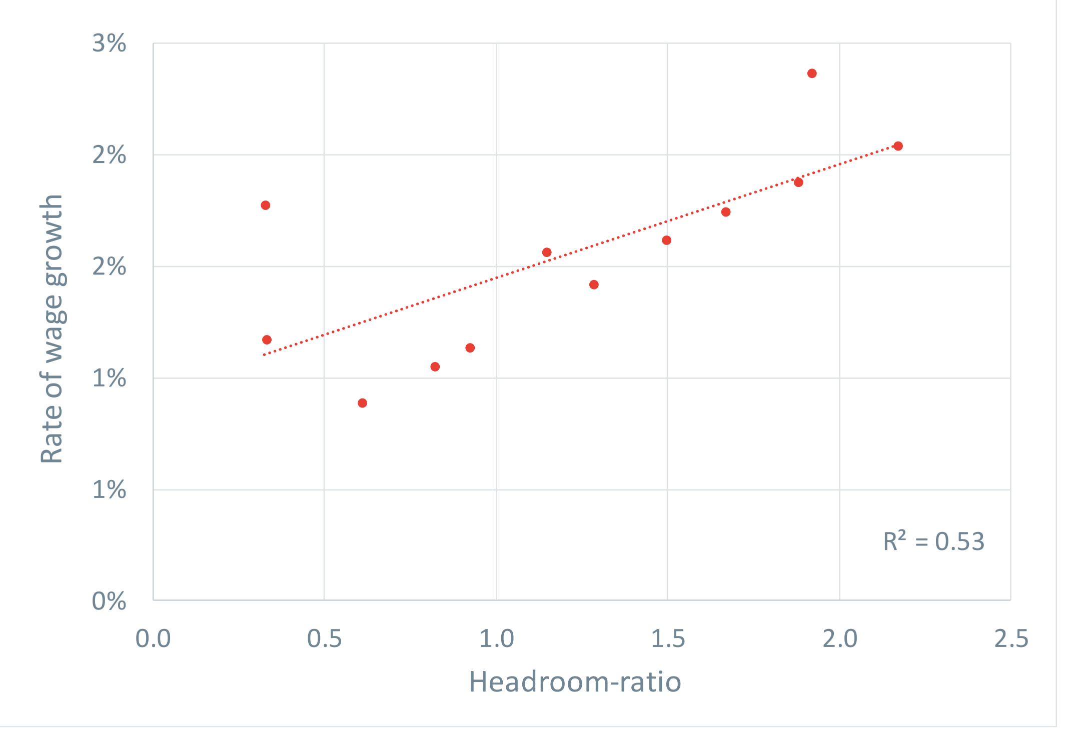

*Source: Hagstofa, Landsnet data and Frontier calculations*

*Note: Wage growth rates are geometric averages of annual growth rates, from 1992 - 2016.*

The economic data supports our theory that headroom could affect long-term growth rates, mostly on the margin. When headroom falls below a "critical" point, the identified correlations could imply that investment is less likely to occur, resulting in more sluggish wage growth and less economic development than otherwise.

However, since we are concerned with the option-value of headroom at the lower end (as headroom-ratio approaches zero) we decided to take a closer look at the correlation between income and headroom-ratio, at the lower end. In Figure 7 we have restricted the sample only to localities with low and moderate headroom-ratios (headroom ratio of less than 3). The figure shows a strong correlation between long-term income growth rates and headroom-ratio at localities with low and moderate headroom-ratios.

**Figure 7 Average wage-income growth rate and average headroom-ratio, 1992 – 2016 (only localities with headroom-ratio below 3)**




*Source: Hagstofa. Landsnet data and Frontier calculations*

*Note: Wage growth rates are geometric averages of annual growth rates, from 1992 - 2016.*

The chart in Figure 7 shows a strong correlation between income wage growth and headroom. In particular, the chart shows that localities with headroom-ratio below 1 enjoyed a significantly lower income growth rates than localities with average headroom-ratio above 1. This difference can also be illustrated by splitting localities into different headroom-ratio groups. Figure 8 shows the average income growth for localities with an average headroom-ratio of:

- less than or equal 1;
- greater than 1 and less than or equal 2; and
- greater than 2.

The chart displays growth rates for both wage-income and gross-income as a measure of economic development. Figure 8 clearly shows that localities with a relatively abundant headroom-ratio (greater than 1) enjoyed higher income growth rates than localities with headroom-ratio below 1.

**Figure 8 Average wage-income growth, by average headroom-ratio groups, 1992-2016**


*Source: Hagstofa. Landsnet data and Frontier calculations*

*Note: Wage growth rates are geometric averages of annual growth rates, from 1992 - 2016.*

Although headroom is certainly not the only thing affecting incomes, the economic data supports our hypothesis that, on the margin, headroom could have impacts on long-term economic development. Therefore there is an indication of the need to account for real option-value, when analysing new grid investment options.

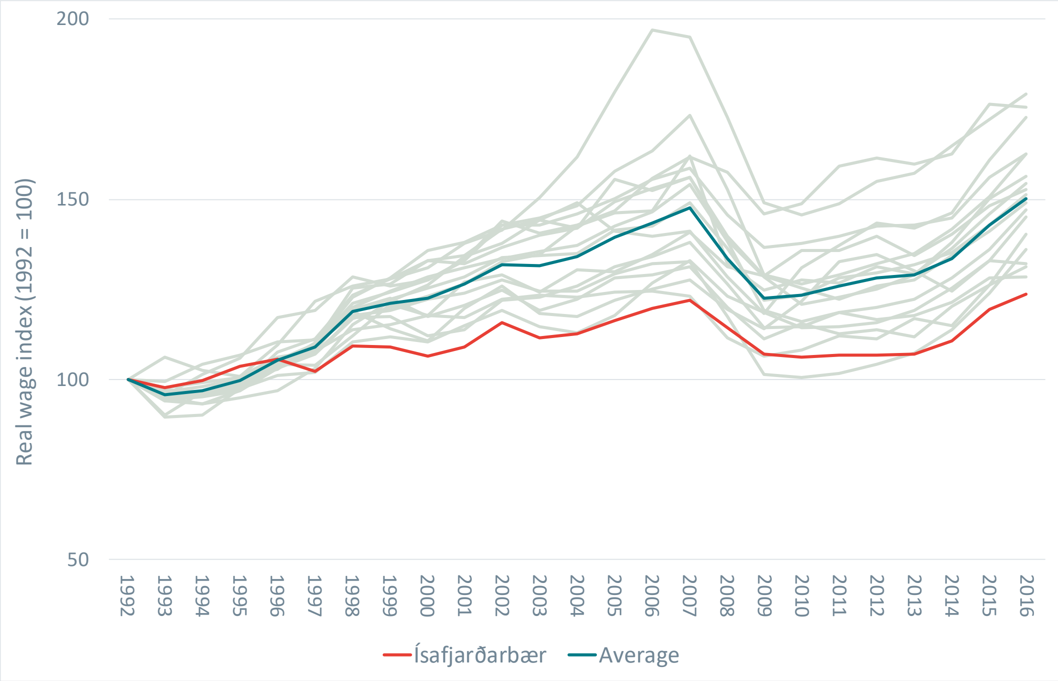
## 4.3 Case study: Ísafjarðarbær

### Long-term effects of lower than average growth rates

In 1992, per-capita wage-income in Ísafjarðarbær was the second highest in our sample of localities. Since 1992 Ísafjarðarbær has been on a steady slide down the list. The 24 years, from 1992 – 2016, were characterised by underperforming growth rates. In 16 out of the 24 years, wage-incomes growth rates in Ísafjarðarbær were below the average growth rate of the towns in our sample. In 2016 Ísafjarðarbær wage-income ranked number 7.

Figure 9 below shows the wage-income index for all localities in our sample (grey lines), the average income for all localities (blue line) and for Ísafjarðarbær (red line). Indexing charts to a base year, as we have done in the figure below, is a common way to show the long-term impact of different growth rates. That is to say, had Ísafjarðarbær enjoyed the average rate of growth, economic development should have followed the same path as the blue line. However, in reality wage growth did not keep up with other localities, which has resulted in wage-income being around 17% below the average.

**Figure 9 Indexed wage-income per-capita, 1992 – 2016.**




*Source: Hagstofa and Frontier calculations*

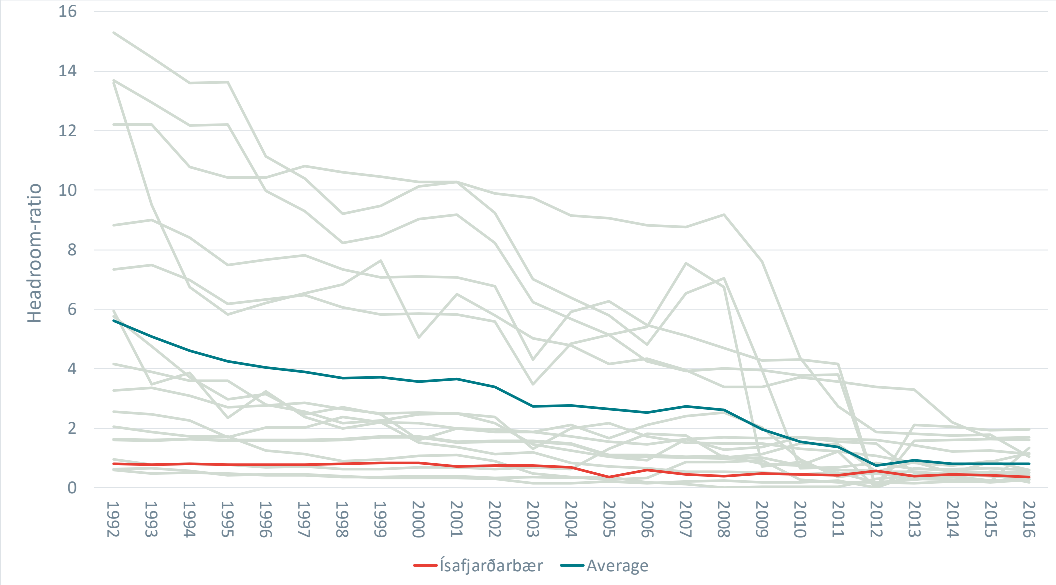
*Note: Straight average (no weights applied), base year is 1992.*

## Long-term effects of low headroom-ratio

A number of factors might explain the below-average figures in recent years in Ísafjarðarbær. However, based on our general correlation of headroom and economic growth it seem not unlikely that a lack of headroom played some role. In fact, Ísafjarðarbær is only one of two localities in which headroom-ratio has not once since 1992 measured above 1. The other locality is Vestmannaeyjar, where wage-income growth rates were also below average.

Figure 10 provides an overview of the extremely low headroom-ratio at Ísafjarðarbær. The figure plots all localities in our sample (grey lines), the average headroom-ratio (blue line) and Ísafjarðarbær (red line). The figure shows how the headroom-ratio has steadily declined across all localities. In Ísafjarðarbær, however, the headroom-ratio has been chronically low. The lack of headroom, which can make investing less attractive in the locality, might well have contributed to the sluggish growth in Ísafjarðarbær.

**Figure 10 Headroom-ratio: all localities; average across all localities; and Ísafjarðarbær, 1992 – 2016**




*Source: Landsnet data and Frontier calculations.*

*Note: Straight average (no weights applied).*

## 4.4 Summary of the evidence

The evidence presented above adds support to our hypothesis that, on the margin, long-term local economic development is restricted if sufficient headroom is not available. The data show:

- at the lowest level of headroom, where the headroom-ratio is less than one, income since 1992 has grown at around 0.6 percentage points lower rate than in areas with headroom-ratio above one; and
- at headroom-ratio levels below three, there is a clear positive relationship between higher headroom ratio and long-term economic development.

These findings suggest that the option-value of headroom should not be ignored when assessing the socio-economic case of network expansion.

# 5 CONCLUSION AND POLICY IMPLICATIONS

In this report we have set out a simple hypothesis: headroom of electricity constitutes a real option-value. In order to investigate the plausibility of that theory we analysed economic data. That data adds support to the hypothesis. The data show a correlations between economic development and headroom, in-line with the hypothesis.

Following from that, if the option-value of headroom capacity is not sufficiently accounted for in Landsnet's future socio-economic cost benefit analysis Landsnet might risk investing too little in network capacity. Even potentially relatively small investment in localities with low headroom levels could potentially yield significant future value, which can be quantified today as option-value.

As a result of our analysis we have come up with two key policy implication, which Landsnet should consider as a part of their socio-economic cost benefit analysis in the future.

### Rule of thumb: headroom should not fall below a critical threshold

There is no magic number for what headroom needs to be. However, based on the income analysis, a simple rule of thumb could be established. The option-value of headroom seems to increase until the ratio of available headroom to peak-load demand reaches 3. The biggest impact is at the lower end, when headroom-ratio reaches 1. Therefore, it would be wise to consider adding network capacity to a locality at the latest when the headroom-ratio falls below 1.

Estimating the exact optimal level of headroom would nevertheless require a more detailed analysis and particularly a comparison of investment costs for additional capacities and the corresponding option-value. A pragmatic solution might therefore be to explicitly consider option-values and add headroom when Landsnet's network models predict headroom-ratio to fall below 1 and incremental costs seems marginal. It might even not be unreasonable to aim for a higher headroom-ratio (closer to 2) depending on actual costs of adding capacities, although the benefit is likely diminishing after a ratio of 1 is reached.

### Future NDPs should account for option-value of headroom in future NDPs

By ignoring headroom in social cost-benefit analysis Landsnet runs the risk of underinvesting in the network. By not including it, Landsnet will underestimate the true value of new projects. Which risks rejecting future projects which are truly economically worthwhile. The option-value must be estimated for each locality individually. That is, option-value analysis should focus on individual localities and the predicted state of headroom in the years to come. In Annex C we provide a simple methodology for assessing option-value of headroom.

# ANNEX A DATA

### Data origin, collection and processing

Income data was retrieved from the website of the Icelandic national bureau of statistics ("Hagstofa").[10] The data is based on tax returns and is provided on the level of municipalities. We adjusted the data for inflation, using CPI (including housing) obtained from Hagstofa. All income figures in this report have been converted to 2018 values, using CPI.

Peak-load demand data was retrieved from Landsnet´s databases. The headroom data was produced by Landsnet. Landsnet models headroom regularly for monitoring purposes. The data they provided us with was produced using the models and/or methods that have been used to monitor the state of headroom in the past. All power data was originally provided on the level of substations.

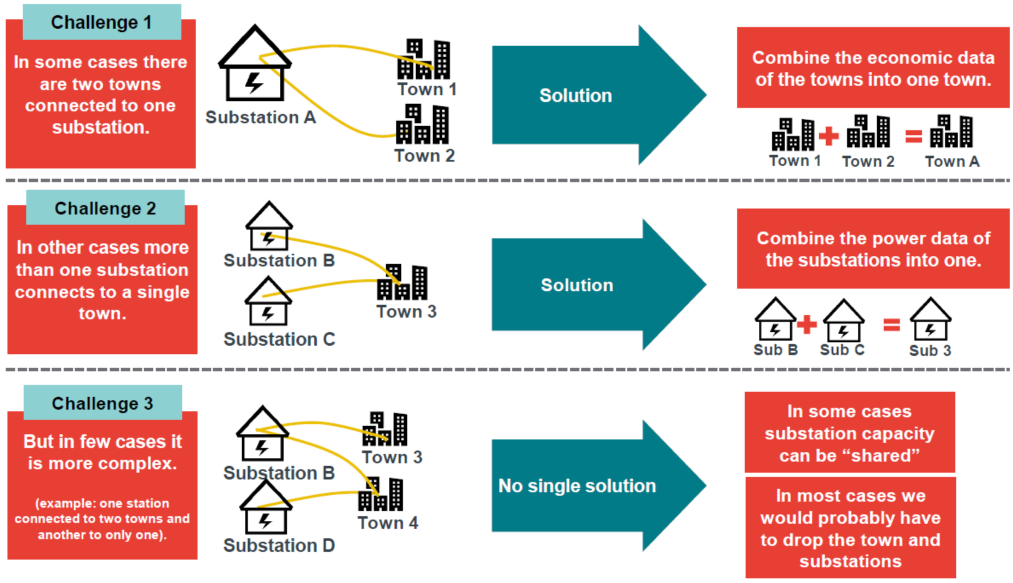
The power data and economic data was provided on two different geographic levels. That meant we had to match and merge the data, for it to be possible to look at incomes and headroom together. We managed to match municipalities and substations in a way where we could compare the income and power data. For 13 municipalities the matching of substation to municipality was straight forward – one substation for one municipality. For other municipalities things were more complicated and presented us with three challenges:

- **Challenge 1 –** In few cases, single substation is connected to more than one municipality. The solution to this challenge was to aggregate the income data, effectively treating the two municipalities as a single economic zone (which we refer to as a locality).
- **Challenge 2 –** In few cases a single town is connected to more than one substation. The solution to this challenge was to aggregate the headroom and capacity data from the substations, effectively treating them as a single substation.[11]
- **Challenge 3 –** In few cases multiple substation are connect to multiple municipalities (best example of this is the Greater Reykjavik area). The solution to this challenge was to combine substation data (as in the solution to challenge 1) and combine the municipalities into a single municipality (as in solution to challenge 2).

[10] Detail and metadata on the tax return data is available on the official website of the Icelandic bureau of statistics, www.hagstofa.is. The series ID is TEK01001 (Tekjur eftir kyni og aldri 1990 – 2018).

[11] We also had to make small adjustments to the peak-load demand data, which is explained in Figure 12 below.

**Figure 11 Challenges and solutions, when there is not a single substation for a single municipality**




*Source: Frontier*

Using these matching rules, we managed to create 23 economic zones, which each had their own delivery-point (or in some cases multiple delivery-points). Five of those localities could not be included in the analysis, due to data issues (see Annex B). At the end of this process we were left with 18 localities, covering more than 85% of the population of Iceland.

Since Landsnet could not provide us with the busiest hour in each locality (they could only provide us with peak-load by substation), we could not just sum up the peak-load demand in localities which had were connected to more than one substation. As peak-load does not tend to occur simultaneously across all substations at once, we had to adjust the peak-load demand in localities with more than one substation.

Since the correlation of peak-load is likely higher the closer the substations are to each other we decided to use the sum of peak-load demand, but adjust it downwards using the historic ratio of peak-load demand during the busiest system hours.[12] The figure below shows how this was done for the Greater Reykjavik area. Mathematically, the adjustment can be described as:

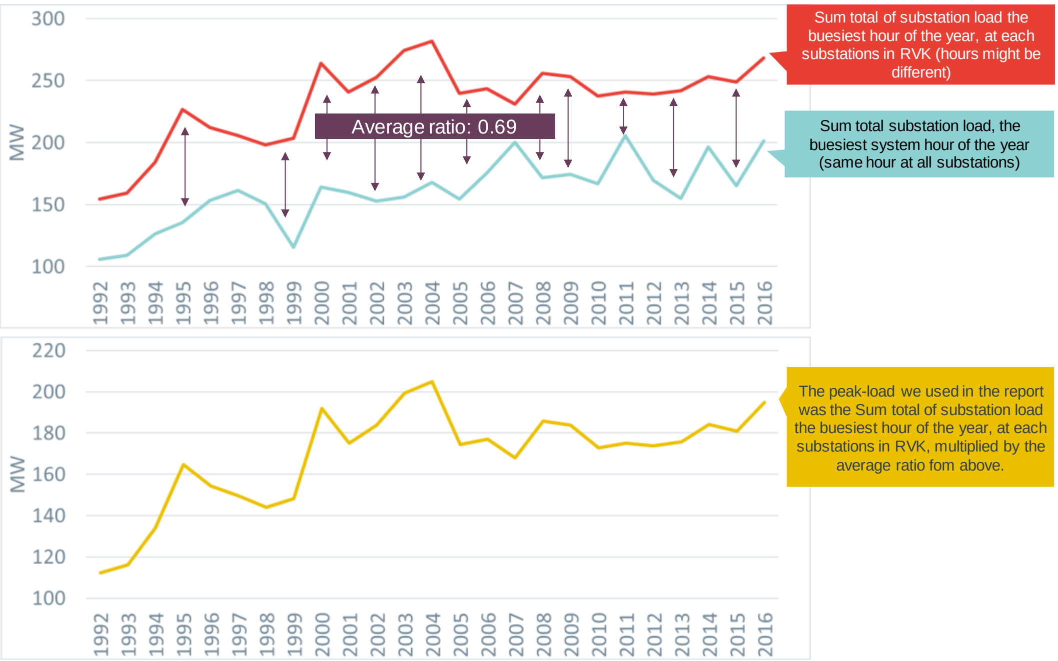
$$LOCALITY_{i,t}^{Adjusted} = \sum_{i=1}^{N} SUBSTATION_{i,t}^{System} * \left( \frac{\sum_{t=1}^{T} \frac{\sum_{i=1}^{N} SUBSTATION_{i,t}^{System}}{\sum_{i=1}^{N} SUBSTATION_{i,t}^{Local}}}{T} \right)$$

[12] Substations near each other, such as substations in Reykjavík, are more likely to be busy at the same time then each of them are likely to be busy when the substation in a faraway location, say Vopnafjarðarhreppur, is busy

Where:

- The left-hand side variable is the measure for peak-load demand at a specific locality *i*, in year *t*.
- *t* denotes the year (1992 – 2016);
- *i* for denotes the substation (which belongs to the locality);
- the subscript *System* denotes that the peak-load measure is the one during the system busiest hour;
- the subscript *Local* denotes that the measure peak-load is the one during t peak-load hour of each substations, in that locality.

**Figure 12 Example: adjusted local demand when more than one substation had to be aggregated.**




*Source: Landsnet data and Frontier calculations*

As a sensitivity, we also ran the same analysis as we did in the report using: only “well defined” localities (single municipalities which could be matched with single substations); and using substation groups during the busiest hour of the system. How peak-load demand was defined did not have any material effect on our reported results in Chapter 4.

# ANNEX B AGGREGATION OF SUBSTATIONS AND MUNICIPALITIES

## Municipality and substation matching – final list used in analysis

**Figure 13 localities (matching of municipalities and substations)**

| Municipality group | Substation 3-digit code |
|---|---|
| Vestmannaeyjar | VEM |
| Sveitarfélagið Árborg | SEL |
| Sveitarfélagið Skagafjörður | SAU |
| | VAR |
| Akureyri | RAN |
| Snæfellsbær | OLA |
| Ísafjarðarbær | ISA |
| | BRD |
| Höfuðborgarsvæðið:<br>- Reykjavík, Kópavogur, Seltjarnarnes, Hafnarfjörður, Mosfellsbær, Garðabær | GEH |
| | KOR |
| | A12 |
| | OLD |
| | HAM |
| Grundarfjarðarbær | GRU |
| Fljótsdalshérað | EYV |
| Vesturbyggð | KEL |
| Bolungarvík | BOL |
| Sveitarfélagið Ölfus | TOR |
| Suðurnes | FIT |
| | STA |
| Vopnafjarðarhreppur | VOP |
| Seyðisfjörður | SEY |
| Rangárþing Eystra | HVO |
| | RIM |
| Rangárþing Ytra | HEL |
| Fjarðabyggð | STU |
| | ESK |
| | NSK |
| | FAS |

*Source: Landsnet and Frontier*

## Municipality and substation matching – localities that could not be included in the analysis due to issues in data

**Figure 14 localities that could not be included in the analysis**

| Municipality group | Substations 3-digit code | Reason for exclusion |
|---|---|---|
| Akranes + Hvalfjarðarsveit | ▪ AKR<br>▪ BRE | The locality was excluded because headroom and peak-load could not be separated for large industrial users and others. |
| Norðurþing | ▪ HUS<br>▪ KOP<br>▪ LIS<br>▪ LAX<br>▪ KRA | The locality was excluded because headroom and peak-load could not be separated for large industrial users and others. |
| húnavatnshreppur + blönduósbær + skagabyggð + sveitafélagið skagaströnd | ▪ LAV | Economic zone was considered too wide and to include too many different municipalities. |
| Hrunamannahreppur + Bláskógabyggð | ▪ FLU | Headroom data was not reliable and had to be excluded. |
| Sveitarfélagið Hornafjörður | ▪ HOF<br>▪ HOL | The locality was excluded because headroom and peak-load could not be separated for large industrial users and others. |

# ANNEX C INCLUDING THE VALUE OF HEADROOM IN FUTURE NDP'S

In order to estimate the expected value of an investment in headroom, the following information is required:

1. local GDP (or a proxy) today; [13]
2. economic growth rates;
3. current and historic headroom and annual peak-load demand data;
4. network operators' incremental cost of additional headroom; and
5. social discount rate.

The first three variables are either known or possible to estimate using historic data and available predictions from the Icelandic statistics office and/or the Icelandic central bank. Estimates of incremental cost (item 4 on the list) should also exist, as a part of Landsnets' cost estimates. The social discount rate (item 5 on the list) will have to be based on informed assumptions of social time preference.

Below we present a simple example of how the calculation could be carried out in one locality in Iceland (Akureyri).

## Baseline local GDP figure

First thing required to carry out the calculation is the approximate gross product of the locality in question (Akureyri in this example). Exact figures are not available on the municipality level in Iceland. There is however high quality aggregated tax-return data available on that level. Historically GDP per-capita in Iceland has been around 60% higher than wage-income per-adult and the gap between the two measures has been fairly constant. Given this strong correlation, we can scale up the local wage-income data, so that it gives us a second best measure for gross local product. From public data we know the following.

1. Total wage-income per-adult (2018):[14] 4.3m kr.
2. Estimated local GDP per-capita: 4.3m * (1 + 60%) = 6.9m kr.
3. Population (2018): 18,920
4. Estimated local GDP in Akureyri: 6.9m * 18,920 = 130.2bn kr.

[13] Throughout this chapter we speak of local GDP. Gross product that is not measured on the domestic level is sometimes referred to as GRP (Gross Regional Product). The gross product of a locality we refer either to as "local GDP" or GRP throughout this report.

[14] In this case adult is defined as 16 years or older. Full definition can be found at www.hagstofa.is, in the metadata of the data series TEK01001

## Economic growth, peak-load and headroom

Economic growth does vary across different localities. We can assume the long-term total income growth to be the same as local GDP growth (which is consistent with our analysis in Annex D), and that the average growth rate will be the same in the next 20 years as it was in the past 20 years.

From our analysis we know that real wage-income has grown at around 1.7% annually, in Akureyri. We also know that the headroom-ratio was only 0.3 in 2016 in Akureyri. Assuming that it has not increased since, option-value today is likely low – or non-existent. Our analysis in chapter 4 showed that localities with headroom-ratio below 1, tend to grow at a reduced rate of around 0.6 percentage points. If we assume that in the future headroom-ratio will keep generating option-value, 0.6% annually is the maximum loss of output, if headroom is not increased to a level beyond 1. At minimum no option-value exists, whereas most likely the true potential local option-value lies somewhere in the range of 0 to 0.6% of local GDP, each year.

## Bringing it all together

In this example, for simplicity, we ignore the incremental cost of adding headroom. However, this should of course be estimated and deducted from the NPV when headroom is added to the socio-economic cost-benefit framework in future NDPs.

The undiscounted option-value could be calculated as:

- $\sum_{t=1}^{T}[GDP_{2018} * (1 + g_{headroom})^{\mathrm{t}} - GDP_{2018} * (1 + g_{no.headroom})^{t}]$

Where:

- $GDP_{2018}$ is the GDP estimate in 2018 (see 4 above);
- $g_{headroom}$ is the growth rate, assuming no headroom investment;
- $g_{no.headroom}$ is the growth rate, assuming headroom investment; and
- the subscript *t* is an indicator for the time in which headroom option is available (for example, 1, 5, 10 or 100 years).

Numerically, assuming counterfactual future GDP that is 0.3 percentage point higher than if no headroom is invested in, and a lifetime of 10 years, the option-value of headroom can be calculated as follows:

- $NetLocalBenefit = 130.2bn * [(1 + 0.02)^{10} - (1 + \ 0.017)^{10}] = 24bn\ kr.$

The calculation above is in nominal terms. If and when headroom-value is added as an indicator to the socio-economic cost-benefit framework, it must take into account the time value of money. This should be done using the NPV formula:

$$\sum_{t=1}^{N} \frac{NetLocalBenefit_t}{(1 + i)^t}$$

Assuming a 5% social discount rate, the stream of economic benefit – at Akureyri – would be calculated at around 17 bn kr.

## Net-benefit for all of Iceland

The method above can however not be used to quantify the net-benefit nation-wide. Because, if extra headroom is not built in Akureyri and desired future entrepreneurial activity that relies on headroom is impossible, the investment might still go forward, for example in other localities. The net nation-wide economic benefit of adding headroom therefore largely depends on the counterfactual (what the investor would do if no investment in headroom was made). In particular, without the headroom:

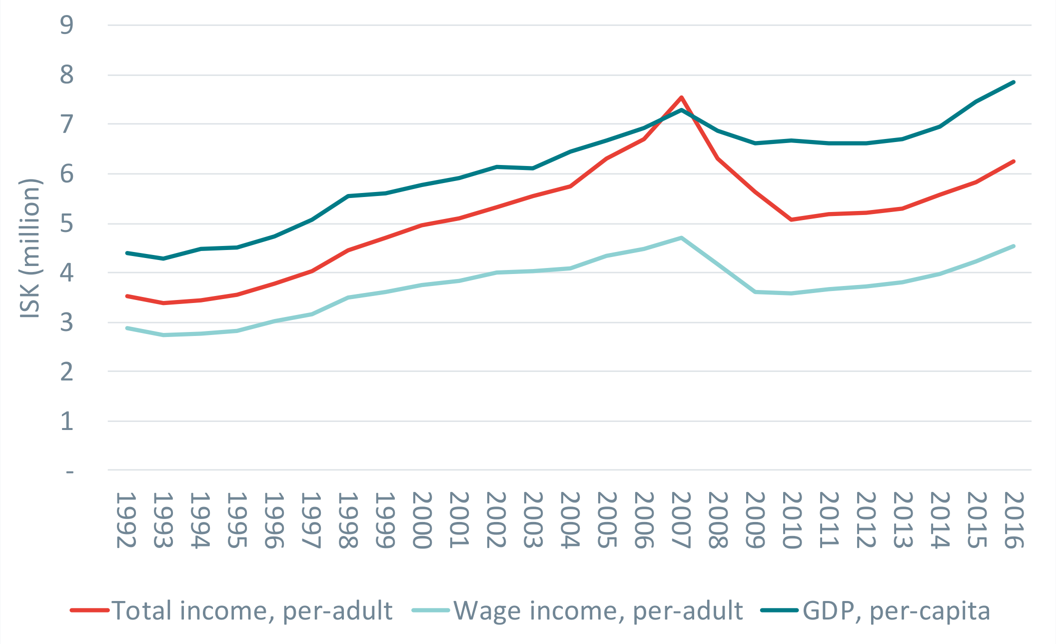
- the investment might be moved between localities. Which would benefit localities with headroom, at the cost of localities without headroom; or
- if the investment might be cancelled (or moved abroad). Which would mean no benefit would be created in Iceland at all.

Therefore, to estimate the net-value of adding headroom, on the national level, *an adjustment has to be made to avoid double counting*. Particularly the likelihood of future development in a specific location (and hence the option-value of headroom) might be lower in each respective location in a situations where investors have the choice between various locations. We therefore recommend that if Landsnet were to include such calculation in their future NDPs, that they account for the possibility that *large proportions of investments would simply be re-located within Iceland*. This would be done by allocating only a proportion of local benefits to the total nation-wide benefit to avoid double counting.

# ANNEX D INCOME DATA AS PROXY FOR ECONOMIC ACTIVITY (GDP)

We looked at two measures that could potentially be used as a proxy for economic development: gross-income per-adult; and wage-income per-adult.[15] On the national level, both income and GDP data in per-capita terms are available, while on a municipality level only income data is available. Before we carried out our correlation analysis, we wanted to make sure that the income data could act as a reliable proxy for economic development. Therefore, we analysed the correlation between the two different income measures against GDP. As Figure 15 below shows, both gross-income and wage-income are highly correlated with GDP, on the national level.[16] The figure plots the development of per-capita: wage-income, gross-income and GDP from 1992 to 2016 (period used in this report).

**Figure 15 Wage-income (per-adult), gross-income (per adult) and GDP (per-capita), 1992 – 2016, m. kr., at 2018 prices**




*Source: Hagstofa and Frontier calculations*

Both income measures function as a proxy for GDP. Total income is however influenced substantially by investment Income. On the national level this is quite clear from the financial service sector boom and bust cycle (2004 - 2010), where at one point total income, per-adult, was actually measured above GDP per-capita. Gross-income is also more volatile than wage-income, ranging from 74% to 104% of GDP. Wage-income, in the same period, has remained in the range of 54% to 66%.

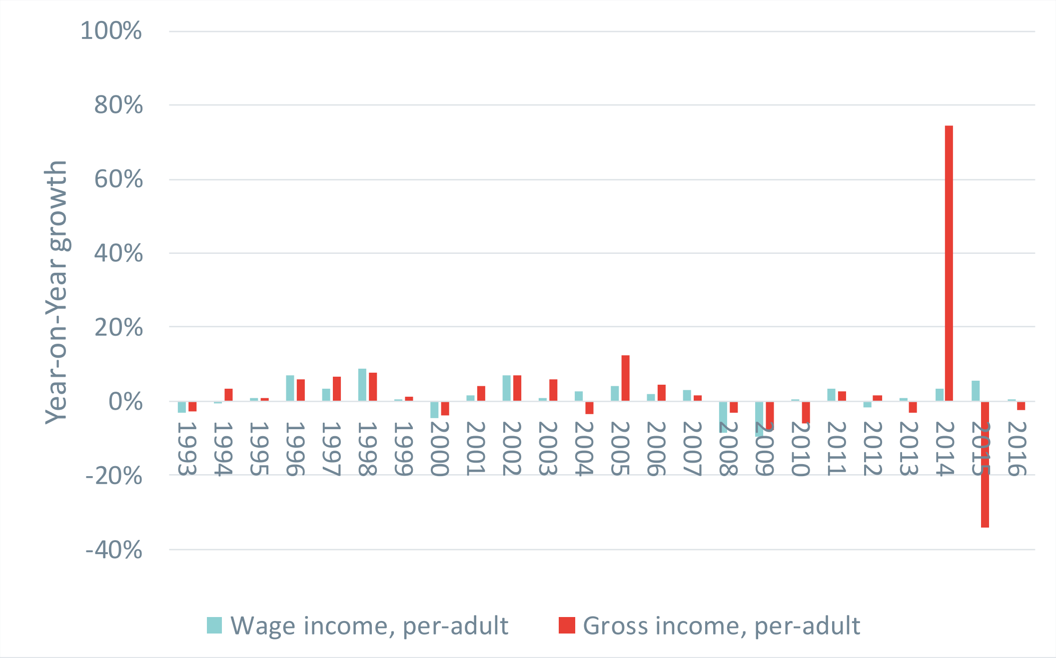
[15] Adults are defined as people 16 years or older. Full definition can be found in the metadata of the data series TEK01001, available at www.hagstofa.is.

[16] Correlation coefficient is around 90% for both series, which is not surprising, since GDP is a factor of wages, other income, amongst other things.

For sensitivity we also looked at changes in GDP growth rate and compared them with changes in wage-income and gross-income growth rates. We also found a strong correlation between both measures. Wage growth rate is however somewhat more strongly correlated with GDP growth (correlation coefficient of 85% vs 78%), caused by the relative volatility of gross-income.

The volatility of gross-income is even more extreme on the local level. The figure below shows the year-on-year growth rate in gross-income and wage-income in Seyðisfjörður. As the chart shows, gross-income is volatile all most years, and subject extreme volatility in few years (2014 and 2015).

**Figure 16 Real growth rate of per-adult gross-income and wage-income in Seyðisfjörður, 1993 – 2016**




*Source: Hagstofa and Frontier calculations*

Since wage-income both reflects economic conditions more closely and tends to be less suspect to outliers than gross-income is, we decided to mainly focus on wage-income in the report. However, as can be seen in section 4 of this report, we did carry out some analysis on the gross-income metric. The main reason was to provide a sensitive check for our results. It turns out that our findings are not sensitive to choice of income metric.