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Copernicus Sentinels' Products Economic Value: A Case Study

Pipeline Infrastructure Monitoring in the Netherlands

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Study Report: Pipeline Infrastructure Monitoring in the Netherlands

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Executive Summary

Pieter took his seat in the half-full hall. He estimated that they were about 50 in total; all coming to hear from the chairman of the local gas distribution company about how their lives were being made easier and safer.

They had received the invitation with their gas bill. It was to be a community meeting where the local utility company would present their investment plans and be open to questions about their operations. He recalled the day 6 months earlier when he had returned home to find the smell of gas as he approached his house. Fortunately, the company had reacted quickly and the leak coming from his neighbour's house had been quickly and efficiently repaired. Now, the company was to return and make repairs to the gas connection for everyone in the street. He saw his neighbour on the other side of the hall and waved to greet him.

The chairman took his place on the stage alongside the town mayor and the meeting started. Pieter was immediately surprised to learn that the gas company had started using images coming from satellites. Apparently (and it is true to say he was amazed to learn) that from nearly 800km above his head, the movement of the ground could be measured to an accuracy of a few mm! Each time the satellite passed over – which he learned was every 11 days – a new picture was taken by a radar which could detect small objects like letter boxes or street lights and, by comparing the images, the very small movements could be detected.

A map showing the ground movement was used by the gas company to see which houses are at risk. If the movement was more than about 80cm, the pipe entering his house could break, causing a leak with the potential to explode. The gas company would use the information to replace the pipe connections before there is any danger.

He thought about this and put his hand up; "does this mean that my house is also at risk of cracking up" he asked the chairman. The answer he got was reassuring, his house is not moving since it is anchored deep into the sub-soil, but because the pipes are not anchored they are moving up or down relative to his house. He heard many people in the room breathe a sigh of relief!

The chairman explained that before using satellites, they only knew about the movement and risk when a pipe cracked and a leak occurred. Now they could measure this accurately and cheaply over the whole area of their business which was saving them many millions of Euros each year. Each customer could expect reduced gas prices in the future which brought a round of applause from the audience.

He went home and told the story to his wife who had been looking after the children. Now we can feel safer at home and even save money thanks to the satellites watching our earth from their orbits way over our heads.

In this case, the third analysed by EARSC and The Greenland under contract to ESA, we examine the impact of the use of satellite imagery to monitor gas and water pipeline infrastructure in The Netherlands. In each case, the goal is to look at the impact that one particular satellite-derived product has on an operational value-chain.

Ground subsidence is a particular problem in the area around Rotterdam. It can be so severe that soil levels can change by as much as 1m within a few years. This causes problems for underground pipelines making up the infrastructure of the area to deliver gas, water and steam to local citizens and businesses. The problem is most acute where pipelines cross over each other and where they connect to the consumers' premises where a fracture risks a severe accident.

How to know where the risk lies? Older connections are more at risk than modern ones due to use of rigid metal rather than flexible plastic combined with the modern practise of installing a loop to absorb movement. Clearly the risk is greater where the ground is subsiding faster. In this case, the stress created on the household gas connection or on the water mains in the street can cause a failure with consequent leaks. In the case of water, this can cause severe disruption to traffic or, as we heard in one case, the flooding of a hospital basement; in the case of gas, the impact can be much worse if gas builds up in the space under a house when it may even explode.

In the past, companies like Stedin and Oasen have planned replacement programmes starting in areas where leaks have been previously reported and found to be due to subsidence. But a more targeted approach is possible using satellite images which show hot spots where movement is taking place. Satellite-borne Synthetic Aperture Radar (SAR) from the Sentinel-1 mission (part of the Copernicus programme) is used to identify where the ground is subsiding and TerraSAR-X (a commercial mission) is used to further pinpoint the movement more precisely which allows the maintenance strategy to become focused on areas of higher risk. Instead of replacing pipes and connections in a single district no matter the age or the actual risk of failure, a much more focused approach becomes possible where pipes which are at risk and serving individual houses or streets can be replaced.

The result is better investment of resources by the pipeline operators and less risk to consumers from gas leaks or disruption from major water leaks. Overall, we calculate an economic benefit coming from the use of this product by 2 infrastructure operators in the Netherlands to be €6.6- €7.9m per annum; extrapolated to all the operators over the whole country leads us to conclude a total potential benefit of €15.2m – €18.3m each and every year.

1   Introduction and Scope

This report describes part of the results obtained in the frame of the study "*Assessing the detailed economic benefits derived from Copernicus Earth Observation (EO) data within selected value chains*", undertaken by the European Association of Remote Sensing Companies (EARSC), in collaboration with the Green Land BV, under an assignment from the European Space Agency (ESA). The goal of the study was to gather quantitative evidence that the usage of Copernicus Sentinel data provides – or will provide - an effective and convenient support to various market applications. As part of it, we defined and applied a new methodology to assess the full benefits (direct and indirect) stemming from the use of EO-derived geo-spatial information, in a way which has not been tackled before.

We examined how the benefits of using these data either do or can affect a full value chain by starting from the primary usage and then following the related impact down various identified tiers in the value chain. The new methodology was applied to three use cases, which have been selected considering the maturity of the application as well as the feasibility for the sake of the study. This is the third case to be published[1,2].

The results are captured in separate, dedicated reports which are written to inform policy makers, in Europe as well as in ESA/EU Member States, who are concerned with (EO) space programmes. However, each single report should also be of interest for the private industries, public authorities and policy makers involved at any level in any of the specific applications described therein.

We examined each case using the specific methodology developed and applied and tested through the 3 cases. This starts with a defined product which is being used operationally to support a process within an organisation (which can be private or public). We then define a value chain linking the various users which is constructed in tiers where the type of information used by each tier differs. It uses a model (a different one in each of the cases) to link the reality of the operation to the economics of the case, it uses an assessment of the role that satellite imagery plays before we make an analysis of the economic benefit being created at each stage of use. Assumptions are used which are there to be challenged by experts.

The current report describes the results obtained for the third of these cases; the case of pipeline infrastructure monitoring in the Netherlands where satellite imagery is used to support distributors of gas and water to monitor the impact of ground movement on their networks. Satellite SAR imagery coming from Sentinel-1 and from TerraSAR-X are used to monitor ground movement to a high degree of accuracy. The final use-case depends on high resolution imagery whilst the preparatory work is performed using lower resolution data.

The case hinges on better planning of the replacement of gas or water pipelines. A more optimised strategy becomes achievable resulting in better use of financial resources and hence a strong impact on the balance sheet of the company.

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[1] Case 1: Copernicus Sentinel's Products Economic Value: A case study of Winter Navigation in the Baltic, EARSC and The Greenland, September 2015.
[2] Case 2: Copernicus Sentinel's Products Economic Value: A case study of Forest Management in Sweden. January 2016.

Study Report: Pipeline Infrastructure Monitoring in the Netherlands

The report is based on research and interviews with persons in the Netherlands who are directly involved in the management of the pipeline infrastructure. Stedin is a publicly owned company (the shares are held by Eneco NV, whose shares are held by municipalities), responsible for the distribution of gas to domestic and industrial users in the area around Rotterdam. This area suffers significant ground subsidence due to the nature of the soil and the high water levels. This generates stresses on the pipelines with the greatest problem at the connection to houses. The ground moves whilst the houses are more firmly anchored creating a risk of fracture and gas leakage which, in extreme cases, can cause explosions with consequent loss of property and risk to life.

A planned system of maintenance replaces these pipe connections with newer technology reducing the risk. Stedin manages nearly 2,000,000 gas connections and presently is able to replace only about 1% i.e. 20,000 per annum. Hence the use of monitoring technology allows the maintenance to be better planned and to target those houses most at risk. Since 2014, the monitoring has been based on the use of satellite InSAR products which discloses very small movements (a few millimetres) of the ground surface.

The same monitoring is presently being tested by Oasen a publicly owned company (the shares are held by municipalities) responsible for water distribution to 750,000 customers in the region around Gouda. This case examines the impact of the improved monitoring on the business models of these two companies.

The InSAR-derived information mentioned is provided commercially by SkyGeo, based in the Netherlands. SkyGeo specializes in applying InSAR methods to solve asset management and engineering problems in the civil engineering, oil and gas sectors. The company has worked closely with both Stedin and Oasen in developing the business application analysed in this business case.

We should like to thank the following people for their assistance in preparing this report:

Ivo Visser; Stedin

Jurjen den Besten; Oasen

Jos Maccabani; SkyGeo

2   Pipeline Infrastructure Monitoring in the Netherlands

2.1   Description of the Case

The case hinges upon the impact to the business model of companies which are responsible for gas and water distribution in the Netherlands. In particular, on two companies responsible for the provision of these services in the area around Rotterdam and Gouda where severe ground movement causes stress on the pipes laying in the ground.

Stedin is a Dutch company responsible for the network and safe transport of gas and electricity in certain areas in the Netherlands (see image). All people living in these areas are clients of Stedin (around 1.9 million households). It should be noted that Stedin is responsible for the gas infrastructure, while energy suppliers (which can be chosen by clients) are responsible for gas supply. Stedin is thus responsible for transportation of highly explosive material (gas) through densely populated areas.

Figure 2-1: Areas in Netherlands services by Stedin (courtesy Stedin).

In its service area, Stedin faces challenges to the planning of maintenance on gas pipelines. The pipe-to-household connections have a lifetime of 35 – 40 years; but with nearly 2 million connections this means some 50,000 would need to be replaced each year to keep the network within this lifetime. Many pipes can last longer however some can last for a shorter time if they are stressed by ground movements. Hence the maintenance policy is strongly driven by ground movement and by those connections which are most vulnerable.

Knowing the extent of the ground movement and where precisely it is occurring can help enormously to improve the maintenance planning; and this is where the case becomes interesting as Stedin use this EO product to support their annual planning.

Oasen is a company, located in Gouda, supplying drinking water to over 750.000 people and 7.200 companies. Oasen delivers 48 billion litres of drinking water to its customers each year.

Figure 2-2: Region served by Oasen (courtesy Oasen)

Oasen maintains 4,200km of pipeline and over 340,000 connections to houses or factories. The area around Gouda is mainly peatland and whilst Oasen uses surface ground water, water extraction from under the peat layers can cause subsidence[3]. Like Stedin, Oasen faces problems of water pipes and connections breaking causing leaks and significant disturbance to both the customers as well as other citizens using streets subject to maintenance work. Not as advanced as Stedin in the use of EO products, Oasen started in 2015 to test its use in their own maintenance operations and planning.

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[3] Land Subsidence in Peat Areas: Deltares, https://www.deltares.nl/app/uploads/2015/02/Dossier-Subsidence-Delta-Life-3.pdf

2.2   Ground Movement in the Netherlands.

In the western parts of the Netherlands, the soil mainly consists of clay and substantial areas of peat – see Figure 2-3. In both types of soil, deformation occurs; in the former due to seasonal and long-term change in moisture level whilst in peat areas, especially where they are low-lying (often in river deltas), water extraction causes the ground to sink.
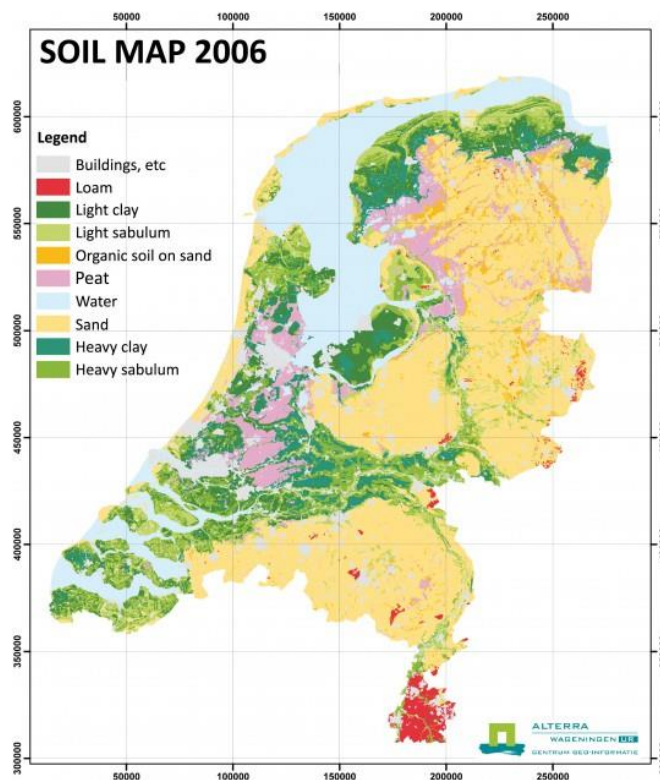
Figure 2-3: Soil map of the Netherlands

A recent report by Deltares[4], looks at the subsidence risk throughout the Netherlands. In Figure 2-4 is shown the map of susceptibility to settlement which is a measure of the likely impact throughout the country. The coastal and delta regions are seen to be those which are especially at risk. This is used later primarily to assess the risk in the areas covered by each pipeline operator.

Dutch houses are well grounded and show relatively little movement due to deformation. But, since the soil is moving and the houses are not, this puts great strain on all sub-surface infrastructure ie. pipelines. This is the situation around both Rotterdam and Gouda where our two companies operate. Two particular situations cause risk:

- For gas pipes, the problem is particularly acute where the pipelines enter the house when the movement can lead them to crack. In the case of gas supply, this can lead to dangerous situations

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[4] Bodemdalingskaarten (subsidence risk), Ger de Lange Mahmoud Bakr Jan L Gunnink (TNO), Deltares 2011

such as the crawlspace under the house filling up with gas. In 2008 an explosion caused by this happening killed one person in the Netherlands.

- For water pipes (and indeed for sewage and hot water distribution) the problem more likely occurs where pipes either cross each other or pass over solid elements in the ground. Distortion over a long length cause the pipes to bend and eventually to fracture.

Legend

Susceptibility to surcharge

Settlement after 40 years under uniform load of 1 m thick sand fill

	0 - 0.01
	0.01 - 0.05
	0.05 - 0.1
	0.10 - 0.3
	0.3 - 0.5
	0.5 - 2
	water
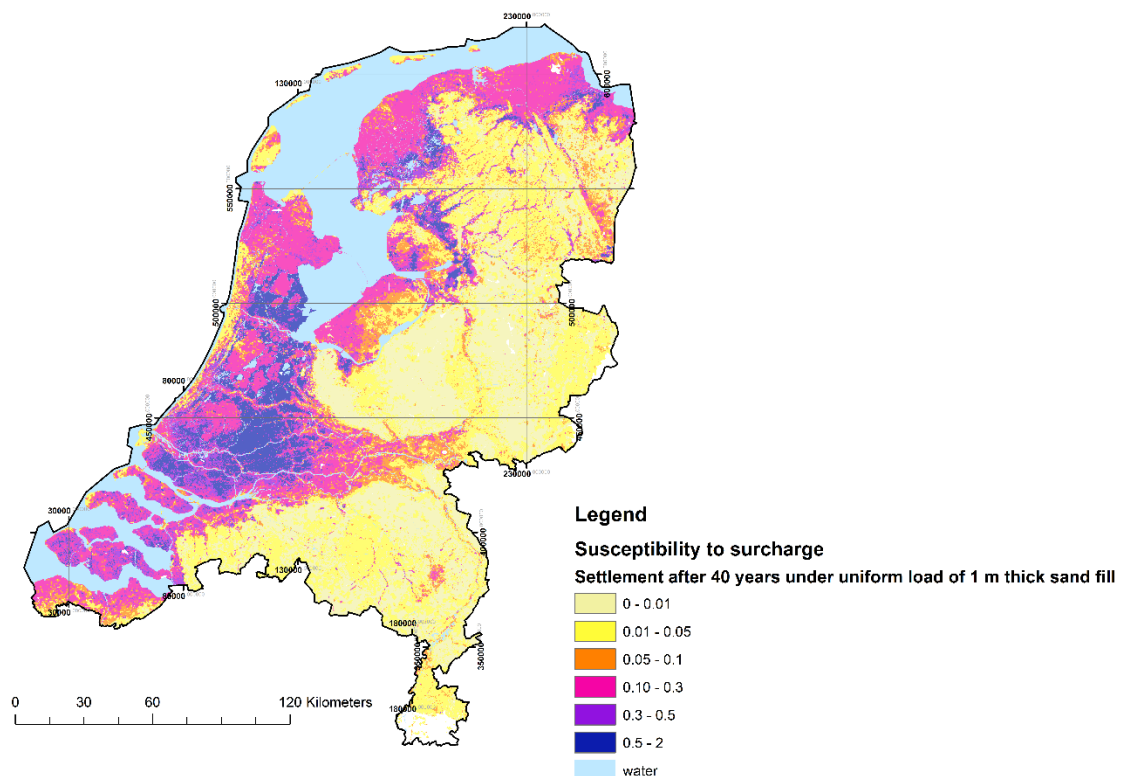
Figure 2-4: Subsidence risk across the Netherlands (courtesy Deltares).

Stedin assesses there are about 100 incidents related to gas leakage every year of which 26 are considered to bear a risk to people. It is calculated that this will increase to 35 per year under the existing replacement plans. Furthermore, there are about 19,000-20,000 gas leakages which do not have serious consequences but necessitate emergency repairs. It is estimated that one third of the gas leakages are caused by deformation and corrosion, one third are caused by excavation works and one third are due to another cause such as vandalism or theft. This means that, each year, about 6,500 leaks in Stedin's service area are caused by deformation or corrosion of the pipelines.

The pipelines are made either of plastic or copper; all newer installations are plastic. Plastic connections can tolerate 60cm to 80cm of relative movement whilst copper will crack much more quickly. In time it is planned that all the copper connections will be replaced.

This problem is not confined to the areas covered by Stedin and Oasen. Other parts of the Netherlands are also built on peat soil. Table 2-1 shows the number of gas connections maintained by each of the 9 service providers in the Netherlands. Whilst only Stedin is using the technology today, the other companies should be able to benefit by its use in the future and we shall use these figures to project a total economic-benefit value for the Netherlands in chapter 6.

Provider	# gas connections *1000	Assessed Risk
Liander	2,210	High
Enexis	1,850	Low
Stedin	1,886	High
Edinet	452	Low
Delta Netwerkbedrijf Infrastructuur	185	Low
Conet	137	Low
Westland Energie	51	High
Rendo Netbeheer	98	Low
Intergas Netbeheer	148	Medium
TOTAL	7,017	

Table 2-1: Gas connections maintained by each Service provider

The risk of failures caused by soil movement in each of the areas has been assessed by the experts involved in the study.

2.3   Pipeline Management Practises

Under present maintenance planning, each year Stedin will replace 27,000 household gas connections (up from 20,000 in the recent past) based on the selection of those areas with the highest history of leaks in previous years. This selection was based on postal code areas and all connections in the postal code area were replaced at an average cost of €1,000 per connection.

The fact that replacements are made over whole postal code areas is not optimally efficient. Firstly, the type of connection is not directly linked to the post code but more importantly, postal code areas are not related to deformations. Hence the process of maintenance or replacement of pipelines can thus become much more efficient if decisions to do so can be made at house level. With information on deformations coming from the InSAR data, coupled with the knowledge of the connection type a much more precise maintenance plan can be drawn up. This more precise planning leads to an overall reduction in risk of fractures as the more vulnerable connections are replaced much earlier than they would be otherwise. In turn, this leads to a more reliable distribution system and more importantly a safer one.

Figure 2-5: Flexible pipe connection at entry to a house (courtesy Stedin).

Whilst the main issue for Stedin is the connection at the point of entry into the houses, they do also monitor the transport pipelines i.e. those serving a neighborhood or district. This is also the main area of concern for Oasen

One of the larger risks concerns situations where pipes cross one another. Here movement over a distance causes the pipe to bend over the other (or any other rigid object) leading to a fracture. Whereas for Stedin the primary concern is that a leak leads to an explosion, for a leaking water-main the impact is less consequential. Nevertheless, it can cause significant disruption to traffic and more importantly, lead to property damage as was the case in a recent incident which led to the flooding of a hospital cellar. Damage was caused to material stored there as well as serious knock-on consequences in terms of health risk and hospital management. More common are water leaks under roads which cause disruption to the traffic and local infrastructure as seen in the instance captured in Figure 2-6.

Figure 2-7 shows a typical area at risk where pipes are crossing in different directions. Ground movement generates a risk to the pipe connections.

Consequently, the metric for Oasen is related to the length of the pipeline network which must be maintained with around 100km needing replacement each year.

Figure 2-6: Fractured water pipe (courtesy of Oasen).

Figure 2-7: Water pipe maintenance (courtesy of Oasen).

2.4 The Use of Surface Deformation Maps.

Stedin and Oasen have recently started elaborating their replacement strategies taking into account surface deformation information delivered by the Dutch service company SkyGeo.

Thanks to a powerful technique based on satellite radar imagery (explained in Section 4 of this report), SkyGeo produces detailed surface deformation maps on a regular basis, based on satellite imagery acquired every 11 days.

These maps are then complemented with information on houses and addresses to map the detected movements with house / customer addresses. With this information, the age and type of gas connection is established and the company is able to generate a list of addresses where the risk of pipeline/connection failure is higher which is then used to plan the maintenance programme.
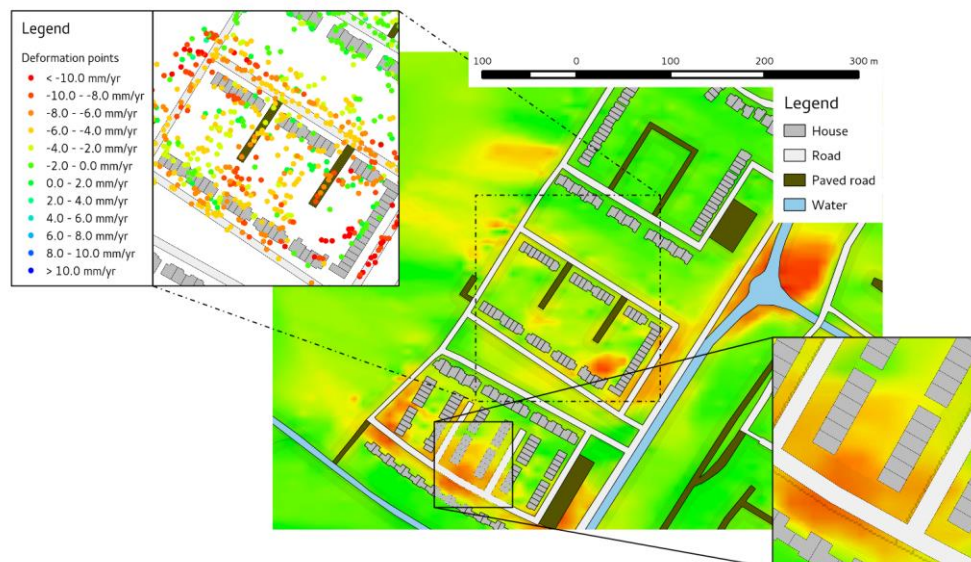
Figure 2-8: InSAR product used for monitoring of household gas connections (courtesy of SkyGeo).

Figure 2-8 shows an example of the product used by Stedin. The upper left image is of the individual scattered measurement points detected within the satellite SAR images. These are analysed to generate a heat-map of the street to show where movement is occurring. Note that the technique is able to show both heave (upward movement) and subsidence (downward movement). Subsidence is by far the most common form of movement due to extraction of water, gas or minerals or of underground water courses changing position and undermining the surface.

For Oasen the product differs slightly since the interest (and risk) lies more in the major pipelines and not in the domestic connections. Hence, the risk is more under the streets than at the house connection. A map is generated to compare the detected movement with the location of the water pipes. Here the risk lies over a length of pipe such that if there is excess movement, the pipe will crack creating a water leak. The

ground movement is scaled over distance and compared to pipe location, age etc. Particular attention is paid to places where water pipes cross other pipes or underground structures such as sewage mains.

Figure 2-9: Heat map used by Oasen showing ground movement mapped along the streets carrying pipelines. (courtesy SkyGeo)

The stars in Figure 2-9 indicate locations where previous pipeline failures have occurred.

Both Stedin and Oasen, then compare this heat-map of ground movement with their own infrastructure maps to determine where the risk lies to their network.

These images may also be used for other kinds of analysis. For example, the presence or absence of persistent scatterers can indicate that some public work has been carried out (street repairs etc) and even to indicate that the ground level may have been restored where some subsidence has occurred. Hence the heat-maps are carefully monitored for signs of change.

3   The Value Chain

3.1   Description of the Value Chain

The value-chain for the case is shown below in Figure 3-1. It is relatively narrow with rather limited secondary beneficiaries. As already described it is based on the users of ground deformation maps provided in this case by a commercial supplier. In this respect it differs from the previous cases which were based on products coming from public sector bodies (PSB's).

The value-chain is part of the methodology used as the framework on which to assess the economic benefit stemming from the primary product. It is developed from the users of derived products and services used by others.

The basic product for which we are assessing the economic value is an InSAR map (see chapter 4) showing ground movement over a period of time. These maps are used by the operators of gas and water distribution pipelines supplying mainly domestic but also some industrial users.

Tier 1	Tier 2	Tier 3	Tier 4
	Insurance companies		
Primary Service Provider: SkyGeo	Infrastructure management companies: - Gas and water utilities	Public Authorities - Municipalities. - Central government	- Local economy - Citizens
Type of information value being used	SAR Imagery from Sentinel 1 and from TerraSAR-X	ground movement maps	- Information on risk management - Maintenance planning and deformation maps - Reporting under public obligations on state of infrastructure	(Information on) perception of safety, security of supply, convenience

Figure 3-1: Value-chain for the use of SAR imagery for Pipeline infrastructure monitoring.

3.2   Tier 1: The Primary Service Provider

The primary service provider in this case is a private company, SkyGeo which is a Dutch private company providing services based on satellite imagery. Satellite SAR data coming from e.g. TerraSAR-X or Sentinel-1, is used to generate the InSAR map which is the basis for calculating ground movement and deformation. This is supplied to Stedin and Oasen as a database of points with their relative movement as well as maps derived from this database - see Figure 4-2.

3.3   Tier 2: Infrastructure Management Companies

In this case, we have worked with 2 infrastructure companies; Stedin delivering gas in the area around Rotterdam and Oasen delivering water in the area around Gouda (see Figure 2-2). Inside Stedin, in addition to the business dealing with the gas pipeline infrastructure, the ground movement map is used in departments dealing with CO_2 (Stedin CO2), hot water (Eneco Warmte) and in Stedin Asset management which is taking a more strategic viewpoint. In Oasen it is used in the department maintaining the pipelines.

In this respect, the value-chain can be considered to be shortened by vertical integration within the activities of Stedin and Oasen. Both employ their own maintenance and ground digging teams and consequently most of the benefit is seen in tier 2 where it might otherwise be shared with another tier. Is this a consequence of private sector efficiencies driving the benefits?

The value of the information is found and evaluated in tier 2 of the value chain. Nevertheless, as it is a commercial operation which is regulated by the government in the Netherlands, the benefits of improvements in working processes which are reflected in lower costs for Stedin and Oasen will both be passed on to their customers by virtue of lower prices. The process is too early to see any of this showing up in regulatory decisions nor in re-pricing of services. Hence, we have not tried to evaluate it further but simply to capture the full benefit in tier 2 where it falls today.

In the anecdote at the start of this report, we have imagined a public meeting at which a pipeline management company is explaining itself to local citizens and how its actions are making life safer and easier for each household which it serves.

3.4   Tier 3: Public Authorities

Improved planning of pipeline maintenance work also benefits the local authorities by enabling them to co-ordinate better between the companies digging up the road. The "ground diggers" as they are called which perform the actual work on the pipelines can be "lined-up" to work one after the other so reducing the impact of the work on the local population. Indeed, this benefits everyone through improved relations with the local citizens.

Public authorities also have potential to use ground deformation information in support of their planning and development responsibilities and in operational management of waste services (sewage pipes). However, today this is all potential and we are not aware of any instances where the information is used.

3.5   Tier 4: Citizens and the Local Economy.

Whilst the direct benefits of the new maintenance process will eventually be passed on to citizens, there are other softer benefits which arise for the 750,000 people served by Oasen and 2 million people served by Stedin.

a.   The risk of a gas explosion is reduced hence making life less dangerous for each citizen.

b.   There is less risk of a disrupted supply of water or gas so allowing citizens to be more assured about their household.

c.   There is less maintenance work which leads to less disruption to businesses in terms of road closures and delays or the need for citizens to attend whilst work is carried out at their property.

4   The use of Satellite Imagery

InSAR (Interferometric SAR) maps are a specific product coming from the processing of SAR (Synthetic Aperture Radar) images[5]. InSAR is a powerful technique which allows changes in "height" on the surface of the Earth to be detected with extraordinary precision. As such it is extremely valuable for monitoring movement of the surface down to mm accuracy. This has many different applications and can be applied to many different situations to detect changes underneath or on the earth's surface.

In this case, the movement of the surface is being monitored for its impact on gas and water pipelines, buried under the city streets, serving homes and factories around Rotterdam and/or Gouda in the Netherlands. SkyGeo is the service provider and quoting from their web-site[6]:

> *Most mission-critical assets for utilities are underground; deformations measured above ground are good proxies for pipelines under stress.*

InSAR measures the difference in reflection between the same point in different images taken of the same area on different days. D-Insar (differential InSAR) relies on a number of points in any scene providing coherent reflections. These are known as persistent or permanent scatterers which leads to the technique known as Permanent Scattering Interferometric SAR[7] or PS-InSAR. This technical term essentially means that the points providing coherent reflections appear the same in each radar image even when using many images covering a long period of time. For these points a direct comparison can be made between successive images. Any change in position shows up leading to the possibility to detect if the point has moved between the images. Taking a whole sequence of many images over a period of time, allows the ground movement to be detected[8] at millimetre precision. Usually these points are located on man-made features or man-made terrains[9].

Several sources of SAR imagery have been used by SkyGeo to provide products. In this case the two main sources are Sentinel-1 and TerraSAR-X but both Envisat ASAR and Radarsat-2 have also been used in the past and are included in Table 4-1 which shows the main, key characteristics of each imagery type.

The time between the images is important. If they are more than about 20 days apart, then the coherence of the point scatterers is diminished and the technique become less useful. An interval of around 10 days is considered to be about optimum also overcoming the effects of seasonal changes. This interval is bettered by Sentinel data and is met by TerraSAR-X as shown in Table 4.1.

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[5] An Overview of SAR Interferometry. Rocca F., Prati C., Ferretti A. ESA Web-site https://earth.esa.int/workshops/ers97/program-details/speeches/rocca-et-al/

[6] http://www.skygeo.com/

[7] Permanent scatterers in SAR Interferometry; Alessandro Ferretti, Claudio Prati, and Fabio Rocca; IEEE Transactions on Geoscience and Remote Sensing, Vol. 39, No. 1, January 2001

[8] PS-InSAR processing methodologies in the detection of field surface deformation—Study of the Granada basin (Central Betic Cordilleras, southern Spain); Sousa et al. Journal of Geodynamics 49 (2010).

[9] The use of man-made features for long time-scale InSAR. S Usai, Proceedings IGARSS 1997.

Also, of particular importance for this case is the spatial resolution of the imagery. The separation of the measurement points on the ground (spatial resolution or ground resolution) determines how far apart the measurement points must be to show up.

Source	Frequency Band	Image width (km)	Resolution on-ground (m)	Revist interval	Comments
Sentinel -1a&b	C	250km	5x20m	6d	Free and open data
TerraSAR-X	X	10km	3mx3m	11d	Commercial data
Envisat - ASAR	C	100km	20mx4m	24d	Free and open data
Radarsat	C	100km	25mx7m	20d	Commercial data

Table 4-1: Main key characteristics of the Radar sources used.

As an example, Figure 4-1 shows a comparison between Envisat and TerraSAR-X. The figure shows typical differences in InSAR measurement point density of standard resolution images (Envisat, left) and very high-resolution images (TerraSAR-X, right). In the left image, the 4 x 20 m pixel size mostly yields measurement points on the buildings, while in the right image the streets are densely covered as well due to the 3 x 3 m pixel size.

Figure 4-1: InSAR measurement point density of standard resolution images (Envisat, left) and very high resolution images (TerraSAR-X, right) (courtesy SkyGeo).

The Envisat mission ended its life in 2012. It has been used in the past (together with Radarsat) before the first Sentinel-1 was launched in April 2014. Recently, a second satellite of the same type (Sentinel-1B) has been launched, bringing the revisit capabilities of the constellation to better than 6 days at these latitudes. The systematic operational coverage and the high revisit of Copernicus Sentinel-1 greatly benefit InSAR analysis for many interferometric applications. The value of space assets (incl. navigation) for monitoring the integrity and safety of gas & oil transmission pipelines is also investigated as part of another ESA project PYMSyS[10]. For the current case, however, the needed revisit frequency is not that stringent and 11 days is considered sufficient.

Recent examples featuring Sentinel-1 data are shown in Figures 4-2. Here we can see several areas which are subsiding with one in particular standing out towards the lower left of the map.

The zooms (lower maps in Figure 4-2) demonstrate why the Stedin and Oasen business case is based on TerraSAR-X. In fact, the granularity of the medium resolution data is too widely spread to serve as a basis for engineering decisions at 'front door level' and with a ground resolution of around 80m^2, the information density provided by Sentinel-1 is too low. Instead, TerraSAR-X ground resolution (between 1 to 10m^2) can pinpoint the movement on the ground with the needed accuracy.

Hence the two images types are quite complementary; Sentinel-1 imagery gives wider coverage (a strip 250km wide at moderate spatial resolution) and can identify areas at risk whilst TerraSAR-X data covers a much smaller area (a strip 10km wide) and can resolve on a horizontal direction to a scale equivalent to houses.

Nevertheless, TerraSAR-X images are commercial and for the areas of interest this results in a substantial investment. Sentinel-1 data, on the other hand, are free and systematically, openly available[11]. Hence, SkyGeo makes use of Sentinel-1 data to make a broad monitoring campaign at low cost[12] to get rough indicators and trigger the acquisition of TerraSAR-X data for the hot spots considered in the need of deeper investigations.

The overall spatial extent of the areas serviced by both Stedin and Oasen do not overlap and require 2 separate sets of satellite images (i.e. multi-temporal "stacks" over the same areas) , leading to significant investments in data in the order of €60k per year for each site. Assuming that on average only 2/3 of the territory is affected by important subsidence effects requiring in-depth analysis to be performed with high-resolution data, a Sentinel-based pre-screening would let the service costs drop of about 1/3 for the utility companies.

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[10] A further application for monitoring transport pipelines also in the Netherlands has been investigated as a research project under the ESA ARTES programme. https://artes-apps.esa.int/projects/showcases/monitoring-pipelines-space

[11] See https://scihub.copernicus.eu

[12] Even if Sentinel data is free there is a processing cost to SkyGeo.
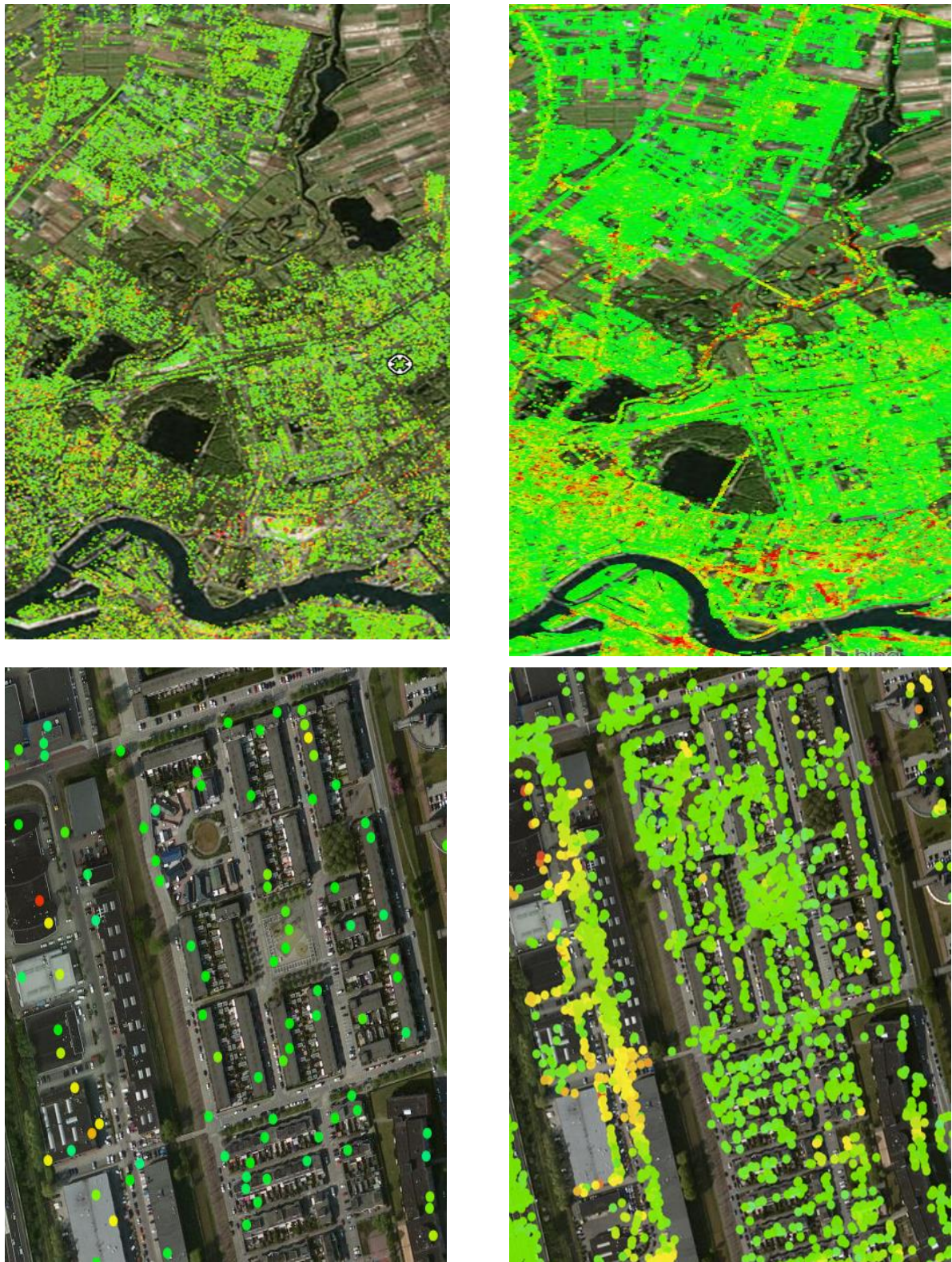
Figure 4-2: Ground Movement maps using standard resolution images from Sentinel-1 (left) and very high resolution images from TerraSAR-X (Stripmap 3x3m resolution, right) (courtesy of SkyGeo).

In conclusion, the efficient combination of low-resolution free Sentinel-1 data and high-resolution commercial TerraSAR-X data allows SkyGeo to provide more efficient and affordable services to their customers. On top of that, the throughput time is much lower as opposed to the situation where the TerraSAR-X stack is established first[13] so the quality of the processed data is improved. In the future, and, particularly for new business in new geographical regions, Sentinel-1 data will be used to show the infrastructure risk exposure at a low cost (free data) and for operational long-term monitoring, whilst TerraSAR-X will be used on an operational basis as described in this case.

The InSAR map generated for Oasen differs slightly from that for Stedin. For the latter, the interest is ground movement in the vicinity around each house. For Oasen, the interest is in ground movement of the streets under which pass the main water pipelines. A sample of the type of product used is shown in Figure 4-3. It clearly shows the distribution of point scatterers selected to be along the streets.

Figure 4-3: Point scatter map used by Oasen (courtesy SkyGeo).

Figure 4-3 also illustrates the density of points coming from the use of the high resolution TerraSAR-X data. Such images are not yet widely available from Sentinel data. Projects such as that mentioned earlier under the ESA ARTES programme[10] are investigating the generation and application of point scatter maps from Sentinel-1 data with the goal to improve the quality of inspection and at the same time to lower inspection costs incurred by pipeline operators.

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[13] In the Netherlands, TerraSAR-X images are acquired over most of the subsiding areas in the Netherlands to provide data to SkyGeo's turn-key products.

5   Linking Economics to Reality

In this chapter we are taking the information which is derived from the satellite imagery and linking it to the economics of the case. This will set the basis for our more detailed assessment of the economic value in chapter 6.

In this case, as in the other two cases analysed within the framework of this study, we can establish fairly solid estimations of benefits sparked by the usage of the imagery at the beginning of the value chain: the companies (Stedin and Oasen) that rely on the imagery and that can calculate the benefits as a result thereof. As always, projected reduction of costs is easier to measure than increase of returns. Moving further down the value chain, it becomes much harder to assess such benefits, in particular in this case, as it concerns conceived public safety – which is really hard to monetize – of a large amount of people (which will likely have different opinions on the value).

Accordingly, we have relied on 'anecdotal evidence' trying to assess the value for the third tier of users, being the municipalities. For the fourth tier - companies and citizens using gas and water through the connections of Stedin and Oasen - we applied the same model as we did in the Finnish Ice Breakers case: putting a price tag on the increased safety of the connections that these companies and citizens would be willing to pay.

So linking economics to reality – the main purpose of this chapter – we will concentrate on the calculation of the benefits that are generated by Stedin and Oasen using the satellite imagery in their business processes, as this requires some modelling (set out below). For the other benefits, the calculation methods are fairly straight forward.

5.1   Economic theory on Life Cycle Costing

To determine the value of the usage of the imagery for Stedin and Oasen, we are relying on so called 'life cycle costing' (LCC). In essence LCC compares the cost-effectiveness of alternative investments from the perspective of an economic decision maker. The time horizon of an LCC analysis is the economic lifetime of the investment which are set by the accounting conventions of the decision maker. The process scope of the LCC includes only those processes imposing direct economic costs (or benefits), or rather the cash streams related thereto, upon the decision maker. The word 'life cycle' refers to the total time period between the acquisition of an asset and the moment that it is either fully depreciated (economic or accounting lifetime), or discarded as waste or sold on the second-hand market (technical lifetime).

In our case it concerns the comparison between two scenarios that Stedin and Oasen are facing running their business processes, being: (1) relying on the imagery (2) not relying on the imagery (packaged and delivered as a service by SkyGeo). Below we will describe this model in more detail, which includes the theoretical formulas we have been using to carry out the calculations as well as the process of applying this calculation method. As we appreciate that for some readers this may be a bit too theoretical, chapter 7 – the chapter where we do the actual calculations on the case – has been drafted in such form that it is comprehensible even without having read this chapter 6 in full.

Below we will first describe the process of application of LCC, followed by an explanation of the key input and output and the underlying formulas.

5.2 LCC application process

In essence LCC is applied by following a 4-step procedure:

a. Definition of the scope of the analysis

b. Identification of the relevant cost components

c. Gathering of data and derive cost estimates

d. Calculation of Key Financial Indicators

a. Definition of scope

What are the criteria and what is the basis for the decision?

In essence LCC is to facilitate a long term decision. Then the main question is which are the main criteria for that decision. Is it 100% client satisfaction, is it optimisation of profit or is it maximum cost reduction? In this case the criterion will be the most efficient use of resources (lowest costs and absorption of financial means).

Which time period is to apply?

The second is to define just how long time horizon is. Obviously, defining the time horizon:

-   It must be the same for each alternative.

-   It is restricted by the longest physical lifetime amongst the alternatives.

-   It is restricted by the investment horizon of the decision maker

In both the Stedin and Oasen calculations we will be applying a 9 year period, which is basically set by the time needed to replace a specific vintage of connections (being those that are 21 years of age in the first year of our calculation period).

What are the system boundaries?

Thirdly, it is crucial to explicitly state the important assumptions on which the analysis rests. These assumptions define the system boundaries, determining which factors will be taken into account.

The main assumption in our case is that the usage of the imagery will actually lead to better decision making as to the connections to be replaced. In the Stedin case, to be on the safe side, we assumed that the quality of the decision making will increase by 10%, meaning that Stedin can pinpoint the connections to be replaced with 10% more accuracy than in the situation without the usage of the imagery.

b. Identification of relevant cost components

Once the scope is defined, the cost components that are to be taken into account need to set. Quite importantly, only those are to be included that differ significantly between the alternatives. Accordingly, we only must take into observation those costs and benefits that are different between the alternatives under consideration. Costs and benefits which are not affected by choosing one of the alternatives, should be left out of the equation. Like for instance the fixed leasing costs of the Stedin and Oasen offices.

For this case these components are:

- Costs of failures

- Capital expenditures (CAPEX)

- Interest costs of the capital measured in the form of weighted average costs of capital (WACC)

-

c. Gathering of data and deriving cost estimates

After determination of scope and identifying the relevant cost components to be taken into account, the relevant data are to be gathered, being the costs for each year of the time horizon. Typically, this involves:

- Making a first rough LCC estimate to guide data-gathering efforts, making sure one does not spend time on insignificant cost components

- Identification of information resources available which includes: historical data, expert opinions

- Selection of an appropriate cost estimation method for each cost component.

In this case we have relied on solid longitudinal data (like failure frequencies of connections of a certain age), assessments of coasts (like failure costs that are incurred when a connection breaks down) and expert opinions (like the likely long term impact of the usage of imagery, and interest rate when discounting the costs of capital (for both we have taken a conservative number)).

5.3   Make the calculations on the costs setting the key financial indicators

As LCC Analysis is made to facilitate a decision - which alternative is the best choice from a long- term perspective? – the time element of money is crucial (as we will also see in this case).

Due to the time value of money costs that are incurred over time cannot simply be added up: adding up costs that occur in different years. It is not the same as inflation, which is the rise in the general level of prices for goods and services. It is the reason why everybody prefers having €500 today and not in five years' time, even if the same amount of goods and services could be bought with it at that point. During these five years, this amount can be invested in several profitable ways and not doing so 'costs' money as well.

a. Present value by discounting

Put differently: each cost that occurs in the future will have a Present Value (PV) that is different from its Future Value (FV). The relation between the PV (in year 0) and the FV (in year k) is given by the following formula:

$$PV = \frac{FV}{(1+i)^k}$$

Application of this formula is called 'discounting', and the most important parameter to determine is the discount rate i, that will define how big the difference is between FV and PV.

The discount rate represents the time value of money. Likewise, inflation, also contributes to the fact that money, normally, loses value over time. As inflation has about the same influence on both scenarios of the Stedin case it can be discarded, so that we can simply use the nominal discount rate.

b. Weighted Average Cost of Capital

In essence, the discount rate reflects the investor's 'opportunity cost of capital': capital employed now does not come for free: either it is borrowed capital (debt) or own capital (equity). Both debtors and shareholders will expect a certain return from their money and will only keep providing funds when their expectations are met. An accepted benchmark for the opportunity cost of capital – and thus for the discount rate – is the Weighted Average Cost of Capital (abbreviated as WACC). WACC is calculated as the rate that one should pay on average to the owners of its capital. In this formula:

$$WACC = \frac{D}{E+D} Rd(1-t) + \frac{E}{E+D} Re$$

- IE represents the market value of the equity
- D is the total debt
- Rd is the interest paid on debt
- t is the tax rate
- Re the return that a shareholders expect

Typically, in high risk business, a company's WACC will be bigger since both shareholders and debtors expect a greater return, while in a stable business context, a company's WACC will be smaller. Accordingly, in the Stedin case we have applied a low Re (as the shares are held by governmental organisations) and we have set the WACC at 2%.

c. The Net Present Value

The Net Present Value (NPV) is the sum of the present values (PVs) of the individual cost components, whereby each instance of each cost component is discounted according to the year in which it occurs. An NPV value can be calculated for each time series of costs, but in the context of LCC it is a way to evaluate the total, long-term cost of each alternative or, in other words', NPV allows for compare between different options in monetary terms. In this formula:

$$NPV = C_o + \sum_{k=1}^{T} \frac{C_k}{(1 = i)^k}$$

- C_k = all costs occurring in year k
- C_o = initial investment in year 0
- T = represents the time horizon
- i = the discount rate

Accordingly, the NPV for each of the alternatives can be determined, which indicates the total cost impact of every alternative, taking the full time horizon into account. Subtracting the NPV of alternative A from the NPV of the base case gives the total cost saving of that alternative over the base case (if it is positive).

In the calculation schemes in the next chapter, we have been relying on these key financial indicators at various points. We will not refer to these formulas explicitly; rather we will translate them into the narrative of the cases (which makes them much easier to comprehend).

6 The Economic Assessment

In this chapter we bring together the information of the previous chapters to analyse the economic benefit arising from the use of the satellite imagery. After the primary supplier (SkyGeo), we shall start with the second tier users – Stedin and Oasen –then move on to the third tier (municipalities) and the fourth tier (companies and citizens relying on the gas and water transported through the pipes of Stedin and Oasen.

As indicated in the previous chapter, this case is truly centred around the assessment of value accrued in tier 2, whereby we will be relying on the method described in chapter 5. The benefits sparked in the other two tiers are assessed rather anecdotally.

6.1 Tier 1: SkyGeo

In the other two cases we analysed, we have not considered the primary service provider to be additive to the benefits as they have both been public sector organisations. Since SkyGeo is a commercial company, where their clients are paying for the services, we consider that there is a net additional benefit coming from their service in the form of extended employment and revenues (delivering taxes). The benefit to SkyGeo is commercial through more business and profit but the exact value of business which SkyGeo is doing is confidential and does not directly figure in the case.

Our approach is that, in the absence of hard figures, we make estimates. If we assume that the business allows to employ 1 FTE who is working on the supply of the products to Stedin and Oasen. From the EARSC industry survey[14] we find that companies of the size of SkyGeo are generating €70k - €80k of revenue per person employed (without data costs). The cost of the TerraSAR-X data for one site is around €60k, hence we can project a cost for the two project areas of €200k (€80k + 2*€60k).

This figure is included as a revenue for SkyGeo but is then deducted as a cost for Stedin and Oasen (see table 6-10).

Economists generally use a multiplier to evaluate the impact of person-revenue on the wider economy. In the market assessment[15] carried out to support the GMES/Copernicus programme, a multiplier of 3.2 has been used for jobs in the downstream sector ie 1 job in the sector creates 3.2 jobs in other sectors. This is a robust figure which has been calculated by the London School of Economics. Hence if we use this, we can assess an additional economic benefit coming from the service provider using EO data of around €250k per annum. This is added into the benefits from the case.

6.2 Tier 2: Stedin and Oasen

The main benefit of the use of satellite imagery is in the fact that both Stedin and Oasen can maintain and manage their assets (pipes and mains transporting gas and water respectively) much more cost efficiently.

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[14] A Survey into the State and Health of the European EO Services Industry; EARSC, September 2015.
[15] Assessing the Economic Value of Copernicus: "European Earth Observation and Copernicus Downstream Services Market Study". Spacetec Partners for the European Commission, December 2012.

Below we will calculate those core benefits. From the benefits we shall deduct the cost of the service as estimated for SkyGeo.

Next to that there are side benefits like: better strategic information allowing for further cost reduction (like staff), lower insurance costs as the number of calamities will go down. Obviously, these side benefits are hard to measure, in particular since both Stedin and Oasen have only recently started to use imagery, in fact still in a project context, so that there are no hard numbers on the occurrence of them, let alone on the financial value.

6.2.1 Core benefits

Using the imagery allows Stedin and Oasen to yield three types of benefits:

- Reduction of the replacement costs (in the form of capital expenditure (=CAPEX)

- Reduction of the failure costs (in the form of capital expenditure (=CAPEX)

- Reduction of the costs of capital absorbed in their assets in the form of weighted average costs of capital (=WACC)

As indicated above the Stedin and Oasen cases are quite similar: both seek to avail themselves of imagery (both high and medium resolution) to increase the quality of their asset management (the pipes through which they transport gas and water respectively). Accordingly, we can apply the same calculation scheme and method: only the values to be plugged in differ. The table below holds the variables as well as the values and the assumptions we will be using to calculate the benefits generated by the usage of the imagery.

Assumptions/variables + given values	Explanation	Stedin	Oasen
Description of the population of the case	The population consists of the assets that establish the basis for calculating the differences in the costs and benefits	The number of connections of pipes entering buildings of potential low quality	The kilometres of potentially low quality mains transporting water
Population qualification criterion	Starting point is the notion that at a certain age the assets will show deficiencies due to age, type of connection and ground deformation, requiring replacement.[16]	This concerns connections that have an age of 21 years in year 1	This concerns mains that have an age of 40 years in year 1

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[16] This point was explicitly discussed with Stedin and Oasen and at present they are involved in researching the correlation between deformation and need for replacement and age and need for replacement. Obviously, at some point the connections have reached the end of their technical life, but due to the current replacement policy, that point is not reached (as they are replaced before that point in time (in the subsiding areas)).

Assumptions/variables + given values	Explanation	Stedin	Oasen
Size population	Both Stedin and Oasen know exactly the ages of their assets for this year where deficiencies start to emerge, so also re-spectively, the number of gas connections and the length of the water mains that have this particular age	243,000 connections	1000 km of mains
Case calculation period and sample size (without and with imagery)	For applying LCC a fixed period is essential. We have started on the basis of the Stedin case: the period of 9 years is set by the fact that in the Stedin case there are 243,000 connections with an age of 21 years and to address the failure risk 27,000 should (and can) be replaced yearly, thus leaving a time period of 9 years if one was to replace all connections of that particular age. To make the Stedin and Oasen cases comparable, we have applied the same period to the Oasen case	9 years and 27,000 connections and 24,300 connections	9 years and 40km and 44km
Failure probability curve over time	Function relating chances of failure and the age of the as-sets based on longitudinal his-torical data on failures. Based on this function the ex-pected number of failures can be calculated for each consec-utive year and for each vintage of assets	Based on longitudinal measurements of Stedin, see Figure 6-1	Oasen has no longitudinal historical data thereon.
Impact on failure probability curve	Assumption is made that the failure frequency will decrease in both scenarios (ie. with and without usage of the imagery) in the same way. Accordingly the failure costs are the same in both scenarios and left out of the equation.		
Cost of failure in euro's	Failure of assets casus costs which include: - Costs of localisation - Costs of repair - Costs of team on alert 24/7	10,000 per failure	5,000 per failure

Assumptions/variables + given values	Explanation	Stedin	Oasen
	- costs of clearance of the area, including costs for police force and other emergency services - insurance costs covering the risk component		
Replacement costs in euro's	Normal replacement activities come at a cost like: - working hours staff - spare parts used - excavation costs - re-instatement costs	1,000 per connection	180,000 per km
interest	Interest used for CAP calculation	2%	2%
Change in asset replacement policy	The enhanced information position allows for identification of only those assets that really require replacement, which leads to a number of economic effects. For Stedin, this 10% is based on two research projects it did relying on imagery while replacing connections. In one project this led to 50% better decisions and in the other (Rhoon) up to 10% better decisions. Accordingly, we have taken the conservative percentage of 10%. As Oasen is only at the starting point of using the imagery, the safe estimation of Stedin has been used.	1. Stedin estimates that it will do 10% less than the replacements that it would have made if the imagery would not be available (so 24,300 instead of 27,000 connections) 2. Stedin leaves the connections which otherwise would have been replaced (ie. Those in a full postal code area) Accordingly, it does not disinvest and extends the life time of its assets, while lowering the CAPEX.	Oasen estimates that it would have to do 10% more replacements if it would not have had the imagery, to achieve same service level, so it should do 44km, instead of 40km with the imagery available

Table 6-1: Assumptions and data used for the analysis

6.2.2   Core benefits from the Stedin case

a.   Scenario without satellite imagery

Starting point in the Stedin case is a recent research report – not taking into account availability of satellite data – that at present it must replace 27,000 connections per year to meet its maintenance requirements. However, the issue is that before it started to use satellite data, it had to cast a rather wide net (simply replacing all connections in a certain postal code if a set number of complaints had come in). Such

replacement operation could involve both old and new connections and, and this is most important to the understanding of the case, also connections which could still be in perfect order.
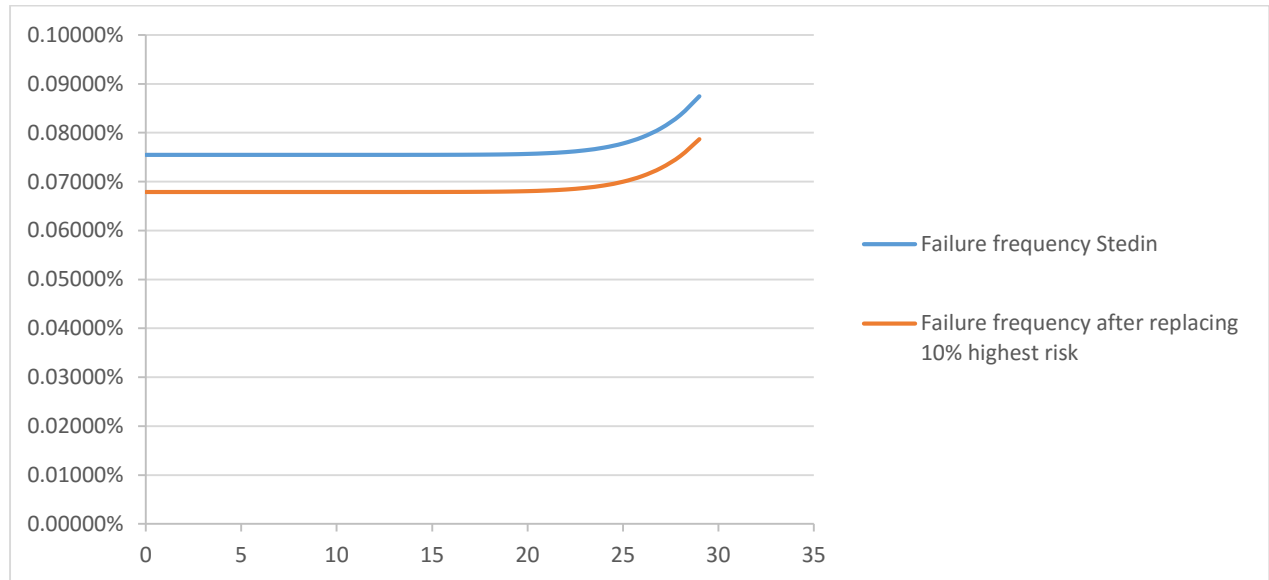
Figure 6-1: failure frequency experienced by Stedin over the ages of the connections

Secondly, Stedin knows, from its failure frequency function (see Figure 6-1 above), that the age at which the connections start to malfunction (as described in chapter 2.2) is 21 years, and as it has a complete overview of the exact ages of its connections, it can establish that there are 243,000 connections with an age of 21 years. Accordingly, these 243,000 connections form the population of this case. Dividing these 243,000 connections over its commitment to replace 27,000 connections per year, gives us the exact period of measurement: Stedin will need 9 years to replace all connections with the current age of 21 years (vintage 21).

If it was to concentrate on vintage 21 – and theoretically it would as it has no other indication to replace other vintages[17] – as consequence it would leave all other vintages untouched. Essentially, Stedin will simply 'follow' vintage 21 throughout the 9 years until it has replaced all 243,000 connections: this is reflected by the diagonal green bar of 100% (representing 27,000 connections each year) moving from the top left corner to the lower right corner in Table 6-2. These replacements lead to replacement costs – or

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[17] Note: in making the business case, Stedin knows that at the age of 21 years the failure curve starts to go up, so there is ground for replacing them. In that sense it does not make a difference which age is taken, as we wish to compare the situation where Stedin does not have a clue as to the **real** risks as opposed to where it knows exactly what the deformation is like. So you could have another vintage. This is a crucial element of this case: it is the calculation method applied to the future. This is described in the first section of 5.1: it is about deciding about an investment for the future and this is a fundamental difference with the other two cases.

rather capital expenditure, so called CAPEX – which are easy to establish: 27,000 connections x 1,000 euro, absorbing 27 Meuro each year, adding up to a **total replacement costs of 243 Meuro**.

Year	Average Asset Age	Failure frequency of total population									CAPEX in Meuro		total failure costs in Meuro
		27000	27000	27000	27000	27000	27000	27000	27000	27000	per year	cumulative	
21	18.67	100%	20.46	20.46	20.46	20.46	20.46	20.46	20.46	20.46	27	27	
22	17.22	20.37	100%	20.53	20.53	20.53	20.53	20.53	20.53	20.53	27	54	
23	15.67	20.37	20.37	100%	20.62	20.62	20.62	20.62	20.62	20.62	27	81	
24	14.00	20.37	20.37	20.37	100%	20.78	20.78	20.78	20.78	20.78	27	108	
25	12.22	20.37	20.37	20.37	20.37	100%	21.00	21.00	21.00	21.00	27	135	
26	10.33	20.37	20.37	20.37	20.37	20.37	100%	21.35	21.35	21.35	27	162	
27	8.33	20.37	20.37	20.37	20.37	20.37	20.37	100%	21.85	21.85	27	189	
28	6.22	20.37	20.37	20.37	20.37	20.37	20.37	20.37	100%	22.58	27	216	
29	4.00	20.37	20.37	20.37	20.37	20.37	20.37	20.37	20.37	100%	27	**243**	
Total # failures over 9 years		163	163	163	163	164	165	165	167	169			
Failure costs		1.629	1.630	1.632	1.634	1.638	1.645	1.654	1.669	1.691			**14.828**

Table 6-2: overview failure frequency replacements and costs and (cumulative) CAPEX without using satellite imagery.

Of course confining itself to vintage 21 (leaving the older vintages untouched) leads to failures. Based on the failure frequency we can calculate the number of failures we can expect throughout each period (these are marked in red). So in year 1, the vintages 22 up to and including 29 can be expected to yield 20.37 failures each, adding up to 163 failures in year 1. With time, this risk will slightly increase (as the average age is increasing) leading to 169 failures in year 9. As we know the costs for failure we can establish how much failure costs we can expect: 1482 failures x 10.000 euro per failure leading up to a **total cost of failures of 14.8 Meuro**.

b. Scenario with satellite imagery

Now consider the situation where Stedin can determine where the replacements are to take place based on the evaluated risk based on the imagery that allows to see where the deformation is taking place at the level of individual addresses of buildings. Accordingly, it can fully focus on those connections that are very likely to malfunction, as the deformation map forms a clear indication of trouble to be expected.

Hence, instead of casting a wide net capturing a full vintage, it will now scatter focus its replacement activities on the gas connections with higher risk regardless of the vintage. We assume that the replacement will still concern about 10% of the connections of the 9 vintages (from age 21 to 30). Also, based on the projects Stedin did, not 100% but only 90% of the original 27,000 connections are to be replaced. So that leads to a **total replacement cost of 267.3 Meuro** as demonstrated in Table 6-3.

As Stedin is now able to pinpoint which connections to replace, the number of failures falls to a lower level of 156 failures per year. Obviously, as the average age of the assets will go up, more failures will happen, but this is largely compensated by the fact that Stedin is able to pick those connections with high likeliness of near future failure. Adding up the expected failures we get to an expected amount of 1262 failures over a period of 9 years, corresponding with a **replacement cost total of 14.0 Meuro.**

| Year | Average Asset Age | Failure frequency of total population | | | | | | | | | CAPEX in Meuro | | total failure costs in Meuro |
		27000	27000	27000	27000	27000	27000	27000	27000	27000	per year	cumulative	
21	18.90	10%	10%	10%	10%	10%	10%	10%	10%	10%	24.3	24.3	
22	19.90	18.66	18.66	18.66	18.66	18.66	18.66	18.66	18.66	18.66	0.0	24.3	
23	20.90	18.74	18.74	18.74	18.74	18.74	18.74	18.74	18.74	18.74	0.0	24.3	
24	21.90	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	0.0	24.3	
25	22.90	19.05	19.05	19.05	19.05	19.05	19.05	19.05	19.05	19.05	0.0	24.3	
26	23.90	19.33	19.33	19.33	19.33	19.33	19.33	19.33	19.33	19.33	0.0	24.3	
27	24.90	19.74	19.74	19.74	19.74	19.74	19.74	19.74	19.74	19.74	0.0	24.3	
28	25.90	20.32	20.32	20.32	20.32	20.32	20.32	20.32	20.32	20.32	0.0	24.3	
29	26.90	21.16	21.16	21.16	21.16	21.16	21.16	21.16	21.16	21.16	0.0	24.3	
29	0.00	100%	100%	100%	100%	100%	100%	100%	100%	100%	243.0	**267.3**	
Total # failures		156	156	156	156	156	156	156	156	156			
Failure costs		1.559	1.559	1.559	1.559	1.559	1.559	1.559	1.559	1.559			**14.037**

Table 6-3: overview failure frequency replacements and costs and (cumulative) CAPEX with the use of imagery.

Comparing these figures with the scenario of not having the satellite imagery, the gains are already substantial. However, the big wins are actually slightly concealed: as Stedin is only replacing those connections which are likely to fail, it is able to postpone its investments. However, to keep the business case sound and on the safe side, we have opted for a big replacement in the last year, meaning that the CAPEX will go up dramatically, ensuring that we have done the same amount of replacements as in the first scenario (as we shall see, this actually creates a very interesting side benefit). However, that large sum – 243 Meuro – has not been frozen as it was in scenario 1. Obviously, freezing this cash comes at cost, which we can calculate on the basis of discounting the weighted average capital costs (WACC), which we have set at 2%. This allows us to 'count', or rather discount, the CAPEX and compare the differences in scenario 1 and scenario 2, as demonstrated in Table 6-4. This delay in investment adds up to the significant sum of **64.8 Meuro savings in capital costs**.

Year	weighing factor	WACC	Cumulative CAPEX in Meuro			benefit in Meuro
			without	with	delayed	
21	9	2%	27	24.3	3	0.5
22	8	2%	54	24.3	30	5.1
23	7	2%	81	24.3	57	8.4
24	6	2%	108	24.3	84	10.6
25	5	2%	135	24.3	111	11.5
26	4	2%	162	24.3	138	11.4
27	3	2%	189	24.3	165	10.1
28	2	2%	216	24.3	192	7.7
29	1	2%	243	267.3	243	-0.5
						64.80

Table 6-4: differences in WACC comparing scenario's with and without imagery

So adding everything up the paramount impact of the usage of the imagery becomes crystal clear, as Table 6-5 shows: the total benefit over the period of the business case amounts to 41.3 Meuro, meaning a benefit per year sparked by the usage of the imagery of 4.6 Meuro.

	without	with	difference without vs with
Total Capex	243.00	267.30	-24.30
Total Failure Costs	14.80	14.03	0.77
Total Costs	257.80	281.33	-23.53
difference capital costs			64.82
total benefit			41.31
Total benefit per year			**4.59**

Table 6-5: Annual benefit for Management of Gas Connections

We saw above that in the last year we actually took on-board a huge investment bringing up the number of replaced connections to the same level as in the scenario without the use of the imagery. Likely and in practice, of course, Stedin will not do this investment in year 9, but rather spread this – obviously, at some point the old connections that were still fine during the 9 years of the business case will need to be replaced – towards the point that they have reached a certain age (or if deformation information requires so any earlier) over the next 10-20 years. This actually creates an invisible benefit: due to the investment in year 9, theoretically, Stedin has replaced *all* connections (of the 243,000) meaning that the average age has come down to 0 years, whereas in the scenario without the imagery the average age is still 4 years. Put differently: in the scenario with the imagery Stedin not only has a core benefit of 4.59 Meuro per year, also the quality of its assets has gone up. We cannot monetize this, but for sure the benefit exists, although, literally, hidden under the soil.

6.2.3 Core benefits from the Oasen case

Starting point in the Oasen case is the assumption that the use of the imagery will allow Oasen to maintain its service level ambitions however with lower efforts: with the imagery Oasen can confine itself to replacing 40km mains per year whereas without the imagery it would have had to replace 44km mains per year. Secondly, in the Oasen case the assumption is that the usage of the imagery will not impact the failure frequency, as at present there is no factual basis for this. Contrary to the Stedin case, Oasen has not experimented yet with the imagery. Accordingly, the failure costs are to be left out of the equation since they will not differ in the two scenario's. Accordingly, the Oasen case centres around the difference in CAPEX and the economic benefits deriving therefrom.

Also the age at which the assets may become potentially weak differs from the Stedin case: Oasen faces that risk as of year 40. Since we have sought to synchronize the cases as much as possible we have maintained the period of 9 years, meaning that the Oasen case applies to a vintage of mains of 40 years and older. That population consists of around 1000km of mains. Replacing 1 kilometre of main costs 180.000 euro (staff, material etc. Accordingly, we can set up the calculation scheme that allows us to compare both scenario's as demonstrated in Table 6-6 and Table 6-7.

| | Failure frequency of total population | | | | | | | | | CAPEX in Meuro | |
Year	1000	956	912	868	824	780	736	692	648	per year	cumulative
40	44.00	0	0	0	0	0	0	0	0	7.9	7.9
41	0	44.00	0	0	0	0	0	0	0	7.9	15.8
42	0	0	44.00	0	0	0	0	0	0	7.9	23.7
43	0	0	0	44.00	0	0	0	0	0	7.9	31.6
44	0	0	0	0	44.00	0	0	0	0	7.9	39.6
45	0	0	0	0	0	44.00	0	0	0	7.9	47.5
46	0	0	0	0	0	0	44.00	0	0	7.9	55.4
47	0	0	0	0	0	0	0	44.00	0	7.9	63.3
48	0	0	0	0	0	0	0	0	44.00	7.9	**71.2**

Table 6-6: overview (cumulative) CAPEX in scenario without using satellite imagery.

Year	Failure frequency of total population									CAPEX in Meuro	
	1000	956	912	868	824	780	736	692	648	per year	cumulative
40	40.00	0	0	0	0	0	0	0	0	7.2	7.2
41	0	40.00	0	0	0	0	0	0	0	7.2	14.4
42	0	0	40.00	0	0	0	0	0	0	7.2	21.6
43	0	0	0	40.00	0	0	0	0	0	7.2	28.8
44	0	0	0	0	40.00	0	0	0	0	7.2	36.0
45	0	0	0	0	0	40.00	0	0	0	7.2	43.2
46	0	0	0	0	0	0	40.00	0	0	7.2	50.4
47	0	0	0	0	0	0	0	40.00	0	7.2	57.6
48	0	0	0	0	0	0	0	0	44.00	7.2	64.8
48									36.00	6.5	**71.3**

Table 6-7: overview (cumulative) CAPEX in scenario with using satellite imagery.

So, as in the Stedin case, in the last year a sharp increase in the CAPEX is visible: this is done to 'close' the business case, so the number of assets replaced (the number of kms of main) is the same, which allows for comparison of costs and benefits (or rather the cash out). Table 6-8 provides an overview of those and as we can see, the delayed investment leads to an overall economic benefit of €2.4M over a period of 9 years, corresponding with a yearly benefit of approximately €274k.

Year	weighing factor	WACC	Cumulative CAPEX in Meuro			benefit in Meuro
			without	with	delayed	
40	9	2%	7.9	7.2	0.7	0.14
41	8	2%	7.9	14.4	1.4	0.25
42	7	2%	7.9	21.6	2.1	0.32
43	6	2%	7.9	28.8	2.8	0.36
44	5	2%	7.9	36.0	3.6	0.37
45	4	2%	7.9	43.2	4.3	0.36
46	3	2%	7.9	50.4	5.0	0.31
47	2	2%	7.9	57.6	5.7	0.23
48	1	2%	7.9	71.3	-71.2	0.13
						2.47

Table 6-8: overview of core benefits Oasen

This being said, likely the core benefits will be higher, as it seems likely that, at least in the longer run, the failure frequency will come down, which will of course also generate savings in comparison with the situation where no imagery was used.

From the benefit, we should deduct the cost of obtaining the ground deformation maps. Note this is not the same as the benefit to SkyGeo as it includes the imagery costs which were given as being €60k per annum approx. Hence the cost to Stedin and Oasen is of the order of €100k each.

As we already mentioned, the exact value of SkyGeo Services is irrelevant along the value chain, because it would exactly balance the gains on the side of SkyGeo. However, without entering into the details of these figures, it is important to notice that the cost of procuring these services at Stedin and Oasen is largely outweighed by the computed benefits. For instance, based on figures from two projects done so far, Stedin assesses that these costs did not exceed 10% of the gains, and this concerned just small scale use of the imagery (representing just 3% of the total amount of connections to be replaced yearly), meaning that the proportion of costs could go down significantly, when used on large scales.

6.2.4   Side benefits

Next to that there are side benefits like: better strategic information allowing for further cost reduction (like staff), lower insurance costs as the number of calamities will go down and better standing with clients. Obviously, these side benefits are hard to measure, in particular since both Stedin and Oasen have only recently started to use imagery, in fact still in a project context, so that there are no hard numbers on the occurrence of them, let alone on the financial value.

Indeed, Stedin and Oasen both advised that they consider it much too early to say something about the lower insurance costs. Furthermore, based on the current numbers, they feel it is unlikely that they will be able to convince their insurance companies to lower their fees. Oasen also only insure the higher risks: where they consider the risks to be affordable – so the costs of an occasional flooding – they prefer to self-insure to avoid paying the overhead and profit of the insurance companies. So only in high risk spots like hospitals will they have insurance and insurance costs.

Based hereon, it is likely that in the long run the insurance costs will go down as the risk to be insured will decrease. However, these insurance fees are based on proven track records and those have not yet been established.

6.3   Tier 3: Public Authorities

Potentially, the imagery could create significant value for municipalities located in the service area of Stedin and Oasen. These benefits would very much relate to the ability to better plan and manage maintenance activities of various utility companies operating in their territories. Obviously, being a in truly infancy state, the SkyGeo maps used by Stedin and to be used by Oasen have not sparked these effects yet. However, just to demonstrate the potential, one could consider the following case.

Stedin's maintenance activities entail digging around 120km of trenches per year, corresponding to 30m per day. The average of costs of digging 1 meter is around 220 euro. If, due to the enhanced predictability of maintenance activities by Stedin and Oasen, municipalities would be able combine digging efforts of utility companies, this could mean that not only the costs could be shared, also the number of trenches being dug would be reduced by 50%, as they are shared. Of course this would also have beneficial implications for citizens as the number of times that pavements are dug up or roads will be closed will decrease significantly (in particular in relation to work on big transport mains).

6.4   Tier 4: Citizens and the Local Economy

Both Stedin and Oasen are serving the interests of citizens and companies residing in their services areas. And those numbers are significant: Stedin is serving some 2 million people and Oasen 750,000. The usage of the imagery will likely impact the service level received by society in three ways:

a. The risk of a gas explosion is reduced hence making life less dangerous.

b. There is less risk of a disrupted supply of water or gas so allowing citizens to be more assured about their household.

c. There is less maintenance work which leads to less disruption of people's activities eg. fewer road closures, fewer trenches through front gardens, less need to attend whilst work is carried out at their property.

Monetizing the potential impact for citizens and the local economy of the use of the imagery is of course tricky: not only is the correlation between the usage and the (potential) benefits of using the imagery unknown – there are no longitudinal data yet – but also how does one value 20% more security or 20% less hassle? Then again, anybody on the street would confirm such improved service level and safety would have a value. So therefore, we have applied a bit of 'gut feeling economics', using the same methodology as in the previous cases by simply asking ourselves "what would a citizen be willing to pay for such improvements?".

We confined ourselves to the Stedin case, not only because we could dig out quite some data there, also the transport and delivery of gas to households is of course a high risk operation, or at least certainly features a higher risk than the transport and delivery of water.

Over the last 9 years Stedin has encountered 4,748 failures, which makes an average of 528 failures a year. Currently around 85,000 of Stedin's connection are 'under suspicion' because the ground they are in is deforming. Without the use of the imagery – Stedin estimates that out of the 20,000 connections that it replaces yearly, only 60% were really needing replacement (and 40% not), corresponding to 12,000 rightly replaced connections. Accordingly the chances of a failure of the residual suspicious connections is 528 failures divided over the difference between the total number of the residual suspicious connections: 528/(85.000 – 12.000) = 0,00724. If the usage of the imagery would bring up the number of rightly replaced connections from 60% to 80%, this would reduce the number of yearly failures from 528 to 500, being 0.00724 x (85,000 – 20,000), so a decrease of 28 failures which corresponds to a 5% risk reduction, including the risk of a real calamity. If we would assume that the percentage of rightly replaced connections could even go up further to 90%, that would bring down the failures to 485, being 0.00724 x (85,000 – 18,000), corresponding with a decrease of 8%.

Now let us look at what this reduction in risk will mean for the average citizen.

At the moment on average a citizen will be confronted with 'digging in his garden' once every 8 years. If the % of unjustified replacements could come down from 40% to 20% or even 10% that would mean that the chances of being hassled for no reason would go down by 50% to even 75% (apart from the long term effect that the number of failures will go down due to an overall improvement of the quality of the system).

Some indication as to the value of (missing out on) a failure can be retrieved from the reimbursement policy that Stedin applies. Stedin pays per connection an amount of 35 euro per failure that lasts more than 4 hours (if shorter no amount is paid) and an extra amount of 20 euro for each next 4 hours that the service is not available. From that it would be safe to say that the perceived value by the user amounts to at least 35 euro and accordingly a reduction of the chances thereof of 5% – 8% corresponds with a value of 1,75 – 2,8 euro per year.

The reduction of the odds of real calamities (again with 5% – 8%) will certainly also have a value, although we have to realize that the chances are really low that such thing will actually happen. On the other hand, the value itself will be considered quite high, in fact priceless, so squaring these we could assume that some people might be willing to pay 1 – 1,5 euro per year.

Then finally, a significant reduction (50% - 75%) of the chances of being hassled for no reason, meaning that the garden will suffer and people may need to stay at home, will most certainly be appreciated. Of course the frequency is quite low (on average once every 8 years), but intuitively we would be tempted to add a price tag to that of 5 – 10 euro per year.

So if we put these (gut feeling) numbers into the equation of the total number of people served, being 1.9 million we can construct the matrix shown in Table 6-9.

	Amount per year a connection would be willing to pay (€)	
	low	high
5% to 8% less chances of failures	1	1.5
5% to 8% less chances of calamities	1.75	2.8
50% to 75% less chance of unjustified	5	10
Total per connection	7.75	14.3
X 2 million connections	15500000	28600000
Value range in Meuro	15.5	28.6

Table 6-9: assessment of value of perceived benefits by Stedin's clients of raised service level

A similar assessment for the Oasen service, would be significantly lower due to the fact that the number of users is much lower (330.000 connections, so about 1/6th) and the risks are much lower (water does not explode). So we would be safe to say that the total social added value perceived by Oasen customers would be in between 0,66 and 1 Meuro (so 1 - 3 euro per connection).

These figures are for the whole benefit. How much is generated through the use of satellite data? We consider that the improved knowledge of location and risk assessment must have a value. We allocate 10% of the assessed benefit to be due to this improvement coming from satellite data. This leads us to a benefit of €1.55m to €2.86m.

6.5 Total Economic Return

The total economic return coming from the two users is shown in the Table 6-10 below.

		Tier Benefit (€)	Comments
Tier 1	Primary Service provider	200k	Estimated revenues to SkyGeo
		250k	Extended benefits to employment
Tier 2	Stedin (gas distribution)	4,570k	
	Oasen (water distribution)	274k	
	Less costs	(200k)	Equivalent to SkyGeo revenues
Tier 3	Municipalities	No data available	Not yet integrated into the process
Tier 4	Citizens and local economy	1.5m-2.8m	
	TOTAL	6.6m – 7.9m	

Table 6-10: Total Benefits coming from imagery use by Stedin and Oasen.

However, this is covering only a part of the Netherlands where the two companies are operating. Other regions can also make use of the products although if the subsidence risk is lower, then the overall impact will be reduced. We seek to extrapolate the benefits from the 2 regions concerned (gas in Rotterdam and water in Gouda) to the whole of the Netherlands.

In Table 2-1 we find the number of gas connections maintained by each of the 9 service providers in the Netherlands and the assessed risk (likelihood) of ground deformation in their region. The risk in a high region is taken to be the same as for Stedin whilst in a region of medium risk it is taken as 50% and in a low risk region 10%. The extrapolation factor is then calculated based on the number of connections so Stedin is a factor of 1 whilst Liander is 2210/1886 = 1.172. The total of all regions then comes to 2.382 which is used as the scaling factor to extrapolate to the whole of the Netherlands. We do not have similar figures for Oasen but as the gas connection dominate the calculations this would not make an enormous difference to the final figures.

Provider	# gas connections *1000	Assessed Risk	Relative risk	Benefit extrapolated
Liander	2,210	High	1.0	1.172
Enexis	1,850	Low	0.1	.098
Stedin	1,886	High	1.0	1000
Edinet	452	Low	0.1	.024
Delta Netwerkbedrijf Infrastructuur	185	Low	0.1	.001
Conet	137	Low	0.1	.007
Westland Energie	51	High	1.0	.027
Rendo Netbeheer	98	Low	0.1	.005
Intergas Netbeheer	148	Medium	0.5	.039
TOTAL	7,017			2.382

Table 6-11: Extrapolation factor from Stedin region to the whole of the Netherlands.

Taking this factor and then scaling the total benefits to the rest of the Netherlands we present the results in Table 6-12. For SkyGEO, we have assumed that their business will double by serving all the gas pipeline operators.

		Area Analysed	Factor	Total for the Netherlands
Tier 1	Primary Service provider	450k	2	900k
Tier 2	Stedin (gas distribution)	4,570k	2.38	10,876k
	Oasen (water distribution)	274k	1	274k
	Costs	(200k)	2	(400k)
Tier 3	Municipalities	No data available		Not yet integrated into the process
Tier 4	Citizens and local economy	1.5m-2.8m	2.38	3,570k-6,664k
	TOTAL	6.6m – 7.9m		15.2m-18.3m

Table 6-12: Economic benefit extrapolated to the whole of the Netherlands.

7 Summary of Findings

7.1 General Approach and Methodology

This study introduces a new approach to evaluating the economic benefit coming from the use of satellite imagery. Our approach is to trace the impact coming from a single product generated using satellite imagery through a value chain. Consequently, defining the value chain and how the information being used flows through it is at the heart of our methodology.

Once we have a detailed understanding of who is using the products, through a series of interviews we develop our understanding of how their processes are changed by the imagery and derived products. This then leads to an economic assessment of the value which is being generated. This can be quite different for each situation and one of the key lessons learned from the study has been around the methodology and adapting it to fit each case. A summary document will be available later drawing comparisons between the three cases.

In this instance three factors stand out:

1. the value chain has been very narrow and the benefits which are found quite specific and concentrated. The economic benefit is being derived through efficient use of financial resources as well as more indirect benefits to citizens and the local economy. It is based on the operational management practices of two organisations in two regions in the Netherlands. Hence it is much more limited in scope than the two previous cases which have been studied which were at national level. A simple extrapolation has been made to try to assess the potential benefits at national level.

2. The service provider is a commercial company rather than a public body and most of the value chain sits in the commercial sector. Legislation again plays a role both through safety measures but also since the regulator of the pipeline operators will ensure (in the future) that benefits get passed on directly to the citizens. Hence if we were to revisit this case in 5 years' time, we should find that the benefits to Stedin and Oasen have been passed through to their customers in reduced gas or water prices.

3. The case rests on financial benefits; by this we mean the operational business of Stedin and Oasen. It means that the case is more complex than the others to calculate the benefits.

7.2 Economic Benefit to the Netherlands

The economic benefit due to the use of SAR imagery to support gas and water distribution pipeline monitoring in Rotterdam and Gouda is assessed to be between €6.3m and €7.6m. This is shown by tier in the lower lines in Figure 7.1. The biggest benefits are felt by the operating companies Stedin and Oasen and by the citizens and local businesses: the local economy.

The potential overall economic benefit to the Netherlands is assessed to be between €15.2m and €18.3m shown in the upper line in Figure 7-1. This is not yet realised as only the two companies mentioned have so far taken up the use of ground deformation maps as part of their maintenance planning process. By

scaling based on the number of domestic gas connections and the vulnerability of the area to subsidence, an extrapolation has been made from the two regions to the whole country.
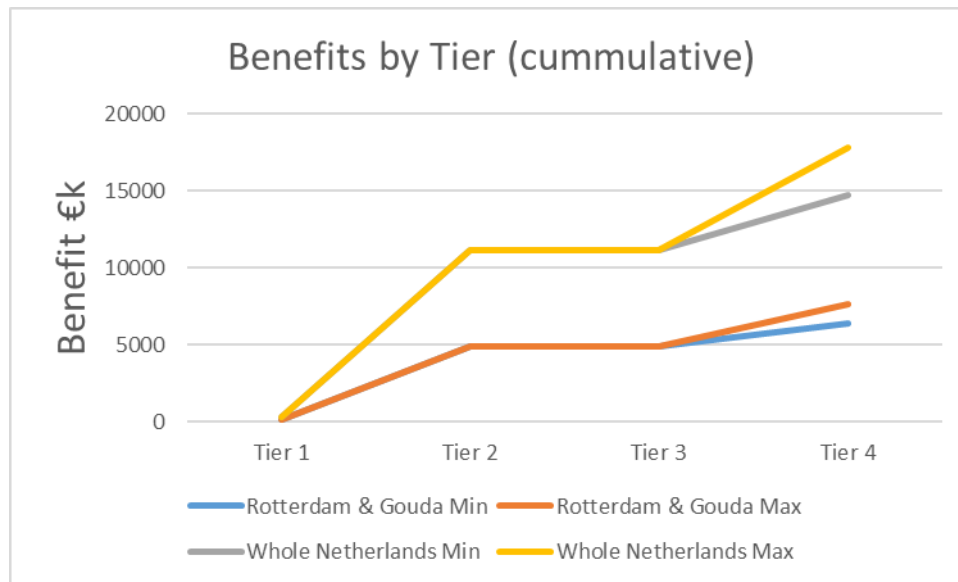

Figure 7-1: Economic Benefits from ground deformation mapping to support Gas Pipeline Monitoring in the Netherlands.

Further benefits can be expected as the technology becomes more widely recognised and used. For instance, we see potential for local authorities with responsibility for development planning, street maintenance and sewage to be able to gain a benefit from its use.

7.3   The Impact of the Sentinel Data

Satellite imagery has been shown to improve management practices of sub-surface pipeline monitoring.

It allows to determine with greater accuracy where maintenance work is required and hence for the utility companies to plan their investment programmes more efficiently.

The greatest benefit measured today comes from the use of high resolution imagery from a commercial satellite system TerraSAR-X which allows measurements to be made to the level of each house.

The overall case is made economic by the use of a lower resolution imagery coming from Europe's Sentinel satellites. This data is free and its' use is essential to help make the case economic. It provides the lower resolution assessment which has value in helping the companies to pinpoint the pipelines and connections which should be replaced. We have discussed in section 4, how using the lower resolution will enable the utility companies to focus their purchase of the costly, high-resolution imagery over the risk areas. This will be especially important in the future as Sentinel-1 derived ground deformation maps become available and

as the product is promoted for use in new regions (maybe outside the Netherlands). Indeed, it can be argued that the case would not be economically viable without the use of lower resolution, free or low-cost data as a starting point.

However, based on our interviews, it is considered that the value contribution from Sentinel-1 is around 30% of the total value. This can also be estimated based on a simple calculation that each company can save about €50k out of €140k budget by focusing and limiting the purchase of the TerraSAR-X data; so around 30% of the value can be assigned to Sentinel data; ie €4.35m to €5.25m is the economic value attributed to the use of Sentinel data.

7.4   Conclusions

In this third case assessing the economic benefits coming from the use of Satellite data, we found some modifications to the methodology as well as a significant benefit.

In terms of the methodology, the case concerns a new product which is only starting to be proven and used in a limited geographic area.

In terms of benefits, the value chain is much narrower and even shorter than in the other cases, hence the benefits are more confined. The scope was limited to two regions in the Netherlands where the benefits are assessed as being €6.6m to €7.9m per annum. Extrapolating to the whole of the country using gas connection figures coupled with a subsidence likelihood suggests that there is potential for total benefits by a factor of 2.38 yielding a total national benefit of €15.2m to €18.3m per annum.

Annex 1: Sources

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Annex 2: List of abbreviations

C(S)EVS - Copernicus (Sentinels') Economic Value Study

EARSC – European Association of Remote Sensing Companies

LCC – Life-Cycle Costing

SAR – Synthetic Aperture Radar

InSAR – Interferometric SAR

PS-InSAR – Point Scaterer InSAR.