Report number: 2019-10
EAN number: 978-87-93674-73-8

NordFoU

ROMA

State assessment of road markings in Denmark, Norway and Sweden – results from 2018

NordFoU

Project
ROMA, State assessment of road markings in Denmark, Norway and Sweden 2017–2021

Report number
2019-10

Date
2019-06-11

Project manager
Jan-Erik Lundmark, Senior Advisor
Road Maintenance, The Swedish Transport Administration.

Financial partners
The Swedish Transport Administration, Sweden
The Norwegian Public Roads Administration, Norway
The Danish Road Directorate, Denmark

Members of the project group
Anna Vadeby, Erik Kjellman, Carina Fors and Sven-Olof Lundkvist, VTI.
Berne Nielsen, Trond Cato Johansen and Christian Nilsson, Ramböll.

Scientific partners
The Swedish National Road and Transport institute (VTI), Sweden
Ramböll, Sweden

National contacts
Jan-Erik Lundmark and Ulf Söderberg, The Swedish Transport Administration, Sweden
Björn Skaar, The Norwegian Public Roads Administration, Norway
Michael Ruben Anker Larsen, The Danish Road Directorate, Denmark

Report title
ROMA . State assessment of road markings in Denmark, Norway and Sweden - Results from 2018

Summary:
Assessments of the performance of road markings is carried out regularly to various degrees in the Nordic countries. The main aim of the Nordic road marking assessment study is to show possible differences in road marking performance between Denmark, Norway and Sweden. Possible differences between road marking performance, dependent on region, country, type of road and AADT (Annual Average Daily Traffic) are studied. Furthermore, a comparison between the TEN-T and the non-TEN-T road network is made. As 2018 is the second year of the project, a comparison between the results for 2017 and 2018 is also made.

A Nordic certification system for road marking materials has recently been introduced in Norway and Denmark and will be introduced in Sweden 2019. This means that a documented product approval (i.e. certification) will be required for use of the material on roads managed by the national road authorities. The requirements are introduced successively as the existing contracts expire. Therefore, one aim is also to study the road marking quality before and under the introduction of the new certification requirements. Continuous assessments give the opportunity to react and adjust the requirements in the future, if the performance does not develop as expected.

The study is based on physical mobile road assessment measurements carried out in Denmark, Norway and Sweden by Ramböll. In total 71 road objects were measured in Denmark, 124 in Norway and 434 in Sweden. The following variables were studied: retroreflectivity of dry and wet road markings, relative visibility of dry and wet road markings, relative pre-view-time (pvt) of dry and wet road markings and cover index.

The results show that the retroreflectivity requirement of dry road markings (150 mcd/m^2/lx) is roughly fulfilled in 50 % of the measured objects. Road markings in Denmark have lower retroreflectivity than those in Norway and Sweden. Some retroreflectivity values are low, e.g. motorway edge lines in Denmark. However, this is compensated for by a large area, which nevertheless means good visibility. Contrary: edge lines on Swedish two-lane roads have high retroreflectivity, which would imply good visibility. However, the road marking area is small, thus reducing the visibility in comparison with both Danish and Norwegian edge lines.

Regarding wet road markings, road markings in Norway have higher retroreflectivity than Denmark and Sweden for every road class. This can probably be explained by the fact that Norway often has inlaid road markings, a solution seldom used in Denmark and Sweden. When analysing the results for wet road markings it should be noted that significant deviations between the results from the mobile measurements and the hand-held measurements were shown during the annual validation of mobile instruments in 2017 and 2018 and therefore, the results for wet road markings should be interpreted with care.

A comparison between the retroreflectivity on the Trans-European Transport Network (TEN-T) and other roads showed that there were only minor differences between the TEN-T and other roads in Denmark, while in Norway and Sweden there are somewhat higher levels for the TEN-T network. The results for relative visibility show larger differences between TEN-T and non-TEN-T and in all three countries, the relative visibility is higher for the TEN-T road network. However, studying the relative pre-view-time shows that in all countries, this measure is lower on the TEN-T roads, due to higher speed limits on the TEN-T road network. For Norway and Sweden, the differences in pvt between TEN-T and other roads are rather small, while for Denmark the difference is significant, and the relative pre-view time is about 0.6 s shorter on the TEN-T roads than on other roads.

There is no significant difference in cover index between the countries, but between road classes the difference is significant. Lane and centre lines seem to have a higher cover index than edge lines. This is difficult to explain, but the reason might be that lane and centre lines are reconditioned almost every year, due to many wheel roll overs. If so, measurements were carried out on almost new lane and centre lines, while the edge lines might have been applied in earlier years. Another explanation might be that the edge lines are profiled to a higher extent than the lane and centre lines.

In the second year of the project, it is not possible to study any effect of the Nordic certification system for road markings. However, in the coming years, some effects might be possible to register.

In conclusion, there is no large difference in road marking performance between the three countries and comparing the results between 2017 and 2018 shows no major differences on country level. For both 2017 and 2018 the main conclusion is the poor visibility of edge lines on two-lane roads in Sweden and the good performance of wet road markings in Norway.

Keywords
Road markings, state assessment, retroreflectivity, relative visibility, relative pre-view-time, cover index, ANOVA, cluster analysis.

Language
English

Number of pages
113

Rapporttitel
ROMA, en studie av vägmarkeringars tillstånd i Danmark, Norge och Sverige - resultat från 2018

Sammanfattning
Vägmarkeringarnas tillstånd studeras regelbundet i olika omfattning i de nordiska länderna. Det huvudsakliga syftet med föreliggande studie är att med tillståndmätningar visa på eventuella skillnader avseende vägmarkeringsprestanda mellan Danmark, Norge och Sverige. Då 2018 är projektets andra år, görs även en jämförelse mellan resultaten mellan 2017 och 2018.

Ett nordiskt certifieringssystem för vägmarkeringsmaterial har nyligen införts i Norge och Danmark och kommer att införas i Sverige under 2019. Detta innebär att ett dokumenterat produktgodkännande (certifiering) kommer att krävas för att materialet ska få användas på vägar som förvaltas av de nationella vägmyndigheterna. De nya kraven införs succesivt efter att de befintliga entreprenaderna löper ut. Ett annat syfte med föreliggande studie är därför att få en bra bild av vägmarkeringarnas funktion dels innan det nya certifieringssystemet börjar tillämpas, dels att med fortsatta mätningar under 2019 – 2021 studera utvecklingen och effekterna av certifieringens införande.

Studien baseras på fysikaliska mobila tillståndsmätningar utförda i Danmark, Norge och Sverige av Ramböll. Totalt mättes 71 vägobjekt i Danmark, 124 i Norge och 434 i Sverige. Följande variabler studerades: retroreflexion för torra och våta vägmarkeringar, relativ synbarhet för torra och våta vägmarkeringar, relativ pre-view-time (pvt) för torra och våta vägmarkeringar samt vägmarkeringens täckningsgrad.

Resultaten visar att retroreflexionskravet för nya, torra vägmarkeringar (150 mcd/m^2/lx) är uppfyllt för ca 50 % av de studerade vägobjekten. Vägmarkeringar i Danmark har lägre retroreflektion än Norge och Sverige. Speciellt låg retroreflexion kan ses på kantlinjer på motorvägar i Danmark. Detta kompenseras dock av att dessa vägmarkeringar har en stor area, vilket innebär att synbarheten ändå blir god. För tvåfältsvägar i Sverige är situationen den omvända, där har kantlinjerna hög retroreflexion, men arean är liten och synbarheten blir därmed lägre än i Danmark och Norge. När våta vägmarkeringar studeras har Norge högre retroreflexion än både Danmark och Sverige. Detta gäller även för relativ synbarhet och pvt. En förklaring till den höga retroreflektionen kan vara att Norge, till skillnad från Danmark och Sverige, ofta har nedfrästa vägmarkeringar vilket minskar slitaget. Det bör dock påpekas att resultaten för retroreflektion på våta vägmarkeringar bör tolkas försiktigt eftersom stora avvikelser registrerades mellan de mobila mätningarna och de manuella referensmätningarna under 2017 och 2018.

En jämförelse mellan retroreflexionen på det TransEuropeiska Transportvägnätet (TEN-T) och andra vägar visade att det endast finns mindre skillnader mellan TEN-T vägnätets och övrigt vägnäts vägmarkeringar i Danmark, medan retroreflexionen i Norge och Sverige är något högre för TEN- T-vägnätet. Resultaten avseende synbarhet visar större skillnader mellan TEN-T eller icke-TEN-T och för alla ingående länder är synbarheten längre för TEN-T-vägnätet. Studerar man skillnader i relativ pvt är den genomgående kortare på TEN-T vägnätet, främst på grund av att hastigheten är högre på TEN-T vägnätet än på övrigt vägnät. För Norge och Sverige är skillnaderna dock små, men för Danmark är pvt ungefär 0,6 sekunder kortare på TEN-T än övrigt vägnät.

Under projektets andra år är det inte möjligt att studera någon effekt av det nordiska certifieringssystemet, men förhoppningsvis kommer vi kunna se effekter längre fram i projektet.

Jämför man resultaten mellan 2017 och 2018 är skillnaden i funktion liten. Sammanfattningsvis är det ganska små skillnader i vägmarkeringarnas funktion när man jämför Danmark, Norge och Sverige. Undantagen är den relativt låga synbarheten hos kantlinjerna på svenska tvåfältsvägar, trots en hög retroreflexion, och en hög synbarhet hos våta vägmarkeringar i Norge.

Nyckelord
Vägmarkeringar, tillståndsmätningar, retroreflektion, relativ synbarhet, relativ pre-view-time, täckningsgrad, ANOVA, klusteranalys.

Table of contents

0 Glossary

	Explanation
Road object	A 10 km road section which is homogeneous with respect to road number, type of road (two-lane or multi-lane road) and road class (AADT).
Measurement object	The road marking measured within a road object. On each road object, three road markings (edge lines, centre or lane line) are measured.
Retroreflectivity	R_L, represents the brightness of a road marking in darkness as seen by drivers of vehicles under the illumination by the driver's own headlamps and expressed in mcd/m^2/lx (milli-candela per square meter per lux).
Visibility	Visibility is the longest distance at which a road marking in darkness is visible to a driver when illuminated by the headlamps of the vehicle (m).
Relative visibility	Relative visibility refers to the visibility at some condition, but when the exact condition is not known. The measure can be used for comparisons between countries and road classes and is used in this study.
Pre-view-time (pvt)	Pre-view-time is the time it takes to drive the distance that corresponds to the visibility distance of the road marking. Pre-view-time is thus dependent on visibility distance and driving speed.
Relative pre-view-time (pvt)	Relative pre-view-time depends on relative visibility and speed limit.
Cover index	Cover index is defined as the part of the original road marking area that remains at the time of measurement.
TEN-T road network	The trans-European transport network (TEN-T) is a network which comprises roads, railway lines, inland waterways, inland and maritime ports, airports and rail-road terminals throughout the 28 Member States.
AADT	Annual Average Daily Traffic.

1 Background

Assessments of the performance of road markings is carried out regularly to various degrees in the Nordic countries. A Swedish study from VTI, "Road marking assessment in the Nordic countries 2003", (Nygårdhs and Lundkvist, 2004) shows how measurements in the five Nordic countries can be summarized and what comparisons regarding road marking retroreflectivity that can be made. However, data in the different countries was collected using different methods, and therefore no clear conclusions from the analysis could be drawn. The outcome of the study was that the measured road objects must be chosen in the same way in each country and that measurements must be performed by professional staff.

Another assessment study was presented in "Road marking assessment in the Nordic countries: a comparison between road marking performance in Norway, Sweden and Finland", (Fors, Yahya and Lundkvist, 2015). The results in this study are based on a large number of mobile measurements carried out in the three countries during the spring/summer/autumn 2014. The lesson learned was that one must consider the partial road marking maintenance that is performed during the summer and autumn, so that this maintenance does not affect comparisons. Furthermore, in order not to make analysis too costly, it is desirable that data from different countries is delivered in a similar way.

The management of road equipment and assessment of this equipment should always be pursued with long-term care and continuity. The two pre-studies have shown interesting snapshots of some performance differences. However, to benefit from the assessments, continuity and annual reconciliation is required. Only then, can you study changes and trends between countries and regions. In addition, this would give a possibility to:

- develop and evaluate RMMS[1]
- act using financial instruments to affect negative trends and differences between countries or regions
- analyse and evaluate the effects of economic measures
- evaluate the effects of changes in the requirements
- analyse differences in road marking performance using different types of contracts
- evaluate any relationship between entrepreneur and road marking performance
- perform life cycle analyses

During the coming years, the Nordic certification system for road marking materials will come into force. It has already started in Denmark 2017 and in Norway 2018. In Sweden it will start in 2019. This means that a documented product approval (i.e. certification) will be required to use the material on roads managed by the national road authorities. The requirements are introduced successively as the existing contracts expire. The introduction of the certification system is expected to result in better road marking quality, both with respect to durability and performance parameters. Certification is given in relation to the number of wheel passages

[1] Road Marking Management System

the road marking material will stand, which will make it possible to select the most feasible materials for a certain road type and/or traffic flow. Materials of low quality will not receive any certification and they will thus not be used any longer. Continuous assessment of the road markings in Denmark, Norway and Sweden is therefore of great importance to investigate whether the certification system will have the desired effects of road marking quality. Further information about the certification system can be found in “Nordic certification system for road marking materials” (Fors et al., 2018).

1.1 Aim of the study

The main aim of the Nordic road marking assessment (ROMA) study is to show possible differences in road marking performance between the three countries, Denmark, Norway and Sweden. The road marking visibility is of special interest as Sweden uses intermittent edge lines to a larger extent than Denmark and Norway. Possible differences between road marking performance, dependent on region, country, type of road and AADT (Annual Average Daily Traffic), will be registered. A comparison between the TEN-T and the non-TEN-T road network is also made. 2018 is the first year in the project where the measurements between two successive years can be compared.

Furthermore, the aim is to study the road marking quality before and under the introduction of the new certification requirements. Moreover, measurements will make it possible to follow the development of the road marking quality and find out any effect of the introduced requirements. Continuous assessments give the opportunity to react and adjust the requirements in the future, if the performance does not develop as expected.

2 Method

The study is based on physical mobile road assessment measurements carried out 2017 and 2018 in Denmark, Norway and Sweden by Ramböll.

2.1 Objects

A road object is defined as a 10 km road section which is homogeneous with respect to road number, type of road (two-lane or multi-lane road) and traffic flow (AADT). In every two-lane road object, three road markings, the two edge lines and the centre line (if any), are measured. On multi-lane roads, the right edge line is measured in one direction, the left edge line in the opposite direction and one lane line in any direction. In total, one road object includes three measured road markings and data from 30 km of road, see Figure 1**.**

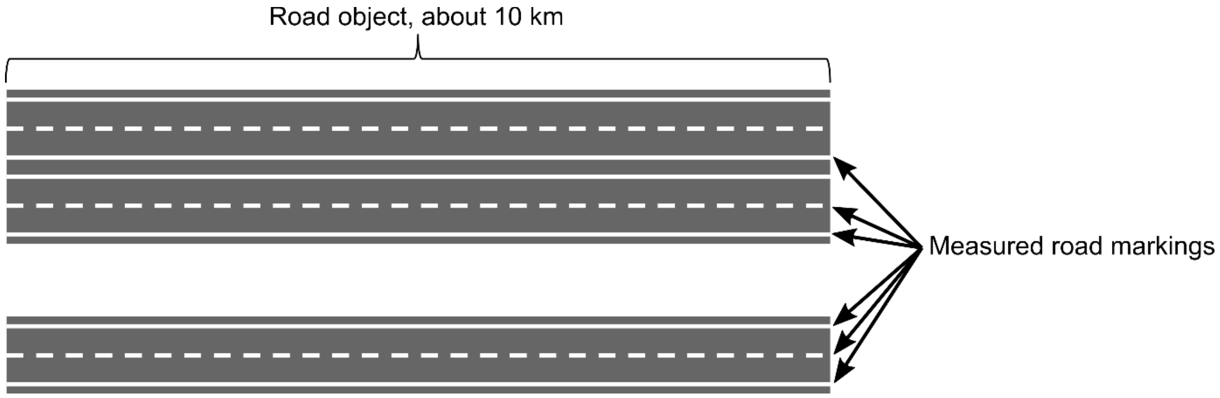

Figure 1. Illustration of road object and measured road markings.

The roads studied are classified into six different road classes defined according to Table 1. In every country, region and road class, measurements are carried out on at least five road objects.

Table 1. Classification of roads

Road class	Description
A	Motorway, AADT > 50 000
B	Motorway or multi-lane roads, 20 000 < AADT ≤ 50 000
C	Motorway or multi-lane roads, AADT ≤ 20 000
D	Two-lane roads, AADT > 5 000
E	Two-lane roads, 2 000 < AADT ≤ 5 000
F	Two-lane roads, 250 < AADT ≤ 2 000

The road objects to be measured are selected randomly from all available roads in each road class. The sampling size was five objects in each road class and region. A more detailed description of the objects and the random selection of objects for each country is given below in section 2.1.1 – 2.1.3. The study handles permanent road markings only.

The actual measured objects are supposed to be as close as possible to the randomly selected road objects. However, if it was not possible to measure the selected road object, the site was moved to the nearest possible site on the same road within the same road class.

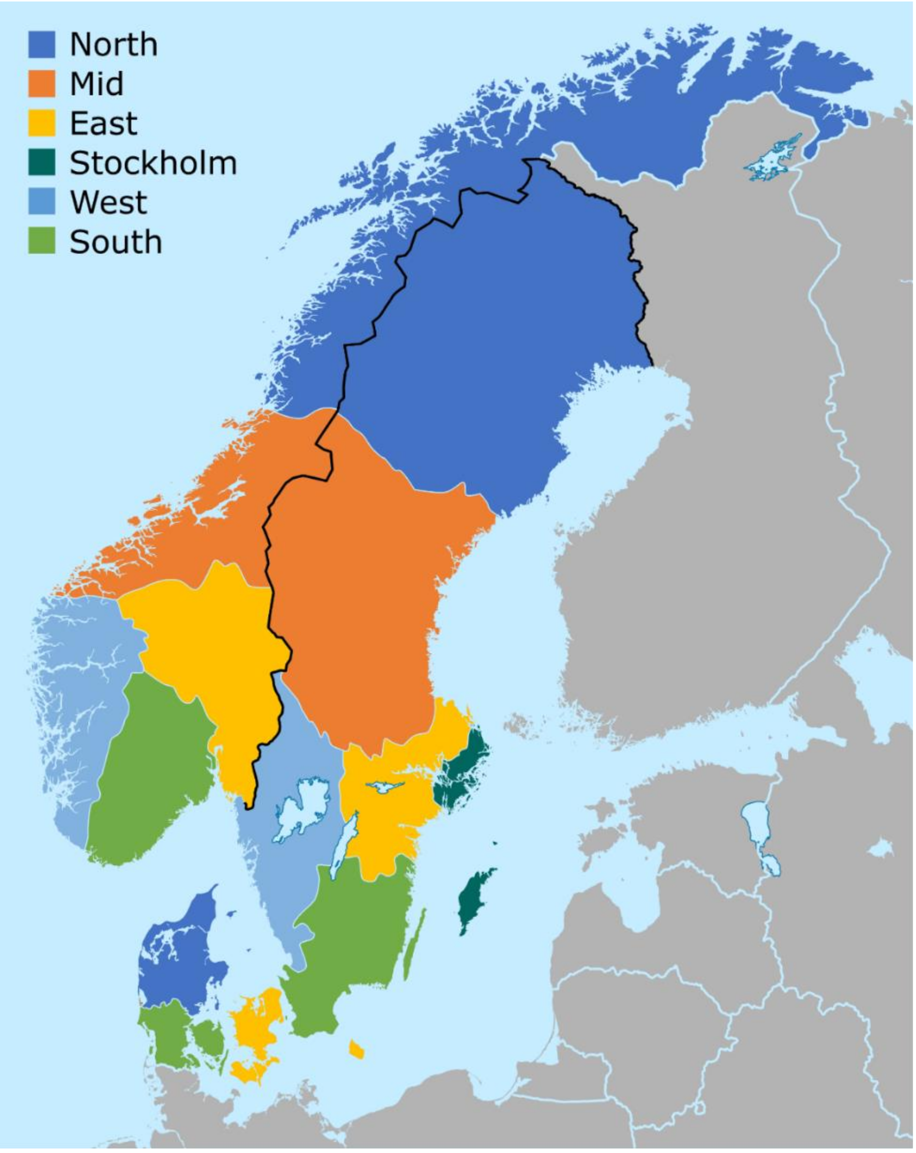

Figure 2. Regions studied in Denmark, Norway and Sweden

2.1.1 Denmark

Denmark is divided into three regions (South, East and North), see Figure 2. In Denmark road classes A – E are studied and for each class and region, five road objects were randomly selected. In one case (region North, class A), the sampling frame did not contain five objects, resulting in only one selected object for that class (the only class A motorway available). In total 71 objects were selected, see Table 2. The selected roads for Denmark are also illustrated in Figure 3. The random selection of objects was made by VTI. In Denmark all permanent road markings are white.

Table 2. Number of road objects for each class and region in Denmark 2018.

	A	B	C	D	E	Total
South	5	5	5	5	5	**25**
East	5	5	5	5	5	**25**
North	1	5	5	5	5	**21**
Total	**11**	**15**	**15**	**15**	**15**	**71**

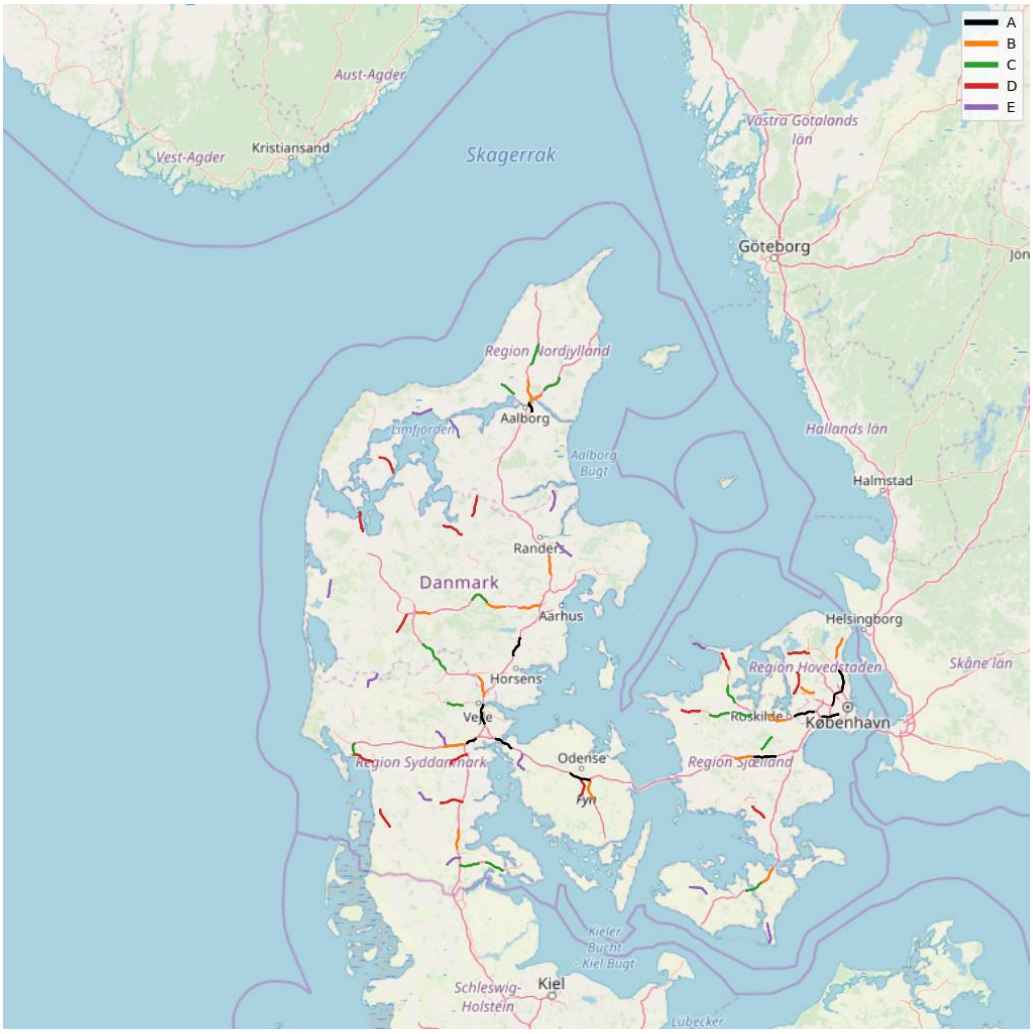

Figure 3. Selected road objects for each class (A-E) in Denmark.

2.1.2 Norway

Norway is divided into five regions (South, West, East, Mid and North), see Figure 2. In Norway road classes B – F are studied and for each class and region, five road objects were randomly selected. In some cases, the sampling frame did not contain five objects (lack of available roads in that region and road class), resulting in fewer objects for those classes. In total, 124 objects were selected for Norway, see Table 3. The selected roads for Norway are also illustrated in Figure 4. The random selection of objects was made by VTI. In Norway the permanent edge lines on two-lane roads are white, while the permanent centre lines and the permanent left edge lines on multi-lane roads are yellow.

Table 3. Number of road objects for each class and region in Norway 2018

Region	B	C	D	E	F	Total
South	6	4	6	7	6	29
West	3	1	6	7	6	23
East	6	6	6	7	6	31
Mid	2	1	6	7	6	22
North	0	0	6	7	6	19
Total	**17**	**12**	**30**	**35**	**30**	**124**

Figure 4. Selected road objects for each class (B-F) in Norway.

2.1.3 Sweden

Sweden is divided into six regions (South, East, West, Stockholm, Mid and North), see Figure 2. The random selection of road objects was made by the Swedish Road Administration in conjunction with the national road assessment programme. For some of the road classes, additional objects were randomly selected to fulfil the needs for the ROMA-project. The total number of objects are specified in Table 4 and in total 434 road objects in road classes A – F were selected for Sweden. The selected roads in Sweden are also illustrated in Figure 7. All permanent road markings in Sweden are white.

Table 4 Number of objects for each class and region in Sweden 2018

Region	A	B	C	D	E	F	Total
South	0	5	21	6	34	35	101
West	2	5	10	13	11	19	60
East	0	8	24	5	21	41	99
Stockholm	5	5	6	6	6	13	41
Mid	0	1	8	6	19	46	80
North	0	0	2	4	8	39	53
Total	**7**	**24**	**71**	**40**	**99**	**193**	**434**

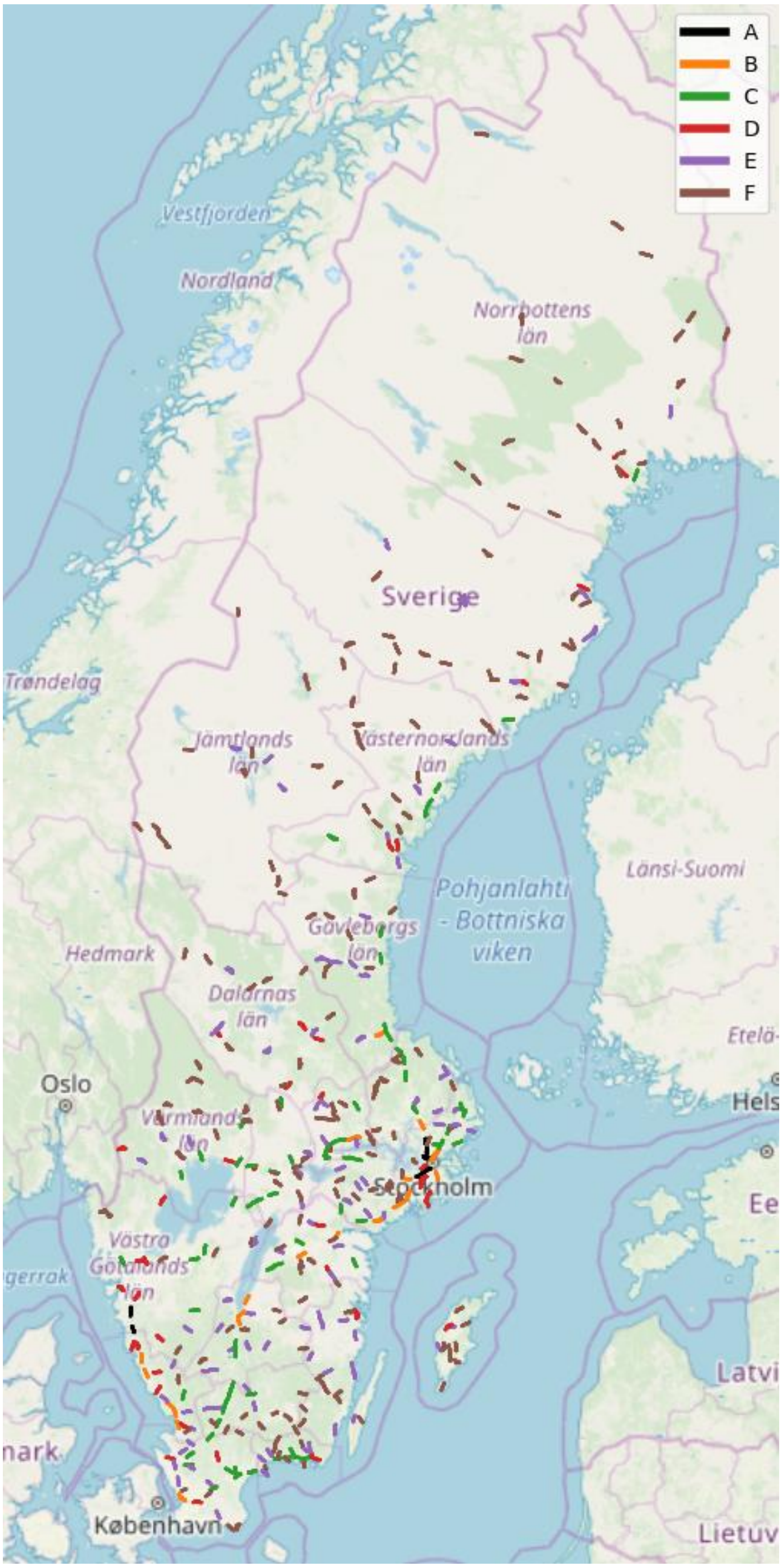

Figure 5. Selected road objects for each class (A-F) in Sweden.

2.2 Measurements and data

The measurements have been performed at speed with Ramböll's mobile measurement system for physical inspection of road markings, RMT (see Figure 6), and according to the Swedish method TDOK 2013:0461_v2 (Trafikverket, 2017).

To ensure the quality of data, calibration of the measuring system shall be performed according to established routines in the quality system of Ramböll. Check against handheld instruments should be performed at least once a week. During 2018, self-control was used for the quality assessments, however all mobile instruments used were also validated by VTI in May 2018.

For registration of the retroreflectivity of *dry* road markings ($R_{L,dry}$) a reflectometer of type LTL-M (Delta, Denmark) was used. The reflectometer sends out visible light, which will resemble vehicle lighting, and measures how much light is reflected back to the instrument. Along with this instrument, the RMT system consists of an optocator, a laser which registers the mean profile depth (MPD) of the road marking. From these two parameters, the *wet* road marking retroreflectivity ($R_{L,wet}$) can be estimated as described in VTI Report 611 (Lundkvist et al., 2008).

Figure 6. Ramböll's system for control of road markings, RMT

The measurements were carried out on dry road markings during the following time periods:

- Denmark: 15 April – 1 October
- Sweden: 15 May (starting in the south) – 1 October
- Norway: 15 June (starting in the south) – 1 October.

The aim of the project was to investigate road marking performance on roads without stationary lighting. However, if a part of the road object, less than 2 km had road lighting, even this part was measured, but later excluded from the analysis with respect to wet road marking retroreflectivity.

Before the analysis started, the following treatment was made to the data:

- If the object has new pavement – that part of the object was removed from the analysis

- If the road markings are dirty – that part of the object was removed from the analysis
- In case of worn road marking and therefore no value for retroreflectivity is collected - standard values of 40 and 10 mcd/m^2/lx for dry and wet road markings, respectively, were inserted.
- If a part of the object, less than 2 km, has road lighting, the wet road marking retroreflectivity of this part was excluded.

2.3 Variables

The dependent variables analysed in ROMA are:
- Retroreflectivity of dry and wet road markings
- Relative visibility of dry and wet road markings
- Relative pre-view-time (pvt) of dry and wet road markings
- Cover index

A brief description of the variables follows below:

2.3.1 Retroreflectivity

The coefficient of retroreflected luminance, R_L, represents the brightness of a road marking in darkness as seen by drivers of vehicles under the illumination by the driver's own headlamps, see Figure 7. It is measured in the direction of traffic and is expressed in mcd/m^2/lx, see European Standard EN-1436 (2018).

Retroreflectivity in wet conditions are estimated by a model developed in Lundkvist, Johansen and Nielsen (2008) and Lundkvist, Johansen and Nielsen (2009). This model uses retroreflectivity and macro-texture (mpd) from mobile measurements of dry road markings to estimate retroreflectivity in wet conditions. However, during the annual validation of mobile instruments in 2017 and 2018, significant deviations between the results from the mobile measurements and the hand-held measurements according to the standard EN-1436 were seen for some of the test objects. Deviations up to 25 mcd/m^2/lx between the mobile and the standard handheld measurements could be noted and therefore the results for wet road markings should be interpreted with care.

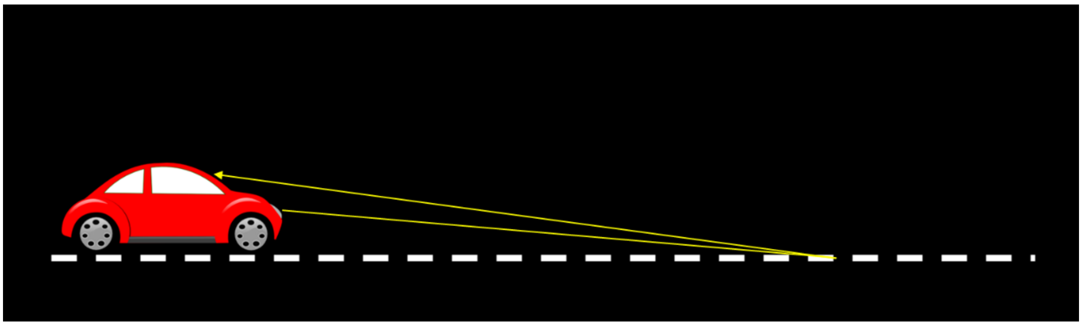

Figure 7. Illustration of retroreflectivity.

The performance requirements for dry and wet retroreflectivity for white and yellow road markings are specified in Table 5. Out of the three countries studied, only Norway uses yellow permanent markings and only for the centre line of two-lane roads and the left edge line on multi-lane roads. Since 2018, Norway has a higher performance requirement for wet retroreflectivity (50 mcd/m²/lx).

Table 5. Performance requirements

Parameter	White markings	Yellow markings
Coefficient of retroreflected luminance, R_L dry [mcd/m²/lx]	150	100
Coefficient of retroreflected luminance, R_L wet [mcd/m²/lx]	35 (50*)	35 (50*)

*In Norway 50 mcd/m²/lx since 2018.

For retroreflectivity in wet conditions there are differences between the countries regarding performance requirements based on AADT. Sweden has requirements that the road marking should be of Type II (profiled) for roads with AADT > 2000 veh/day, Norway for AADT > 4000 veh/day while Denmark has no AADT requirements meaning that in principle all (edge line) road markings should be of Type II.

2.3.2 Relative visibility

The longest distance (m) at which a road marking is visible to a driver when illuminated by high beam illumination, Figure 8, depends on the retroreflectivity and the area of the road marking, but also on the driver's eyesight, the vehicle lighting, the traffic situation, the road geometry, etc.

The model for calculating visibility is under revision and we have therefore chosen to study *relative visibility*. Relative visibility refers to the visibility of some specific condition, but we cannot say exactly which condition, except that the road marking is illuminated by high beam. This means that it is not relevant to draw conclusions of the specific values of relative visibility reported, but the measure is intended for comparison between, e.g., visibility of road markings in the three countries or in different road classes.

Relative visibility, S_{rel} is defined as:

$$S_{rel} = k \cdot log(R_L \cdot A), \qquad \text{Eq. (1)}$$

Where

R_L = retroreflectivity [mcd/m²/lx]
A = theoretical area of the road marking of a 60 m long section of the road [m²]. The area is calculated based on the measured width and effective length of the road marking. The effective length is based on country standards.
k = constant reflecting visibility level, which depends on the age of the driver, the status of the headlights etc.

In the analyses, we use k = 25 which gives the realistic visibility distance of 75 m in high beam illumination (no oncoming traffic) for a continuous road marking of width 10 cm and R_L = 150 mcd/m²/lx.

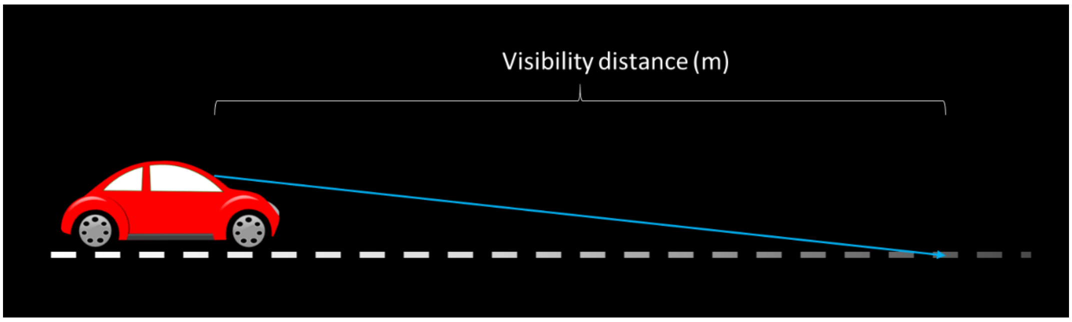

Figure 8. Visibility distance [m]

2.3.3 Relative pre-view-time

Pre-view-time is defined as the time it takes to drive from point A to point B (see Figure 9) and is dependent on visibility distance and driving speed. *Relative pre-view-time* depends on relative visibility distance and the speed limit.

Relative pre-view-time has been calculated as $pvt_{rel} = \frac{s_{rel}}{speed\ limit}\ [\frac{m}{\frac{m}{s}}]$. Eq. (2)

The speed limit used in this study is defined as the *dominating speed limit* over the distance of the road object. For instance, if 7 kilometres of the road object has speed limit 90 km/h, and 3 kilometres has 70 km/h, the speed limit for calculation of relative pvt is set to 90 km/h. An alternative speed limit to use in the analyses would be the *mean-speed limit* over the measured road section. Overall, the mean difference between *the dominating speed limit* and *the mean-speed limit* is rather small, about 2 km/h higher for the dominating speed limit.

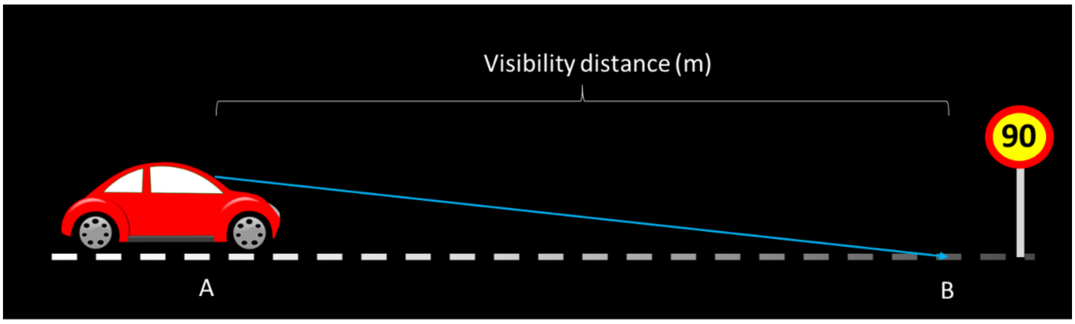

Figure 9. Pre-view-time [s]

2.3.4 Cover index

The cover index (%) has been defined as the part of the original road marking area that remains at the time of measurement. The definition is: "*Area of white (or yellow) road marking relative to the area within the theoretical outer dimensions of a longitudinal marking*". This parameter is measured using photo imaging at an angle of 90 degrees to the road marking surface.

The cover index is measured in % and can have values above 100 % if e.g. a new road marking overlaps with an old road marking. Profiled markings might have values below 100 % even when they are new if the pattern contains unfilled parts, such as a chessboard pattern. The measure is new and under development. The ambition for the coming years is to relate the cover index to road marking type (i.e. whether the road marking is profiled or not). However, this information is not available yet. In the future, cover index might be used instead of the theoretical area when estimating the relative visibility. A special study to compare the theoretical area and the effective area based on the cover index will be made during 2019.

For Sweden cover index should be more than 60 % for continuous road markings and 100 % for broken road markings while in Denmark the lower limit for cover index is in general 60 %. Norway has no specified limit for cover index.

2.3.5 Other variables

Except the variables analysed in ROMA, also the distance, coordinates and photos every tenth meter are registered. Furthermore, the luminance coefficient (Qd) and the skid resistance, though not analysed here, are available for analysis. This would make it possible to provide other information of interest for future studies.

2.4 Statistical analyses

The results are analysed and compared both between countries and road classes (A-F) for all variables, but also between regions and road classes in each country. The between-countries-results are reported in Chapter 3 and the within-country-results in Annex 1 for Denmark, Annex 2 for Norway and Annex 3 for Sweden.

The between-country-analyses are mainly made using analysis of variance, ANOVA (see Montgomery, 1991). The dependent variables (Y) are retroreflectivity of dry and wet road markings, relative visibility of dry and wet road markings, relative pre-view-time (pvt) of dry and wet road markings and cover index. The factors considered in the model are country and road class and the model are specified below:

$$Y_{ij} = \mu + \alpha_i + \theta_j + \alpha\theta_{ij} + \varepsilon_{ij},$$

where μ is the mean effect and ε is an error term and

α_i = country (Denmark, Norway, Sweden)
θ_j = road class (A, B, C, D, E, F)

The interaction $\alpha\theta_{ij}$ in the model reflects that there might be a different development of the dependent variable between countries and road classes. The mean levels estimated are estimated marginal means and therefore adjusted for unbalance in the design.

If a factor of interest is shown to be significant in the ANOVA analysis, pairwise comparisons between different levels of the factor are made. The comparisons are based on the estimated marginal means which compensate for an unbalanced design if that is the case. The Bonferroni adjustment for multiple comparisons is used. All significant tests are carried out at the risk level 5 %.

The ANOVA-analysis is supplemented by a cluster analysis. Data of mean retroreflectivity on dry roads has been analysed at regional and country level with a cluster analysis (k-means clustering). In short, this analysis means that the different regions are divided into three clusters: one cluster that has higher retroreflection than the rest, one having lower retroreflection and a cluster between them. All cluster analysis applies to mean retroreflectivity.

Comparisons are also made to study the differences between 2017 and 2018. These results are presented in Chapter 4.

3 Results 2018

Below, the results from the between-country-comparisons for 2018 are shown. Some more results from the ANOVA-analysis are shown in Annex D. Results for within country comparisons are shown in Annex A for Denmark, Annex B for Norway and Annex C for Sweden. Comparisons between 2017 and 2018 are shown in Chapter 4.

3.1 Dry road markings

In Table 6, the number of measured road markings (as described in section 2.1) used in the analyses for dry road markings is shown. For Denmark 210 road markings are analysed, while for Norway and Sweden, the numbers are 346 respectively 1267.

Table 6. Number of measured road markings used in the analyses for dry road markings 2018.

Road class	Denmark	Norway	Sweden
A	31		24
B	45	51	75
C	45	33	211
D	45	88	119
E	44	103	296
F		71	542
Total	**210**	**346**	**1267**

3.1.1 Retroreflectivity

In Figure 10, the percentage of road marking length within various levels of retroreflectivity is shown. The figures are based on all road markings and on total measured road length. For Norway, the figure includes both yellow[2] and white road markings, while in Denmark and Sweden only white road markings are used. Since Norway is the only one of the three countries studied using yellow road markings, Figure 11 shows the percentage of road marking length for white respectively yellow road markings for Norway.

Looking at all white road markings, the performance requirement for retroreflectivity is 150 mcd/m^2/lx. In Denmark, 38 %, in Norway 58 % and in Sweden 55 % of the measured road markings reach this level. Road markings with a level of retroreflectivity below 80 mcd/m^2/lx, are 2% in Denmark, 5 % in Norway and 7 % in Sweden.

For yellow road markings, the performance requirement for retroreflectivity is 100 mcd/m^2/lx. In Norway, about 86 % of the yellow road markings (centre line and left edge line in road class A, B and C) fulfil these requirements.

[2] In Norway, the centre line and the left edge line on multi-lane roads are yellow.

Figure 12 illustrates how the retroreflectivity on dry road markings (R_L) is distributed for all countries. Sweden, with only white road markings, has a peak around 150 mcd/m^2/lx, while Denmark (also only white road markings) has a peak around 130 mcd/m^2/lx. The distribution for Norway, using both white and yellow road markings, is broader with a peak around 160 mcd/m^2/lx. Annex E shows the distribution of retroreflectivity and relative visibility for right edge road markings only.

NordFoU

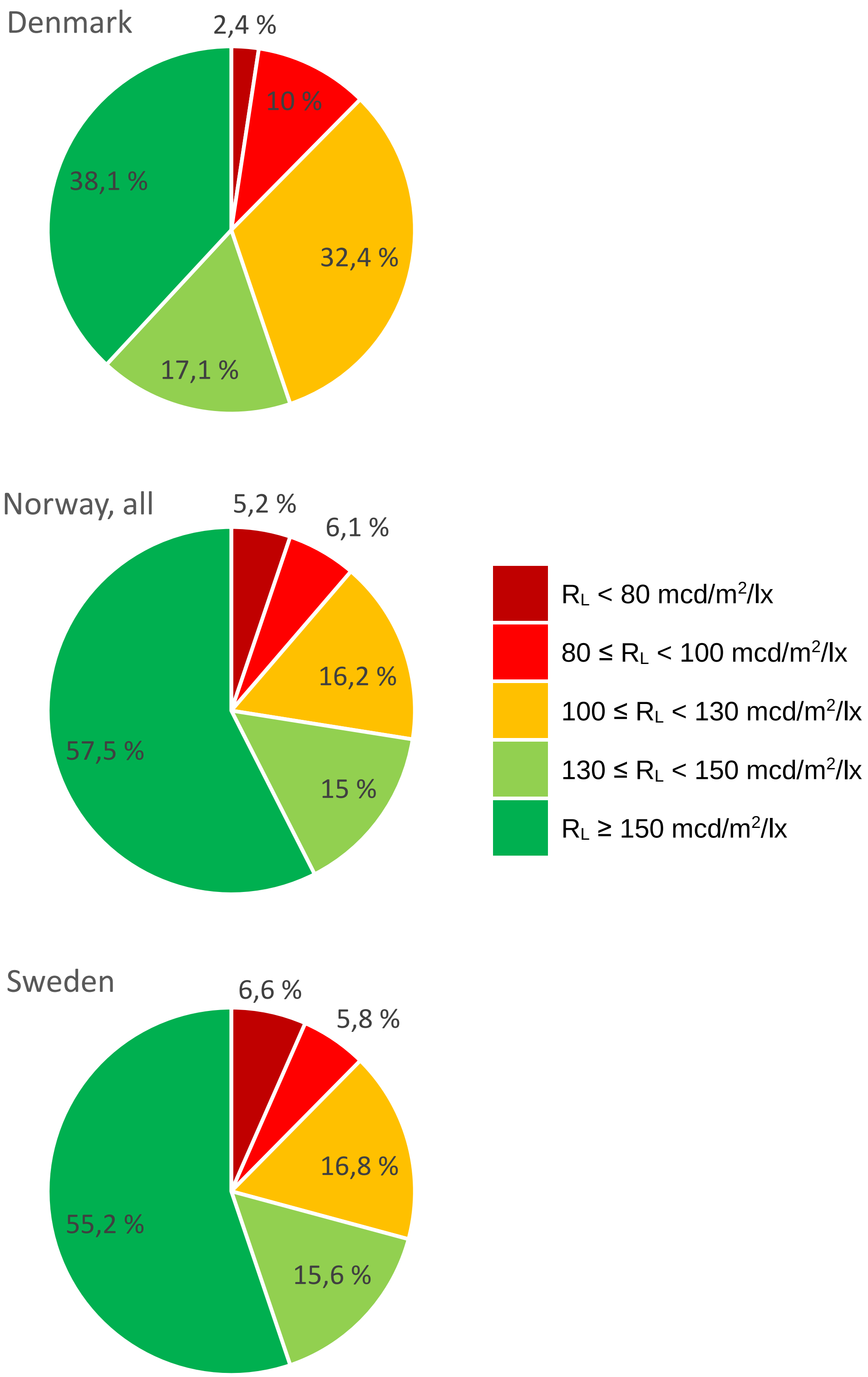

Figure 10. Percentage of road marking length within different levels of retroreflectivity for Denmark, Norway and Sweden. All road markings, white and yellow, based on total measured road length.

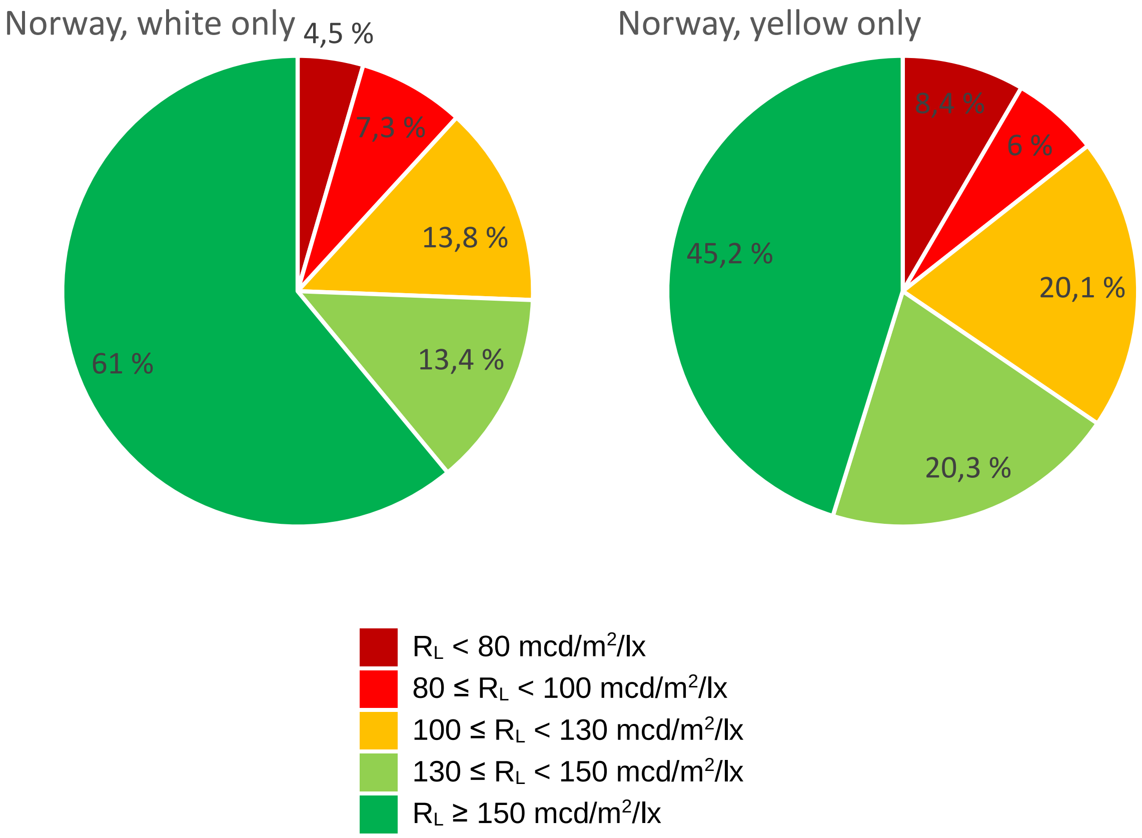

Figure 11. Percentage of road marking length within different levels of retroreflectivity for Norway. Only white respective only yellow road markings.

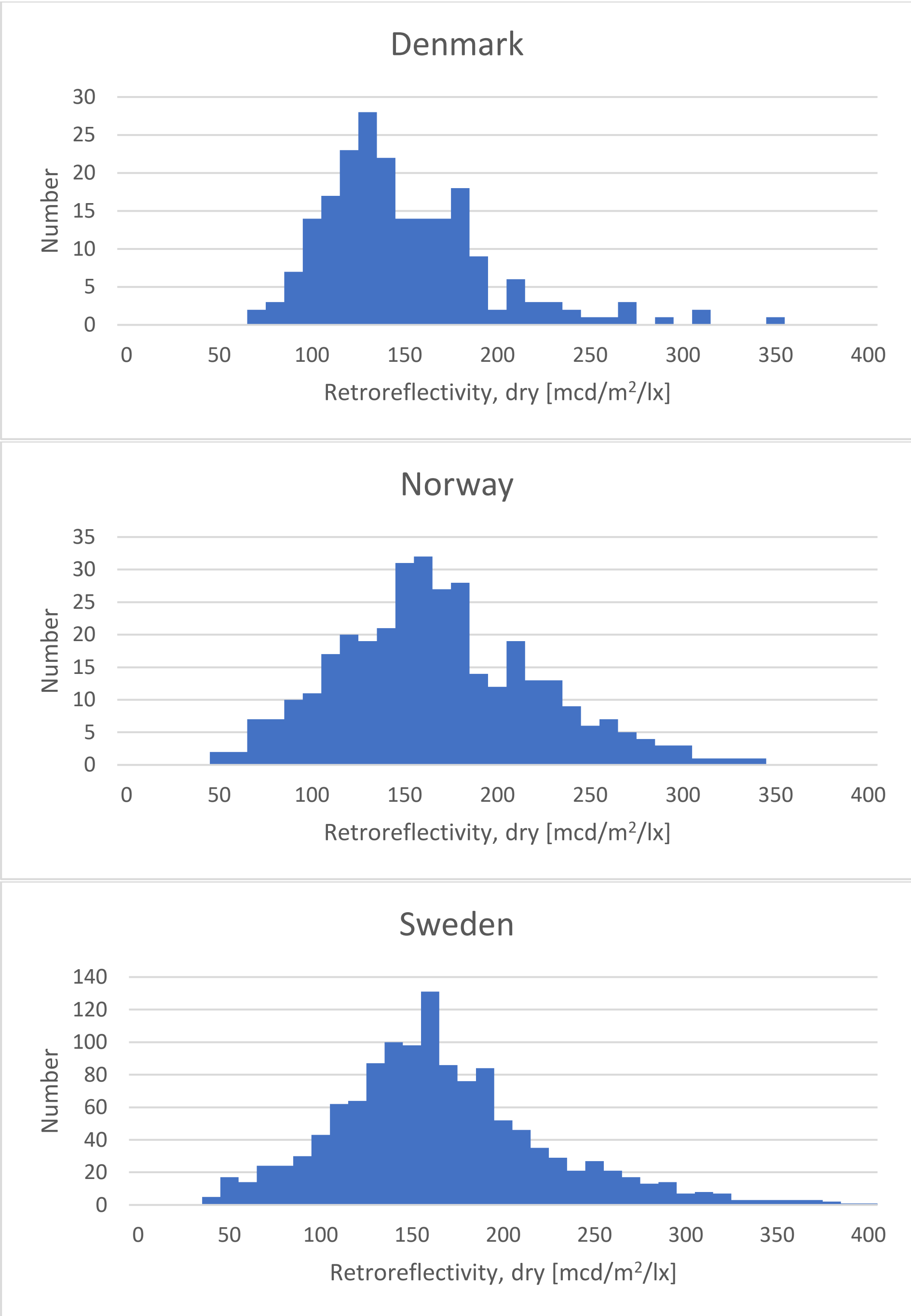

Figure 12. Distribution of retroreflectivity for Denmark, Norway and Sweden. All road markings (refers to edge, centre and lane-lines) dry road markings.

The mean performance of retroreflectivity is studied by an analysis of variance (ANOVA). In Table 7, the result from the ANOVA is shown for dry retroreflectivity of all road markings. There is a significant difference between the retroreflectivity in different countries and between road classes as well as a significant interaction effect between road class and country. A significant interaction effect means that the differences between road classes are not the same between countries. Table 8 shows mean levels and standard error of dry road marking retroreflectivity for Denmark, Norway and Sweden. The mean levels are estimated marginal means and adjusted for unbalance in the design. In Table 9, the mean levels are compared between countries. Bonferroni adjustment for multiple comparisons are made. Norway has the highest mean value and Denmark the lowest. The difference between Norway are Sweden is not statistically significant, while the differences between Denmark and Norway as well as Denmark and Sweden are significant. Note that Sweden and Denmark have only white permanent road markings, while Norway has both white and yellow.

Table 7. Results from ANOVA, dry retroreflectivity of all road markings.

Dependent variable	Independent variable	Degrees of freedom	F-ratio	p-value
Retroreflectivity (dry road markings)	Country	2	11.322	<0.001
	Road class	5	10.853	<0.001
	Country*road class	8	2.114	0.032

Table 8. Mean levels and standard error of retroreflectivity for Denmark, Norway and Sweden.

Country	Mean [mcd/m²/lx]	Standard error [mcd/m²/lx]
Denmark	144	4.0
Norway	167	3.4
Sweden	162	2.6

Table 9. Comparison of mean levels of retroreflectivity between countries. All road markings, white and yellow.

Comparison	Difference (95% CI) [mcd/m²/lx]
Sweden - Denmark	17.8 ± 11.5
Sweden - Norway	-5.2 ± 10.2
Norway - Denmark	23.0 ± 12.6

In Figure 13, the retroreflectivity for all dry road markings is compared for different road classes. Note that in Denmark there are no measurements in road class F (rural roads with AADT<2000) and in Norway there are no measurements in road class A (motorways with AADT>50 000). For road class B and C Norway, and for road classes A, D, E and F Sweden has the highest mean retroreflectivity, though the differences are rather small.

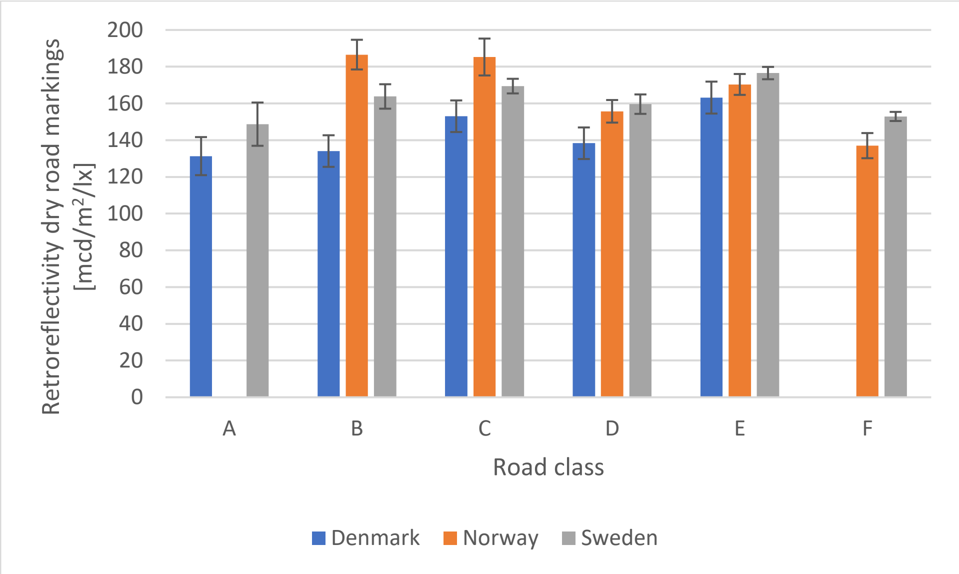

Figure 13. Retroreflectivity for dry road markings. All road markings (white and yellow).

In Figure 14 the retroreflectivity for dry right edge lines are shown. Sweden has the highest retroreflectivity for all road classes except for road class B, where Norway has much higher levels than both Denmark and Sweden.

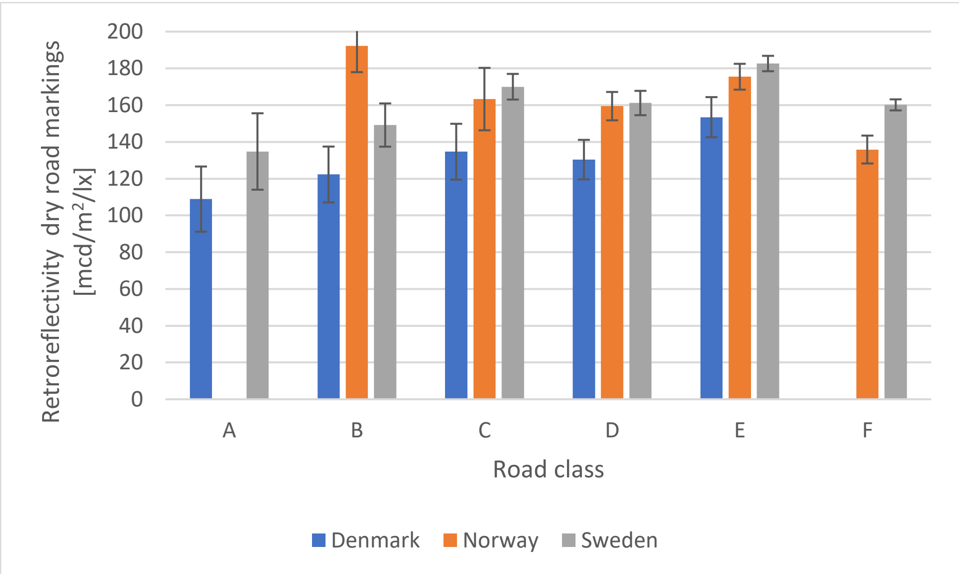

Figure 14. Retroreflectivity for dry road markings. Right edge line (only white).

In Figure 15, retroreflectivity for dry centre/lane lines are shown. For Denmark and Norway, white road markings, and for Norway, yellow road markings. One notes that, although Norway uses yellow centre lines on two-lane roads (classes D, E and F) the level of retroreflectivity is almost the same as in Denmark and Sweden.

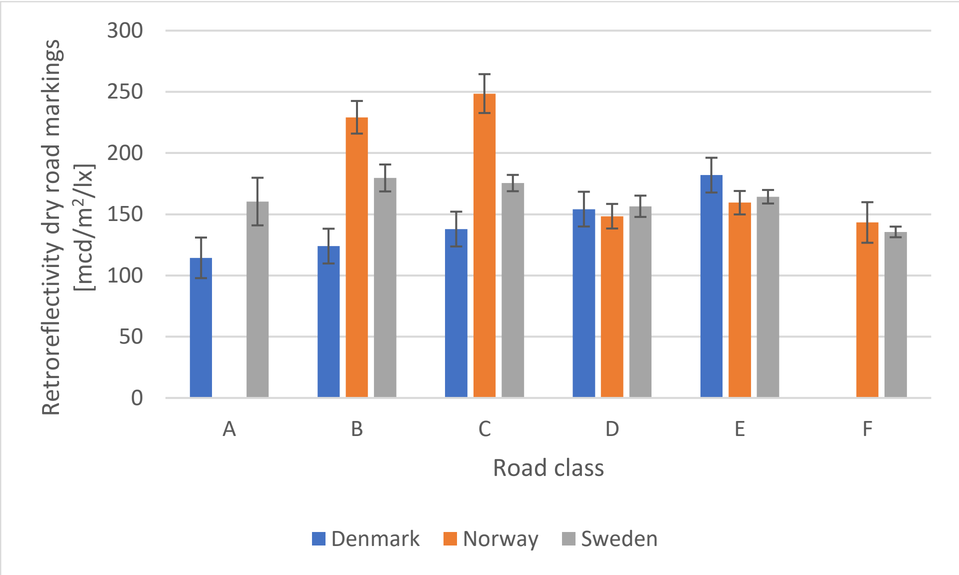

Figure 15. Retroreflectivity for dry road markings. White lane line (class A, B and C), centre line (class D, E, and F), white in Denmark and Sweden and yellow in Norway.

Cluster analysis

The figures below show the results from the cluster analyses with three different levels. The three levels indicate how the results in the different regions relate to each other, within the respective category (all, right edge, lane/centre). The results should not be interpreted in absolute terms (i.e. the *high* category means that the retroreflectivity is higher than in the *medium* category, but the categories say nothing about whether the retroreflection is "good enough" or "approved").

Figure 16 shows mean retroreflectivity for dry road markings divided by country and region. Both white and yellow road markings are included. Figure 17 shows mean retroreflectivity on dry road markings for the right edge line (only white road markings) for all regions and countries and Figure 18 shows mean retroreflectivity on dry road markings for lane lines (class A, B and C), and centre lines (class D, E and F). Note that Denmark and Sweden have white road markings and Norway has yellow markings.

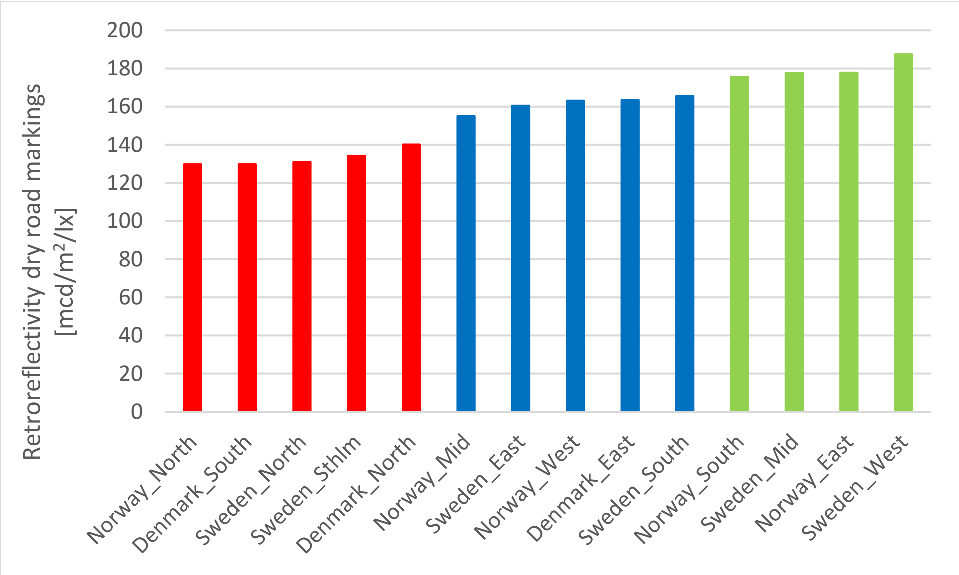

Figure 16. Results from cluster analysis. Mean retroreflectivity [mcd/m^2/lx] on dry road markings. All regions and countries. All road markings (white and yellow).

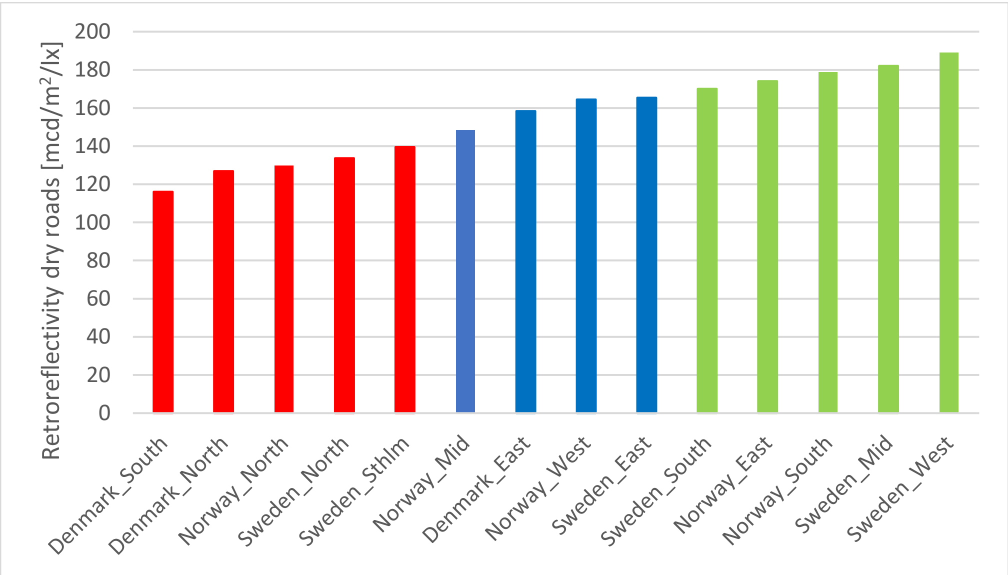

Figure 17. Results from cluster analysis. Mean retroreflectivity [mcd/m^2/lx] on dry road markings. All regions and countries. Right edge line (only white).

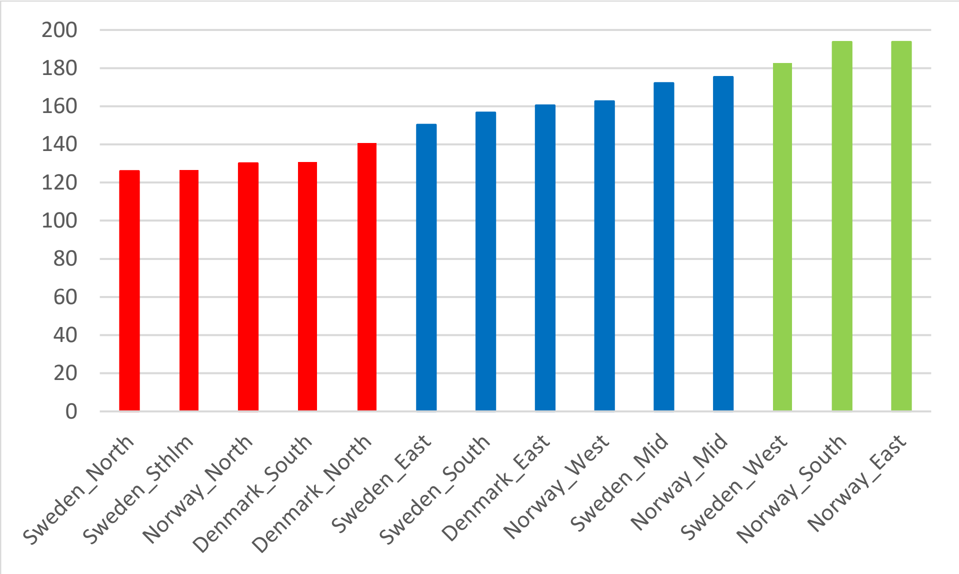

Figure 18. Results from cluster analysis. Mean retroreflectivity [mcd/m^2/lx] on dry road markings. All regions and countries. Lane line (class A, B and C), centre line (class D, E and F). White markings in Denmark and Sweden and yellow in Norway.

The results from the cluster analyses show that, for all road markings at the regional level, the retroreflectivity is generally worst in the Danish, Swedish and Norwegian north-regions and highest in the Swedish Mid and West regions and the Norwegian East and South regions. None of the regions in Denmark have been clustered in the highest category.

3.1.2 Relative visibility

In Table 10, results from the ANOVA are shown for relative visibility of the right edge line on dry road markings. There is a significant difference between the visibility of the road markings in the different countries and between road classes, as well as a significant interaction effect (country*road class). Table 11 shows mean levels and standard errors of dry road marking relative visibility for Denmark, Norway and Sweden. The mean levels are estimated marginal means and adjusted for unbalance in the design. In Table 12, the mean levels between countries are compared. Bonferroni adjustment for multiple comparisons are made. Sweden has the lowest mean value and Denmark the highest. The relative visibility of right edge road markings in Denmark is significantly longer than in both Norway and Sweden. The relative visibility difference between road markings in Norway and Sweden is also significant with longer values for Norway. Note that all permanent right edge road markings are white.

Table 10. Results from ANOVA, relative visibility of right edge line on dry road markings.

Dependent variable	Independent variable	Degrees of freedom	F-ratio	p-value
Retroreflectivity (dry road markings)	Country	2	10.49	< 0.001
	Road class	5	95.21	< 0.001
	Country*road class	8	4.26	< 0.001

Table 11. Mean levels and standard error of relative visibility for right edge line on dry road markings for Denmark, Norway and Sweden.

Country	Mean [m]	Standard error [m]
Denmark	79	0.7
Norway	77	0.6
Sweden	75	0.5

Table 12. Comparison of mean levels of relative visibility for right edge lines on dry road markings between countries.

Comparison	Difference (95% CI)
Sweden - Denmark	-4.5 ± 2.1
Sweden - Norway	-2.1 ± 1.8
Norway - Denmark	-2.4 ± 2.2

In Figure 19, the relative visibility for right edge lines are compared for different road classes. Note that in Denmark there are no measurements in road class F (rural roads with AADT<2000) and in Norway there are no measurements in road class A (Motorways with AADT>50 000). For road classes D, E and F, Sweden has the lowest mean relative visibility. The largest difference between countries is found in class E, two-lane roads with AADT between 2000 and 5000 vehicles per day. For class A, B and C (motorways and multiple lane roads), the differences are small.

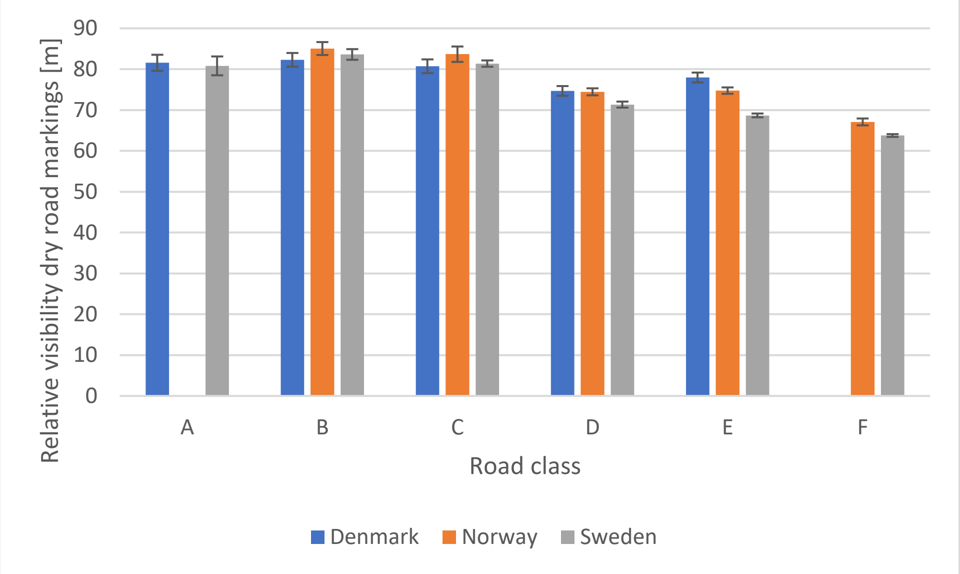

Figure 19. Relative visibility of dry road markings. Right edge line.

In Figure 20, the relative visibility of dry lane and centre lines is shown. Denmark and Sweden use white road markings, and for Norway yellow road markings. The pattern is somewhat different from Figure 19 with relatively lower levels for Norway in class D, E and F (2-lane roads) compared to the other countries.

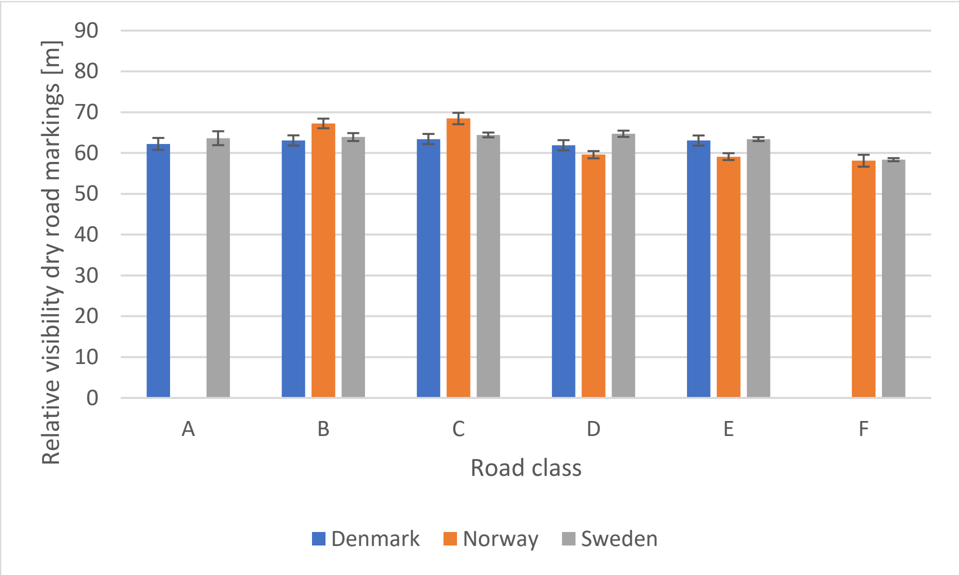

Figure 20. Relative visibility of dry road markings. Lane line (class A, B and C) and centre line (class D, E and F). White markings in Denmark and Sweden and yellow centre lines in Norway.

3.1.3 Relative pre-view-time

In Table 13, results from the ANOVA are shown for relative pre-view-time (pvt) of the right edge line on dry road markings. There is a significant difference between the different countries and between road classes, as well as a significant interaction effect (country*road class) Table 14 shows mean levels and standard errors of relative pvt for dry road markings for Denmark, Norway and Sweden. In Table 15, the mean levels are compared between countries. Norway has the highest mean value and Denmark and Sweden the lowest, the difference between Norway and the other two countries is statistically significant.

Table 13. Results from ANOVA, relative pvt for right edge line on dry road markings.

Dependent variable	**Independent variable**	**Degrees of freedom**	**F-ratio**	**p-value**
Relative pvt (dry road markings)	Country	2	65.77	<0.001
	Road class	5	44.42	<0.001
	Country*road class	8	17.35	<0.001

Table 14. Mean levels and standard error of relative pvt for right edge line on dry road markings for Denmark, Norway and Sweden.

Country	Mean [s]	Standard error [s]
Denmark	2.9	0.04
Norway	3.4	0.03
Sweden	3.0	0.03

Table 15. Comparison of mean levels of relative pvt for right edge line on dry road markings between countries.

Comparison	Difference (95% CI)
Sweden - Denmark	0.09 ± 0.12
Sweden - Norway	-0.41 ± 0.11
Norway - Denmark	0.51 ± 0.13

In Figure 21, the relative pvt for all dry road markings are compared for different road classes. Note that in Denmark there are no measurements in road class F (rural roads with AADT<2 000) and in Norway there are no measurements in road class A (motorways with AADT>50 000). Norway has the highest relative pvt for road class B, C, D and F.

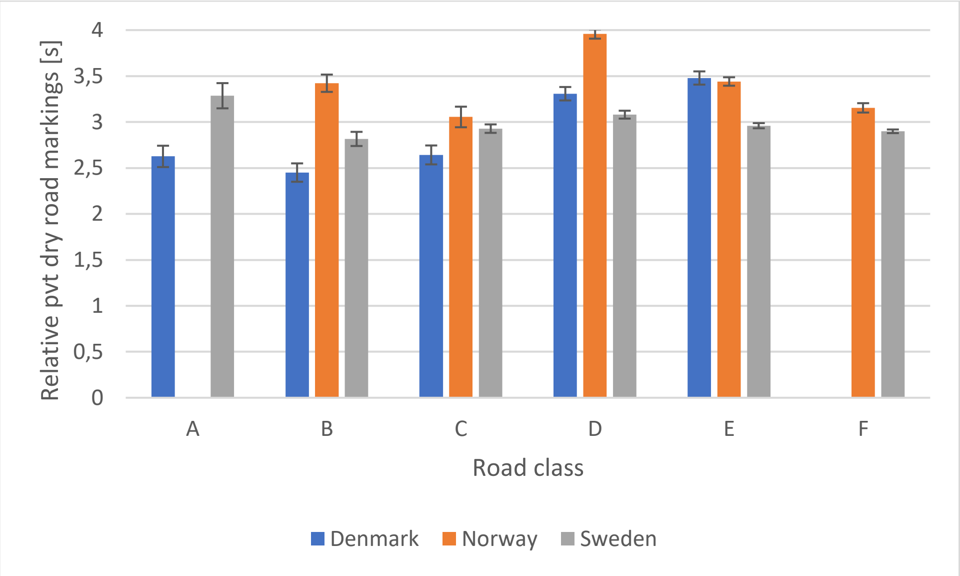

Figure 21. Relative pvt for dry road markings. Right edge line.

In Figure 22 relative pvt for dry lane lines (class A, B and C) and centre lines (class D, E and F) are shown. Denmark and Sweden have white road markings and Norway has yellow. For class B, C and D, Norway has the highest relative pvt, while for centre lines in class E and F, the differences between countries are small.

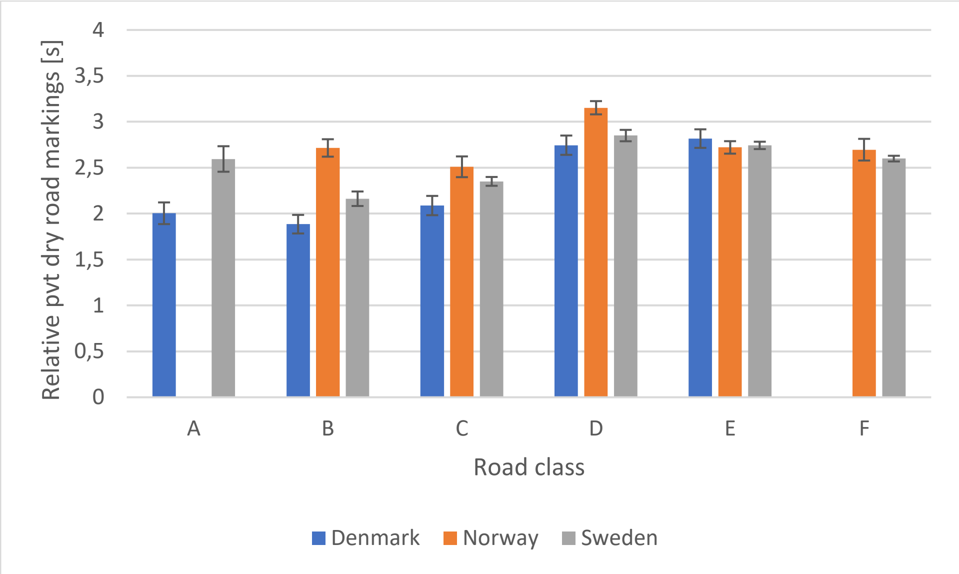

Figure 22. Relative pvt for dry road markings. Lane lines (class A, B and C and, centre lines (class D, E and F). White markings in Denmark and Sweden and yellow in Norway.

3.2 Wet road markings

Below are the results for wet road markings shown. As mentioned in section 2.3.1, during the annual validation of mobile instruments in 2017 and 2018, significant deviations between the results from the mobile measurements and the hand-held measurements according to the standard EN-1436 were seen for some of the test objects and the results for wet road markings should therefore be interpreted with care.

In Table 16, the number of measured road markings (as defined in section 2.1) used in the analyses for wet road markings is shown. For Denmark 137 objects are analysed, while for Norway and Sweden, the numbers are 90 and 408 respectively.

Table 16. Number of measured road markings used in the analyses for wet road markings.

Road class	Denmark	Norway	Sweden
A	19		3
B	30	26	35
C	27	21	136
D	34	21	88
E	27	20	146
F		2	
Total	**137**	**90**	**408**

3.2.1 Retroreflectivity

In Figure 23, the distribution of retroreflectivity for wet road markings in all countries is shown. The values in Norway are distributed towards higher retroreflectivity than in Denmark and Sweden.

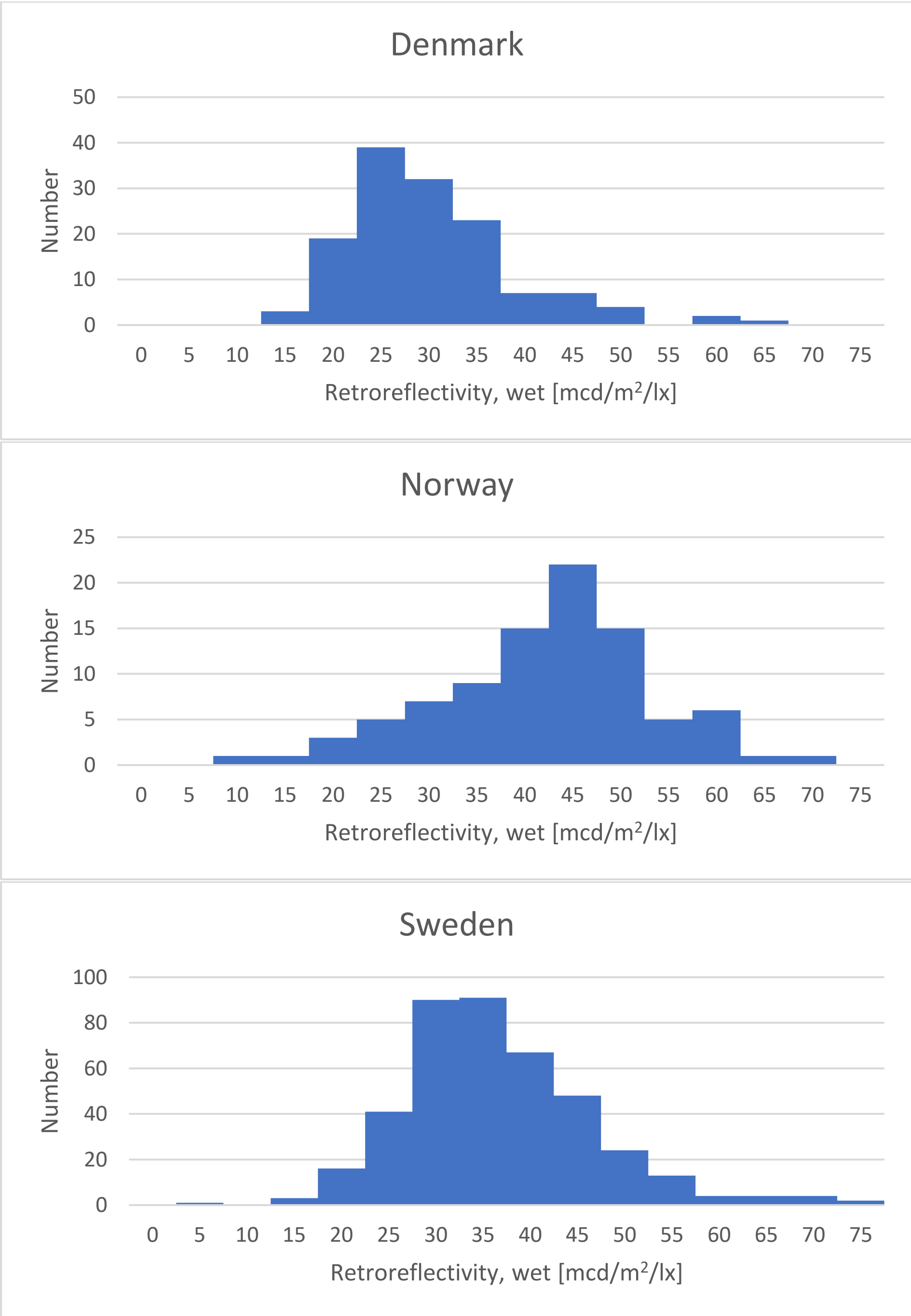

Figure 23. Distribution of wet road marking retroreflectivity for Denmark, Norway and Sweden. Wet road markings.

The mean performance of retroreflectivity on wet road markings, studied by an ANOVA is shown in Table 18. There is a significant difference between the retroreflectivity in the different countries, between road classes, as well as a significant interaction effect (country*road class). Table 19 shows the mean level and standard error of wet road marking retroreflectivity for Denmark, Norway and Sweden. The mean levels are estimated marginal means and adjusted for unbalance in the design. In Table 19, the mean levels are compared between countries. Bonferroni adjustment for multiple comparisons are made. Norway has the highest mean value and Denmark the lowest. The retroreflectivity difference between Denmark and Sweden as well as between Denmark and Norway is significant. Note that Sweden and Denmark have only white permanent road markings, while Norway has both white and yellow (centre lines and left edge lines on multi-lane roads).

Table 17. Results from ANOVA, retroreflectivity all road markings, wet road markings.

Dependent variable	Independent variable	Degrees of freedom	F-ratio	p-value
Retroreflectivity (wet road markings)	Country	2	37.32	< 0.001
	Road class	5	5.06	< 0.001
	Country*road class	6	1.75	0.095

Table 18. Mean levels and standard error of wet road marking retroreflectivity for Denmark, Norway and Sweden, all road markings.

Country	Mean [mcd/m²/lx]	Standard error [mcd/m²/lx]
Denmark	28	0.9
Norway	37	1.6
Sweden	33	1.1

Table 19. Comparison of mean levels of wet road marking retroreflectivity, all road markings between countries.

Comparison	Difference (95% CI) mcd/m²/lx
Sweden - Denmark	4.6 ± 3.3
Sweden - Norway	-3.9 ± 4.7
Norway - Denmark	8.4 ± 4.4

In Figure 24, the retroreflectivity for all wet road markings are compared for different road classes. Note that Denmark has no measurements in road class F (rural roads with AADT<2000) and Norway has no measurements in road class A (motorways with AADT>50 000). For all road classes, Norway has the highest mean retroreflectivity for wet road markings.

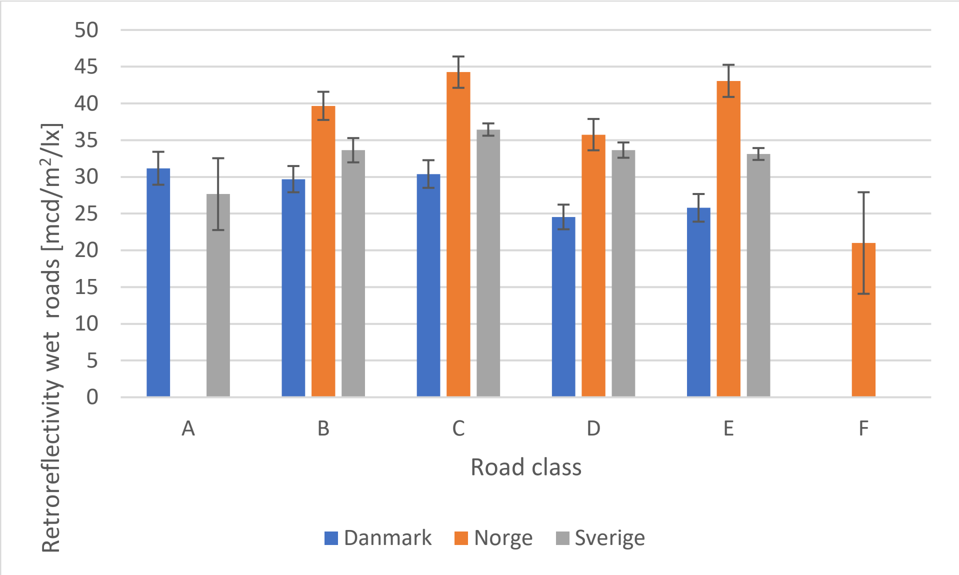

Figure 24. Retroreflectivity for wet road markings. All road markings.

In Figure 25 the retroreflectivity for wet right edge lines is shown. The pattern is similar as in Figure 24, with higher levels for Norway.

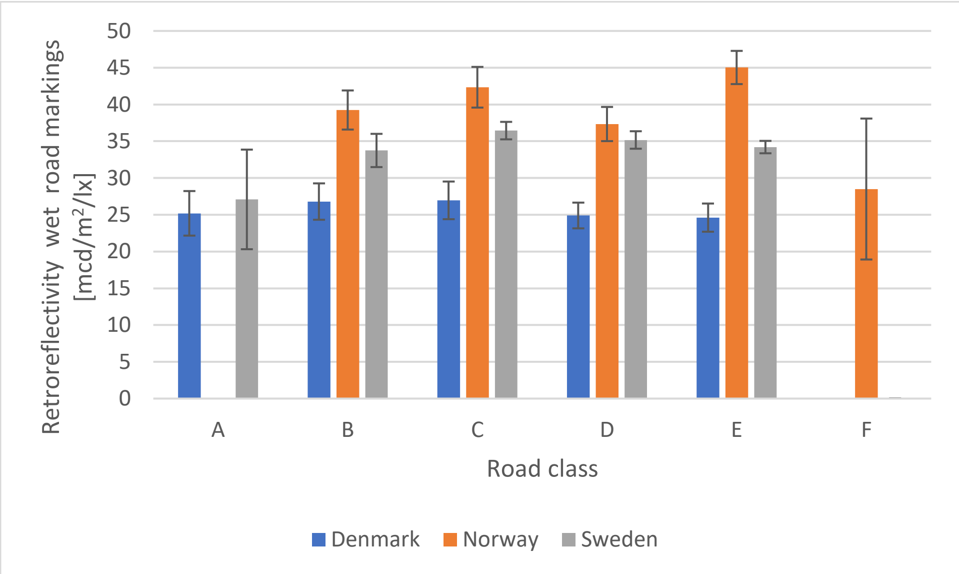

Figure 25. Retroreflectivity for wet road markings. Right edge line.

3.2.2 Relative visibility

In Figure 26, the relative visibility for right edge lines is compared for different road classes. Note that in Denmark there are no measurements in road class F (rural roads with AADT<2000) and in Norway there are no measurements in road class A (Motorways with AADT>50 000). For all road classes, Norway has the highest mean relative visibility, but some of the differences are rather small. The relative visibility for wet right edge road markings is particularly low for Sweden in road class E.

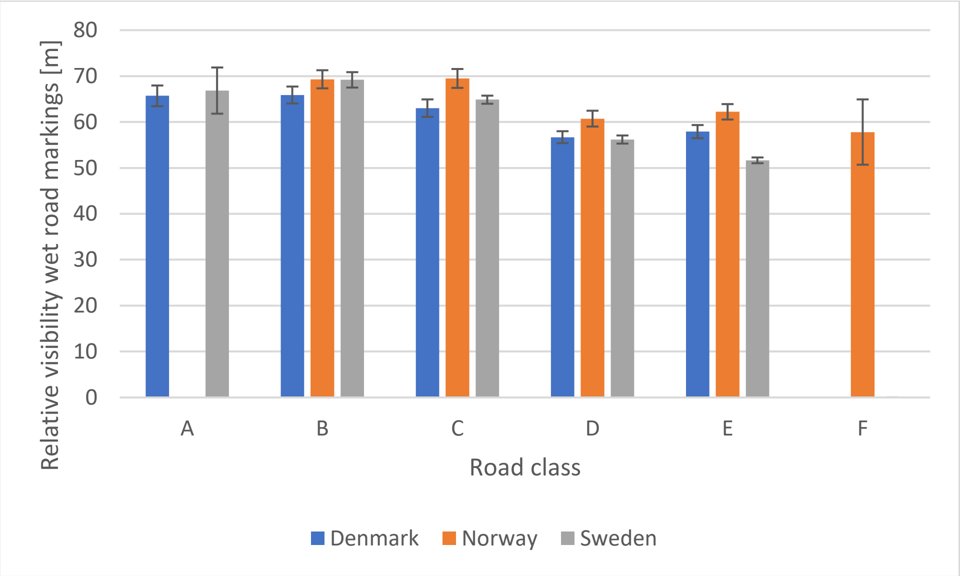

Figure 26. Relative visibility of wet road markings. Right edge line.

3.2.3 Relative pre-view-time

In Figure 27, the relative pre-view-time for wet right edge road markings are compared for different road classes. Note that in Denmark there are no measurements in road class F (rural roads with AADT<2000) and in Norway there are no measurements in road class A (motorways with AADT>50 000). Similar to Figure 26, Norway has the highest values for relative pvt in all road classes where there are measurements.

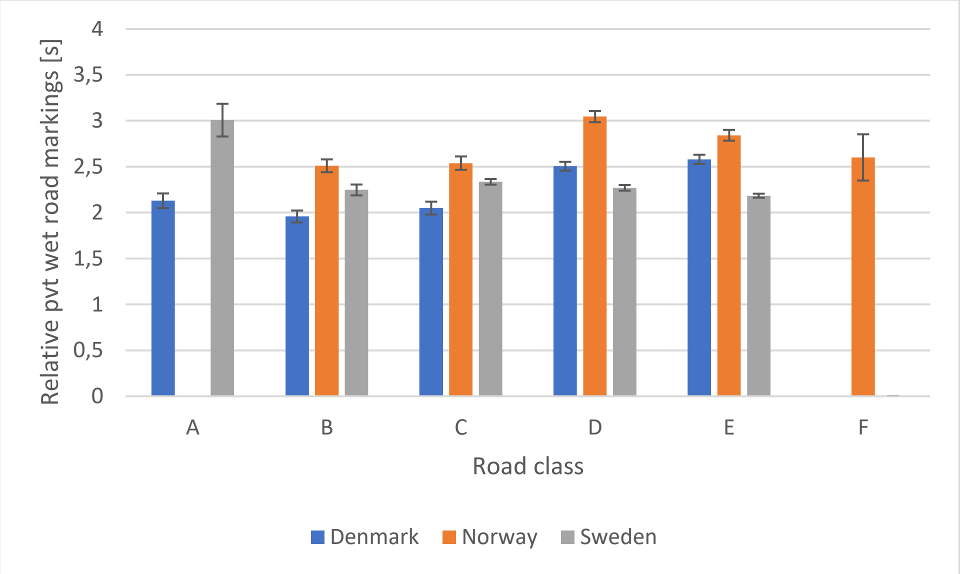

Figure 27. Relative pvt for wet road markings. Right edge line.

3.3 TEN-T road network

In total, about 32 % of the measured objects belong to the TEN-T network. The distribution is different between the three countries which is shown in Table 20. In Denmark the share of the measured roads is 63 %, in Norway 35 % and in Sweden 26 %.

Table 20. Share of measured TEN-T roads in Denmark, Norway and Sweden.

Country	Share TEN-T roads (%)
Denmark	63
Norway	35
Sweden	26
All	**32**

Table 21. Retroreflectivity for dry road markings, all road markings. TEN-T and non-TEN-T.

Country	Road network	Retroreflectivity dry road markings [mcd/m²/lx]	Standard deviation
Denmark	TEN-T	143	5.1
	Non-TEN-T	147	6.7
Norway	TEN-T	176	5.3
	Non-TEN-T	157	3.9
Sweden	TEN-T	172	3.2
	Non-TEN-T	159	1.9

In Figure 28, a comparison between retroreflectivity for dry road markings for the TEN-T road network and the non-TEN-T road network is made. There are only minor differences between the TEN-T and other roads in Denmark, while in Sweden and Norway there are somewhat higher levels for the TEN-T network with retroreflectivity 159 mcd/m^2/lx for non-TEN-T and

172 mcd/m²/lx for TEN-T roads in Sweden and retroreflectivity 157 mcd/m²/lx for non-TEN-T and 176 mcd/m²/lx for TEN-T roads in Norway, both differences are significant.

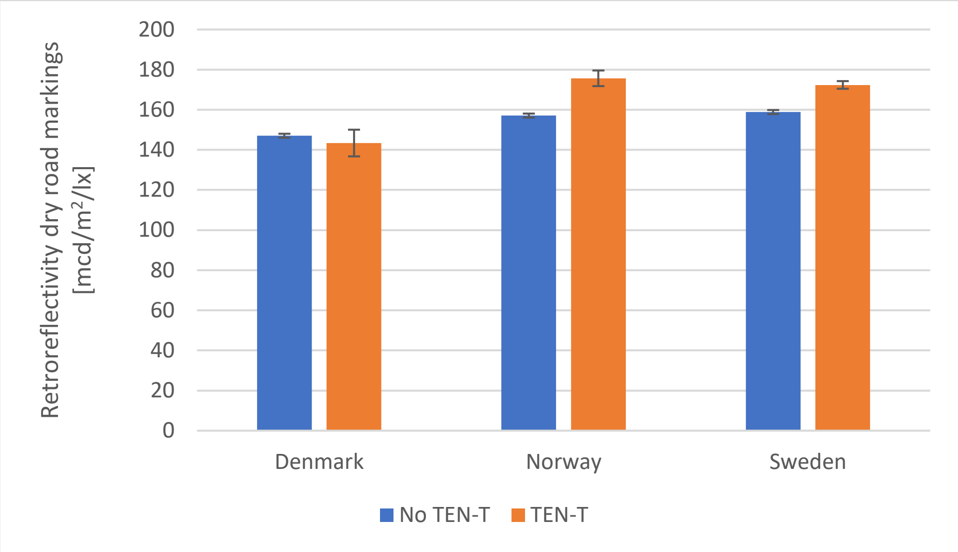

Figure 28. Retroreflectivity for dry road markings, all road markings. TEN-T and non-TEN-T.

In Figure 29, retroreflectivity for dry right edge road markings for the TEN-T road network and the non-TEN-T road network are shown. The pattern is very similar to the results for all road markings, minor differences in Denmark and higher levels for the TEN-T road network in Sweden and Norway.

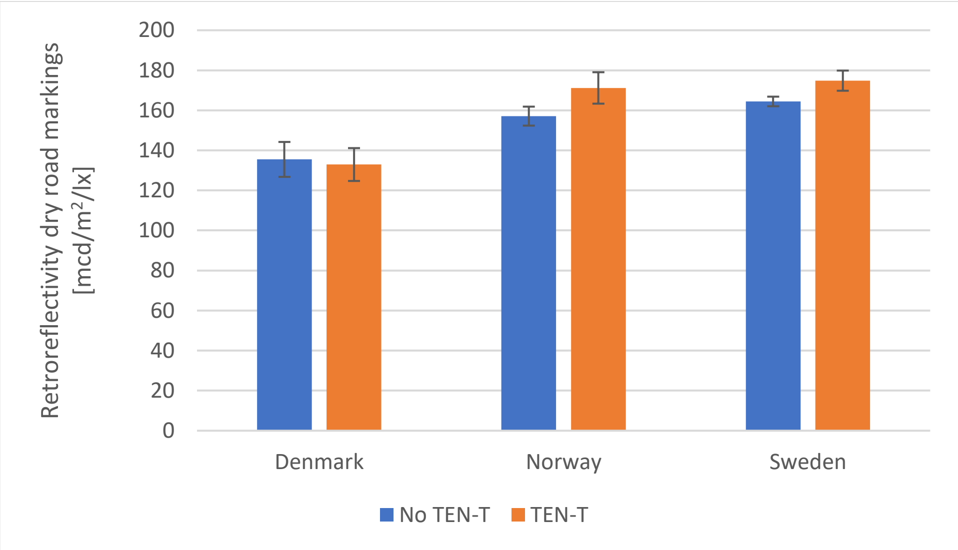

Figure 29. Retroreflectivity for dry road markings, right edge lines. TEN-T and non-TEN-T.

The results for relative visibility for right edge lines are shown in Figure 30 and it is shown that the relative visibility is larger for the TEN-T road network for all three countries. For Sweden the relative visibility on the TEN-T roads are 80 while the relative visibility for the non-TEN-T roads are 66. For Denmark the relative visibility is 81 (TEN-T) and 75 (non-TEN-T) and for Norway 79 (TEN-T) and 72 (non-TEN-T). For all countries, the difference between TEN-T and non-TEN-T is significant.

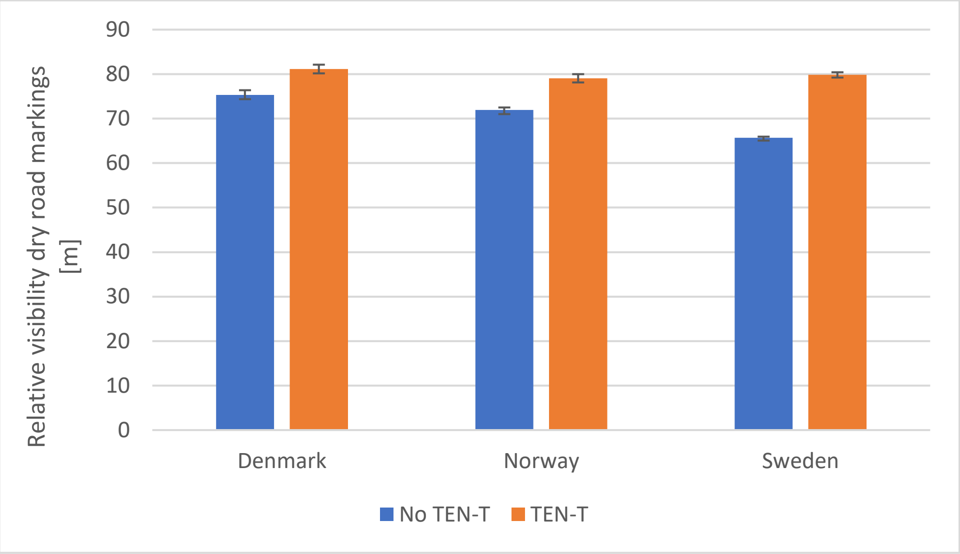

Figure 30. Relative visibility for dry road markings, right edge lines. TEN-T and non-TEN-T.

In Figure 31, relative pre-view-time for right edge lines is shown for the measured TEN-T roads as well as for the other roads. In Denmark, the relative pvt is lower on the measured TEN-T roads, but in Norway and Sweden there are no major differences. The positive effect of a higher relative visibility for the TEN-T road network is not present when studying relative pvt and this is probably due to that the TEN-T, in general, has higher speed limit than the non-TEN-T road network. In Table 22, the mean speed limits for the two types of road networks are shown. For all countries, the mean speed limits are higher on the TEN-T roads than on other roads, but there are also differences between countries. In Denmark, the mean speed level on TEN-T roads is 107 km/h, in Sweden it is 100 km/h and in Norway 84 km/h. For the non-TEN-T network, the mean speed limit on the measured roads is 77 km/h for Denmark, 75 km/h for Norway and 81 km/h for Sweden.

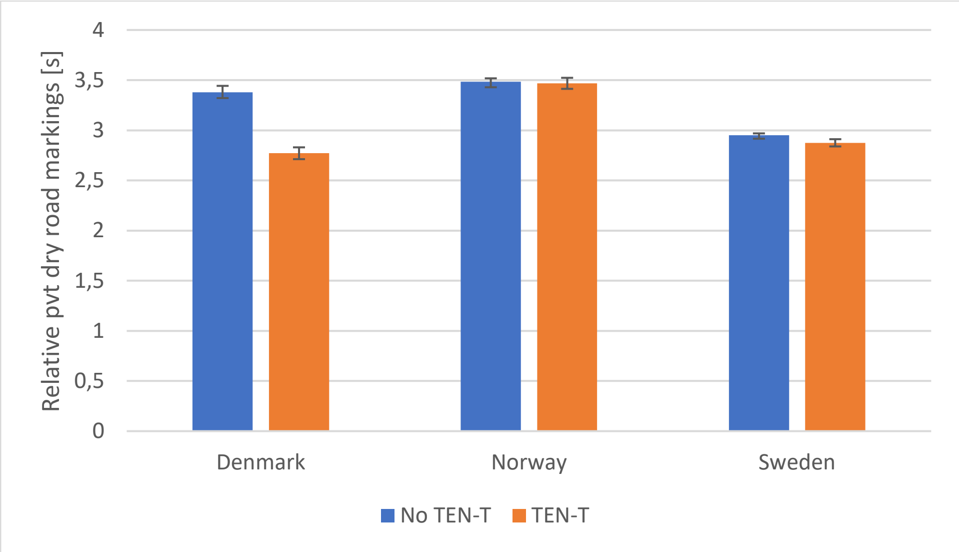

Figure 31. Relative pvt for dry road markings, right edge lines. TEN-T and non-TEN-T.

Table 22. Mean speed limits 2018 on measured TEN-T roads and non-TEN-T roads.

	TEN-T (km/h)	**Non-TEN-T (km/h)**
Denmark	107	77
Norway	84	75
Sweden	100	81

3.4 Cover index

The cover index (%) is defined as the part of the road marking area that remains at the time of measurement. The measure is new and still under development. The ambition for the coming years is to relate the cover index to road marking type, i.e. whether the road marking is profiled or not. However, this information is not available yet.

The cover index is measured in % and can have values above 100 % if, e.g., a new road marking overlaps with an old road marking. Profiled markings might have values below 100 % even when they are new if the pattern contains unfilled parts, such as a chessboard pattern. Consequently, a cover index of 60 % can represent a partially worn road marking or a new profiled road marking.

3.4.1 All road markings

In Figure 32 and Figure 33, it is illustrated how the cover index is distributed among all measured road objects for all countries. In Denmark about 85 % of the measured objects have a cover index above 60 %, while in Norway the share of measured objects with cover index above 60 % is about 80 % and in Sweden that share is 86 %. It is not known whether the road markings are profiled or not.

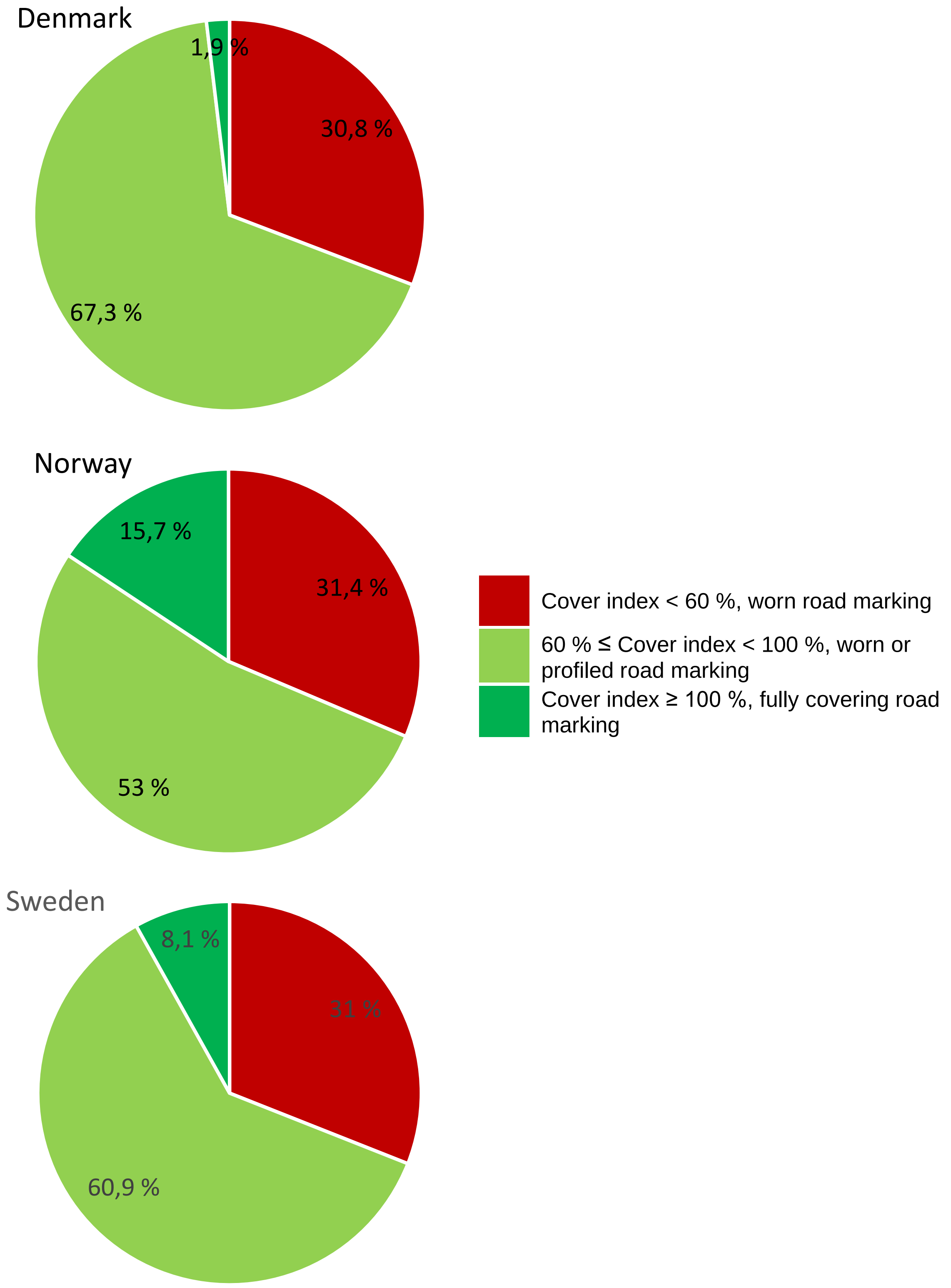

Figure 32. Cover index for Denmark, Norway and Sweden, all road markings.

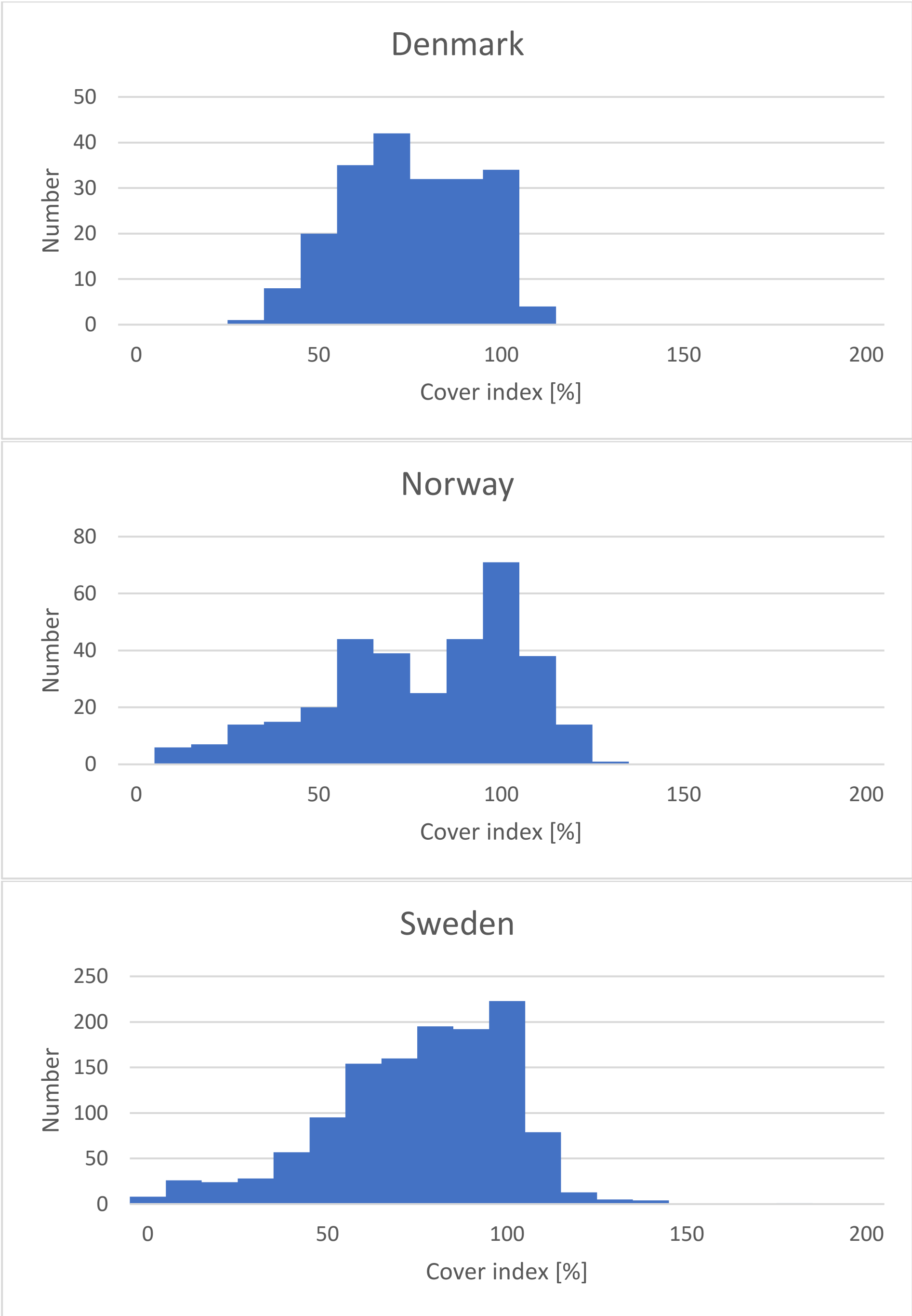

Figure 33. Distribution of cover index for Denmark, Sweden and Norway. All road markings.

In Table 23, the result of the ANOVA is shown for cover index for all dry road markings. There is no significant difference between countries. However, there is a significant difference between road classes, but no significant interaction. Table 23 shows mean levels and standard error of cover index for Denmark, Norway and Sweden. In Table 25, the mean levels are compared between countries. Norway has the highest mean value and Denmark the lowest, but none of the differences between countries are significant.

Table 23. Results from ANOVA, cover index for all road markings, dry road markings.

Dependent variable	Independent variable	Degrees of freedom	F-ratio	p-value
Cover index	Country	2	2.13	0.12
	Road class	5	4.70	<0.001
	Country*road class	8	1.84	0.066

Table 24. Mean levels and standard error of cover index for Denmark, Norway and Sweden.

Country	Mean (%)	Standard error (%)
Denmark	71	1.7
Norway	74	1.4
Sweden	72	1.1

Table 25. Comparison of mean levels of cover index between countries. All road markings, white and yellow.

Comparison	Difference (95% CI)
Sweden - Denmark	0.7 ± 4.8
Sweden - Norway	-2.3 ± 4.3
Norway - Denmark	3.0 ± 5.3

In Figure 34 the cover index for all dry road markings is compared for different road classes. Note that in Denmark there are no measurements in road class F (rural roads with AADT<2000) and in Norway there are no measurements in road class A (motorways with AADT>50 000).

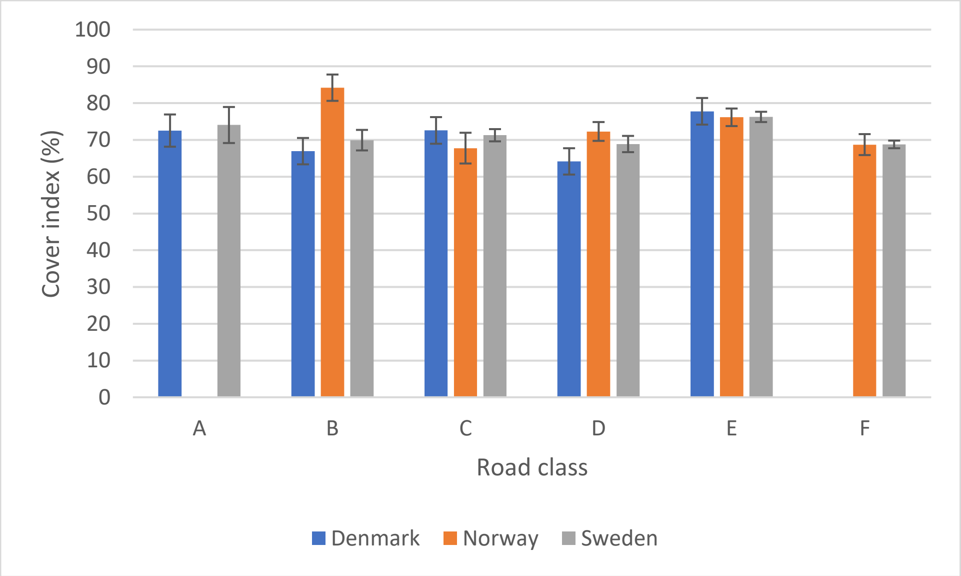

Figure 34. Cover index for all road markings (white and yellow).

3.4.2 Right edge line

For right edge line, there is no significant differences between countries, but between road classes. There is either no significant interaction effect (country*road class). Table 26 shows the mean level and standard error of dry road marking cover index for Denmark, Norway and Sweden. In Table 27, the mean levels are compared between countries. Sweden has the highest mean value and Denmark the lowest, however, none of the differences between countries are significant. Compared to the mean levels in Table 24, the cover index for the right edge line is lower for all countries.

Table 26. Mean levels and standard error of cover index, right edge line.

Country	Mean (%)	Standard error (%)
Denmark	62	2.5
Norway	65	2.0
Sweden	67	1.6

Table 27. Comparison of mean levels of cover index between countries. Estimated marginal means, adjusted for unbalance in the design. Right edge line, 95% confidence interval.

Comparison	Difference (95% CI)
Sweden - Denmark	5.1 ± 7.1
Sweden - Norway	1.7 ± 6.1
Norway - Denmark	3.4 ± 7.5

In Figure 35 the cover index for right edge lines are compared for different road classes. Note that in Denmark there are no measurements in road class F (rural roads with AADT<2000) and in Norway there are no measurements in road class A (motorways with AADT>50 000).

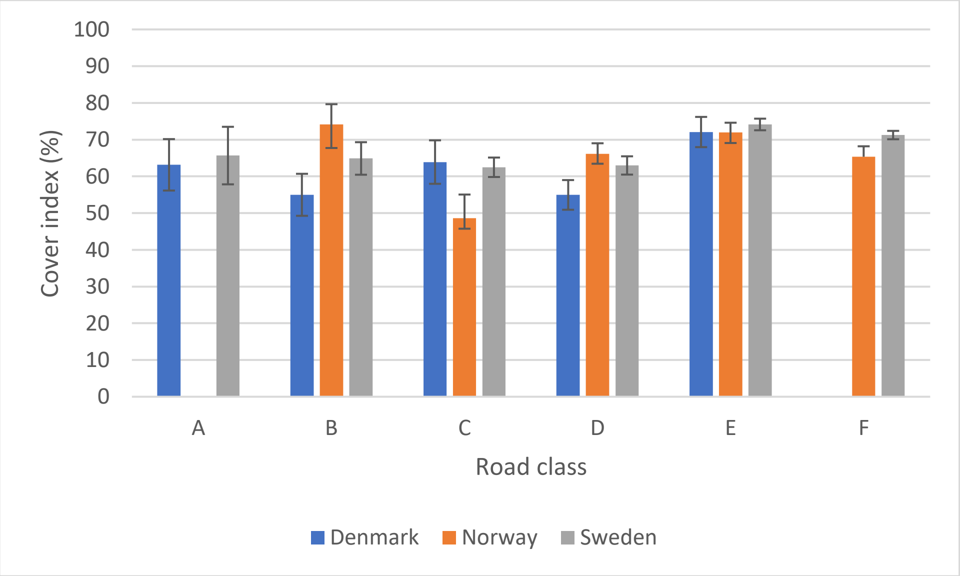

Figure 35. Cover index for right edge lines.

3.4.3 Lane and centre line

For lane line (class A, B and C) and centre line (class D, E and F), there is a significant difference between countries, road classes as well as a significant interaction effect (country*road class). Table 28 shows the mean level and standard error of dry road marking cover index for Denmark, Norway and Sweden. In Table 29, the mean levels are compared between countries. Compared to the mean levels of right edge lines in Table 26, the cover index on right edge line is lower compared to the lane and centre line. This applies to all countries. Norway has a significantly higher cover index than Sweden.

Table 28. Mean levels and standard error of cover index. Lane line (class A, B and C) and centre lane (class D, E and F). Denmark and Sweden have white markings and Norway has yellow centre line.

Country	Mean (%)	Standard error (%)
Denmark	87	2.9
Norway	94	2.6
Sweden	83	1.9

Table 29. Comparison of mean levels of cover index between countries. Lane line (class A, B and C) and centre lane (class D, E and F). Denmark and Sweden have white markings and Norway has yellow centre line.

Comparison	Difference (95% CI)
Sweden - Denmark	-3.7 ± 8.2
Sweden - Norway	-11.0 ± 7.8
Norway - Denmark	7.2 ± 9.3

In Figure 36, cover index for lane lines (class A, B and C) and centre lines (class D, E and F) are shown for different road classes. The cover index for lane and centre lines is generally high, especially for motorways road in class B and C in Norway.

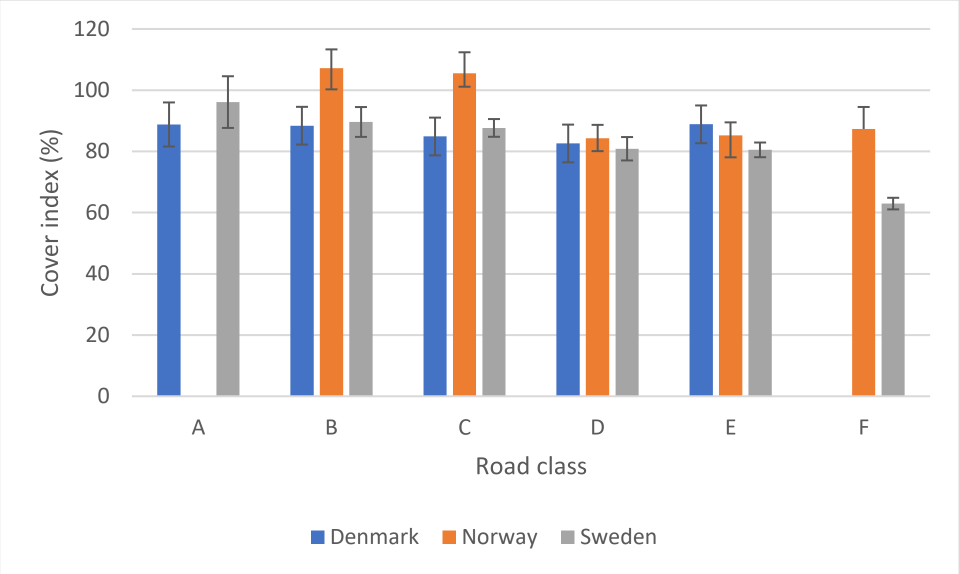

Figure 36. Cover index for lane line (class A, B and C) and centre line (class D, E and F). Denmark and Sweden white markings and Norway yellow centre line.

4 Results. Comparisons 2017 and 2018

4.1 Dry road markings

In this chapter some comparisons between the measurements in 2017 and 2018 are presented. In Table 30 the number of measured dry road markings for 2017 and 2018 is shown. For Denmark and Sweden, the number is about the same for 2017 and 2018, while for Norway, the number of measured dry road markings has increased from 278 in 2017 to 346 in 2018.

Table 30. Number of measured road markings used in the analyses for dry road markings 2017 and 2018.

Road class	Denmark		Norway		Sweden	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**
A	31	31	-	-	21	24
B	45	45	43	51	103	75
C	45	44	32	33	224	211
D	45	45	75	88	81	119
E	44	45	73	103	280	296
F	-	-	55	71	561	542
Total	**210**	**210**	**278**	**346**	**1270**	**1267**

4.1.1 Retroreflectivity

Figure 37 shows the difference in retroreflectivity for all dry road markings between 2017 and 2018. In Denmark and Sweden there are no changes between 2017 and 2018, while for Norway, the mean retroreflectivity has increased from 154 mcd/m^2/lx to 167 mcd/m^2/lx. Figure 38 shows retroreflectivity on dry right edge road markings.

In Figure 39, a comparison of the distribution of retroreflectivity between 2017 and 2018 for Denmark, Norway and Sweden is depicted. All dry road markings are included (refers to edge, centre and lane-lines). For Denmark, the distribution is shifted to the left towards lower retroreflectivity in 2018 compared to 2017. In Norway, the distribution is rather similar for 2018 compared to 2017, although 23 more roads were measured during 2018 resulting in almost 70 additional measured road markings. Sweden, which is the country with most measurements, has a rather stable distribution between the years.

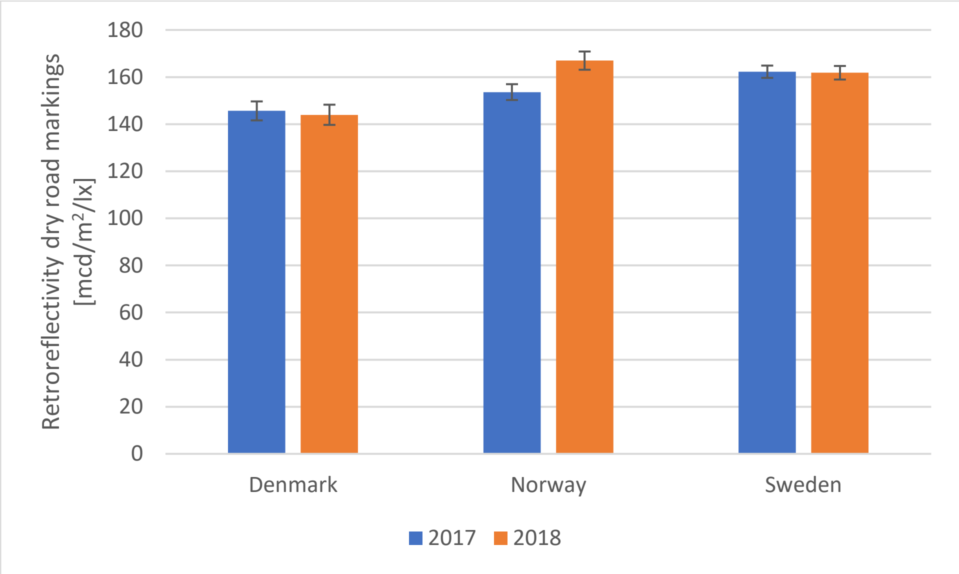

Figure 37. Retroreflectivity for dry road markings. All road markings (white and yellow). Comparison between 2017 and 2018.

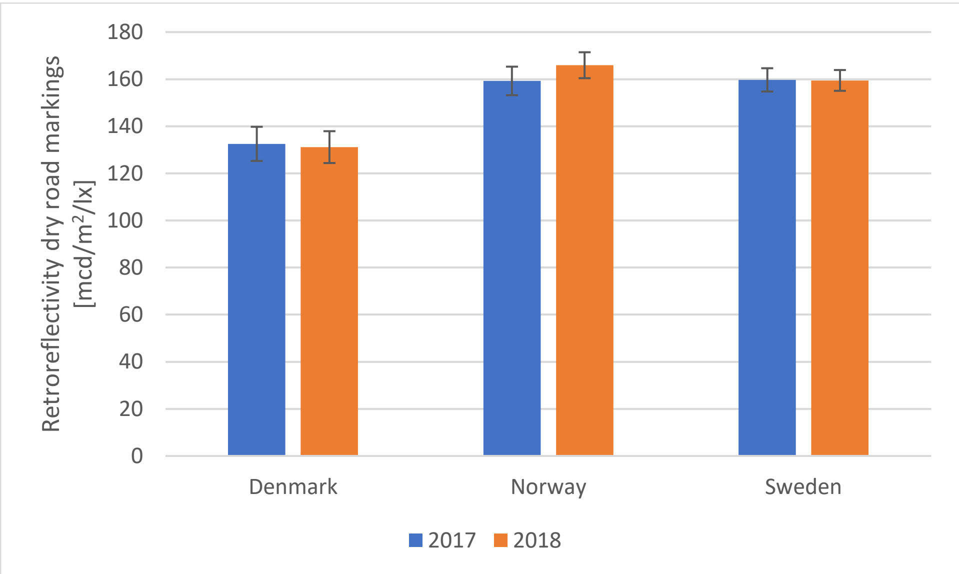

Figure 38. Retroreflectivity for dry road markings, right edge line. Only white road markings. Comparison between 2017 and 2018.

In Figure 40, a comparison between retroreflectivity for all road markings (white and yellow) for 2017 and 2018 is shown for all road classes and countries. The largest differences are seen for Norway in road class B (Motorway or multi-lane roads, 20 000 < AADT ≤ 50 000) and C (Motorway or multi-lane roads, AADT ≤ 20 000), where the mean retroreflectivity is more than 30 mcd/m^2/lx higher in 2018 than in 2017. This difference is statistically significant. For all the other road classes within each country there are no significant differences between the years. Figure 41 shows the retroreflectivity for dry right edge line road markings. For right edge lines, there are no significant differences between 2017 and 2018.

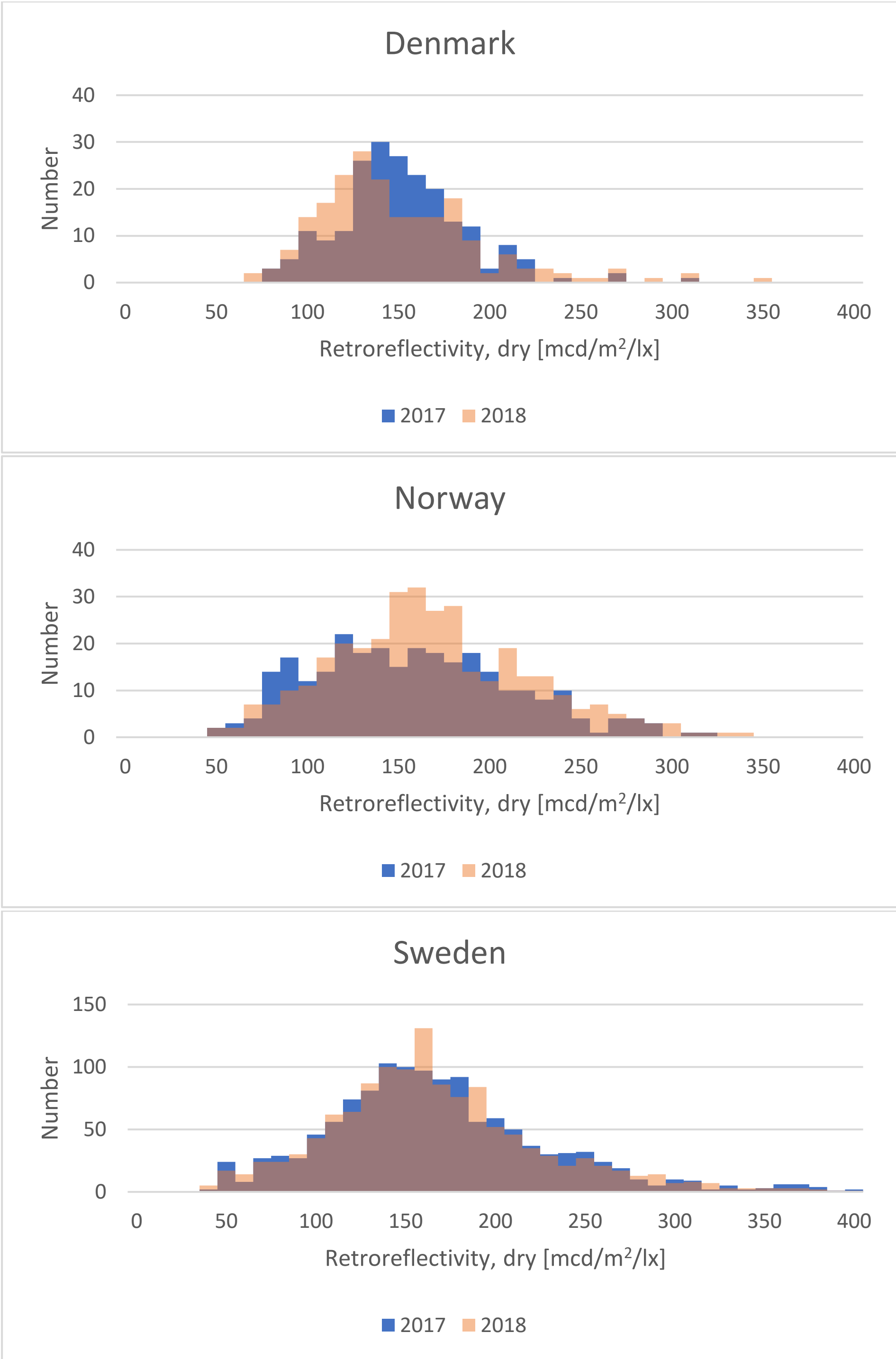

Figure 39. Comparison of the distribution of retroreflectivity for Denmark, Norway and Sweden 2017 and 2018. All road markings (refers to edge, centre and lane-lines) dry road markings.

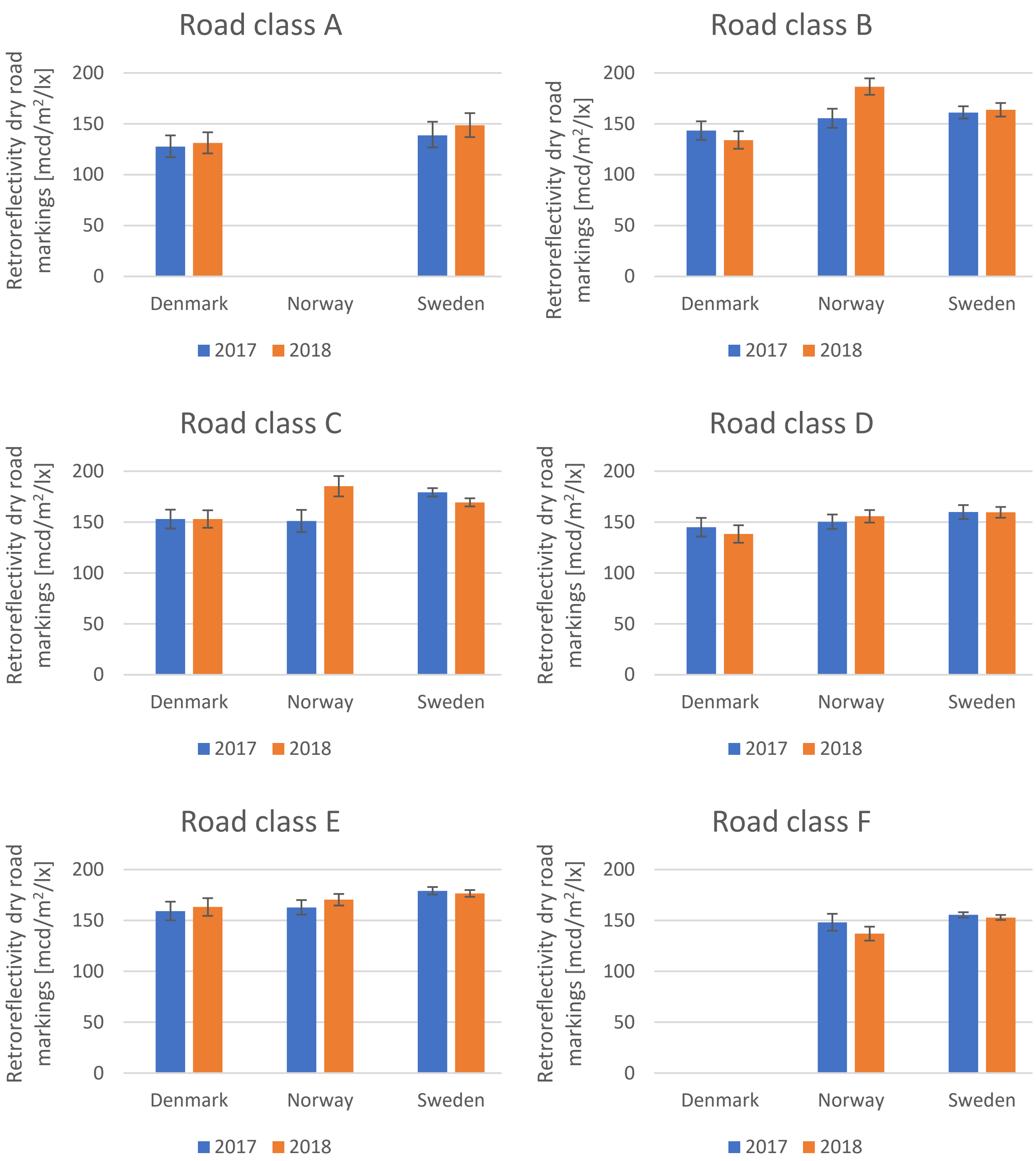

Figure 40. Retroreflectivity for dry road markings. Comparison between 2017 and 2018 for country and road class. All road markings (white and yellow).

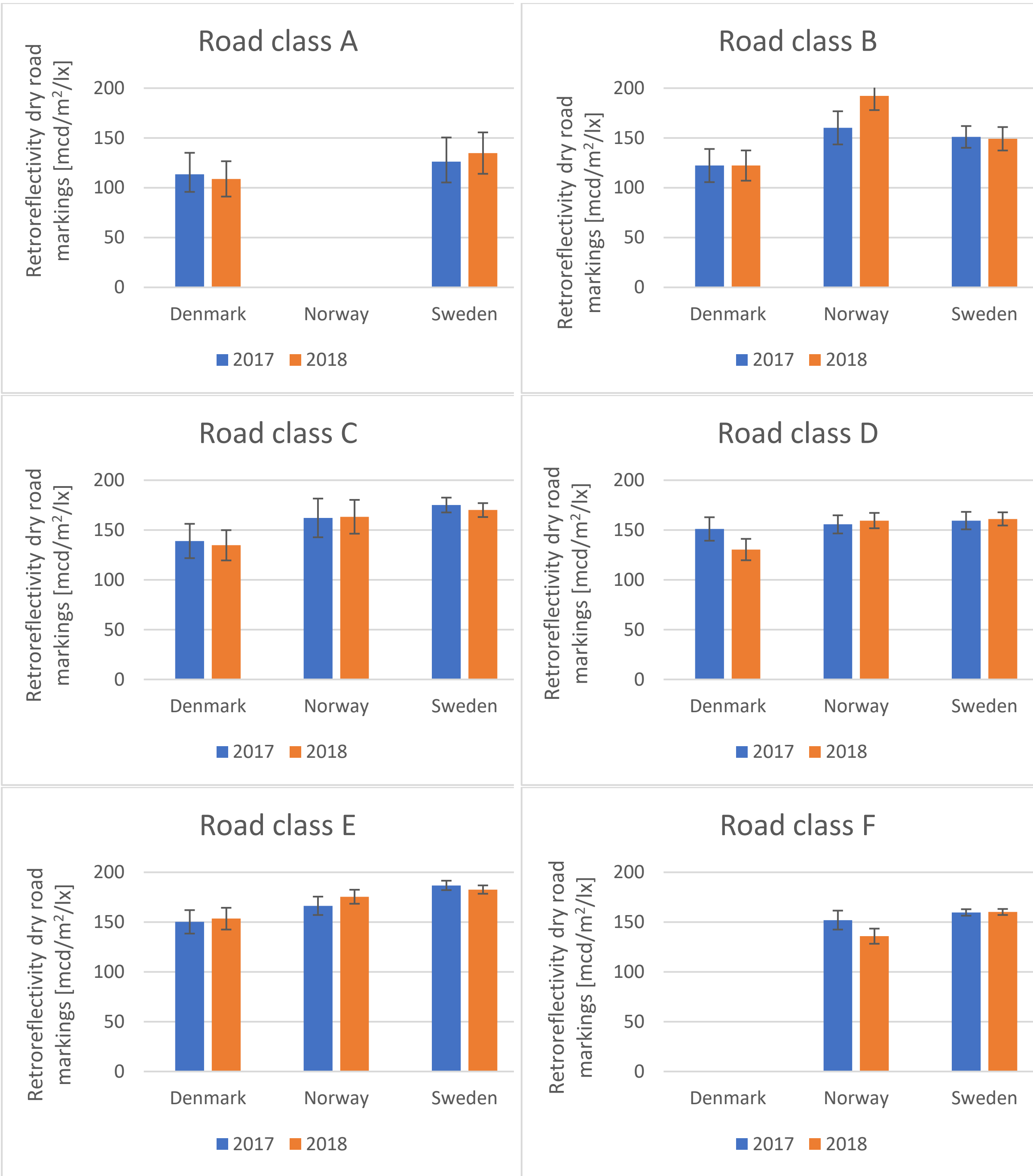

Figure 41. Retroreflectivity for dry road markings, right edge lines (only white). Comparison between 2017 and 2018 for country and road class.

4.1.2 Relative visibility

In Figure 42, the mean relative visibility for right edge lines are compared for 2017 and 2018. The mean levels are estimated marginal means and adjusted for unbalance in the design between the countries. Regarding relative visibility for dry roads, there are only minor differences between the performance in 2017 and 2018 and Denmark has the highest relative visibility.

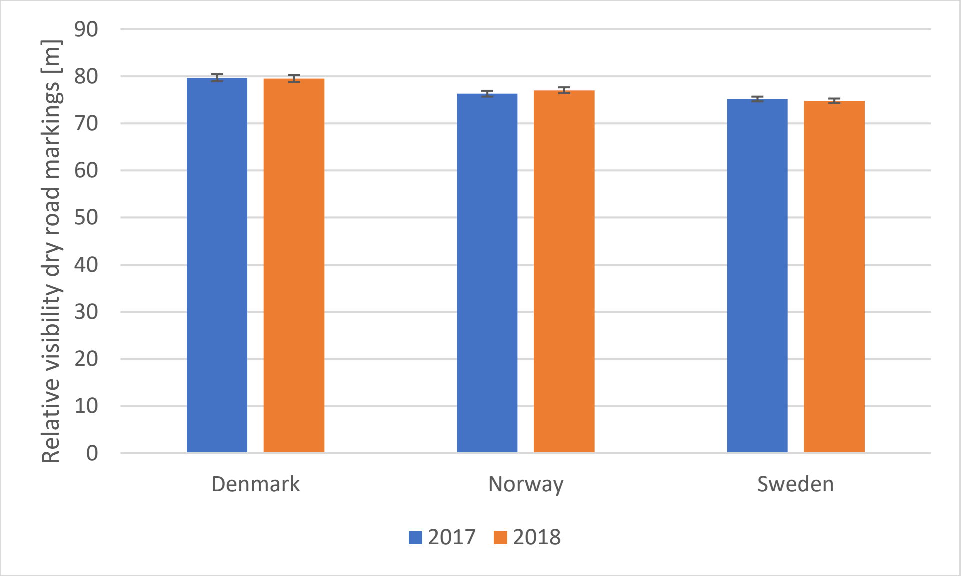

Figure 42. Relative visibility [m] for dry road markings, right edge line. Only white road markings. Comparison between 2017 and 2018.

In Figure 43, a comparison between relative visibility for right edge lines (only white) for 2017 and 2018 is made for all road classes and countries. In general, there are minor changes between 2017 and 2018. Only the change for Denmark in road class D is significant.

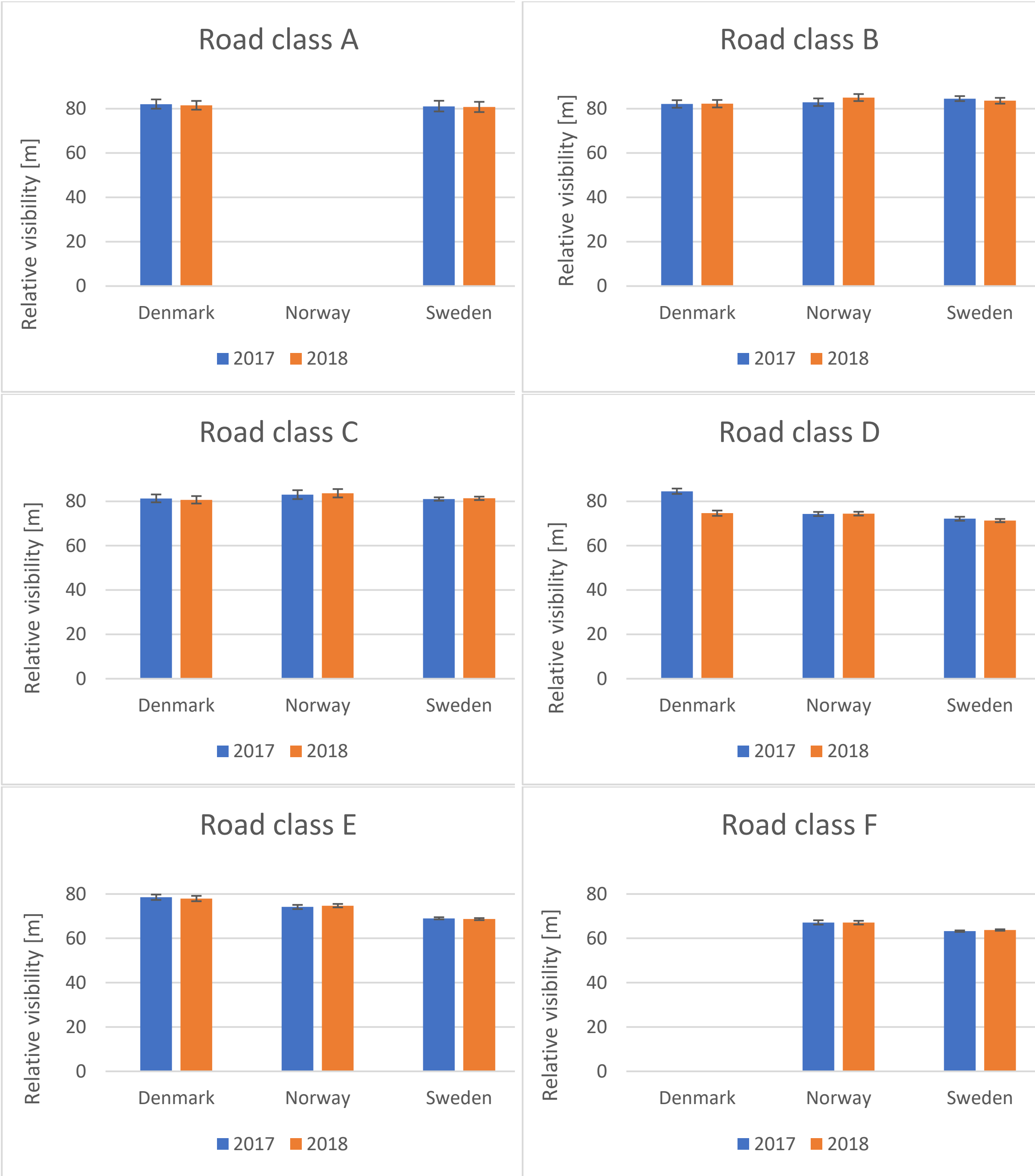

Figure 43. Relative visibility for dry road markings, right edge lines (only white). Comparison between 2017 and 2018 for country and road class.

4.1.3 Relative pvt

In Figure 42, the mean relative pvt for right edge lines is compared for 2017 and 2018. The mean levels are estimated marginal means and adjusted for unbalance in the design between the countries. Regarding relative visibility for dry roads, there are only minor differences between 2017 and 2018 and Norway has the highest relative pvt.

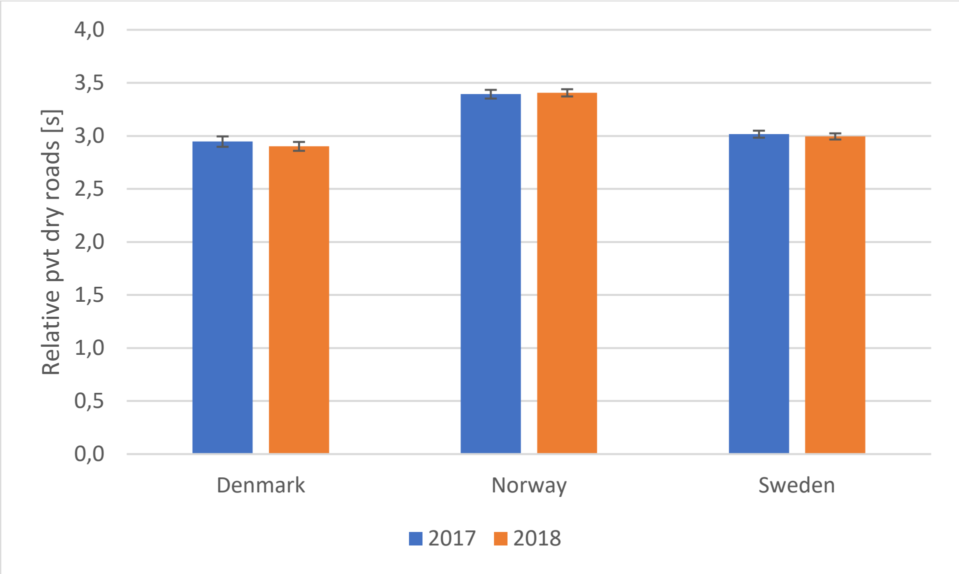

Figure 44. Relative pvt [s] for dry road markings, right edge line. Only white road markings. Comparison between 2017 and 2018.

In Figure 44, a comparison between relative pvt for right edge lines (only white) for 2017 and 2018 is made for all road classes and countries. There are minor changes between 2017 and 2018, with the change for Denmark in road class D being the only one that is significant.

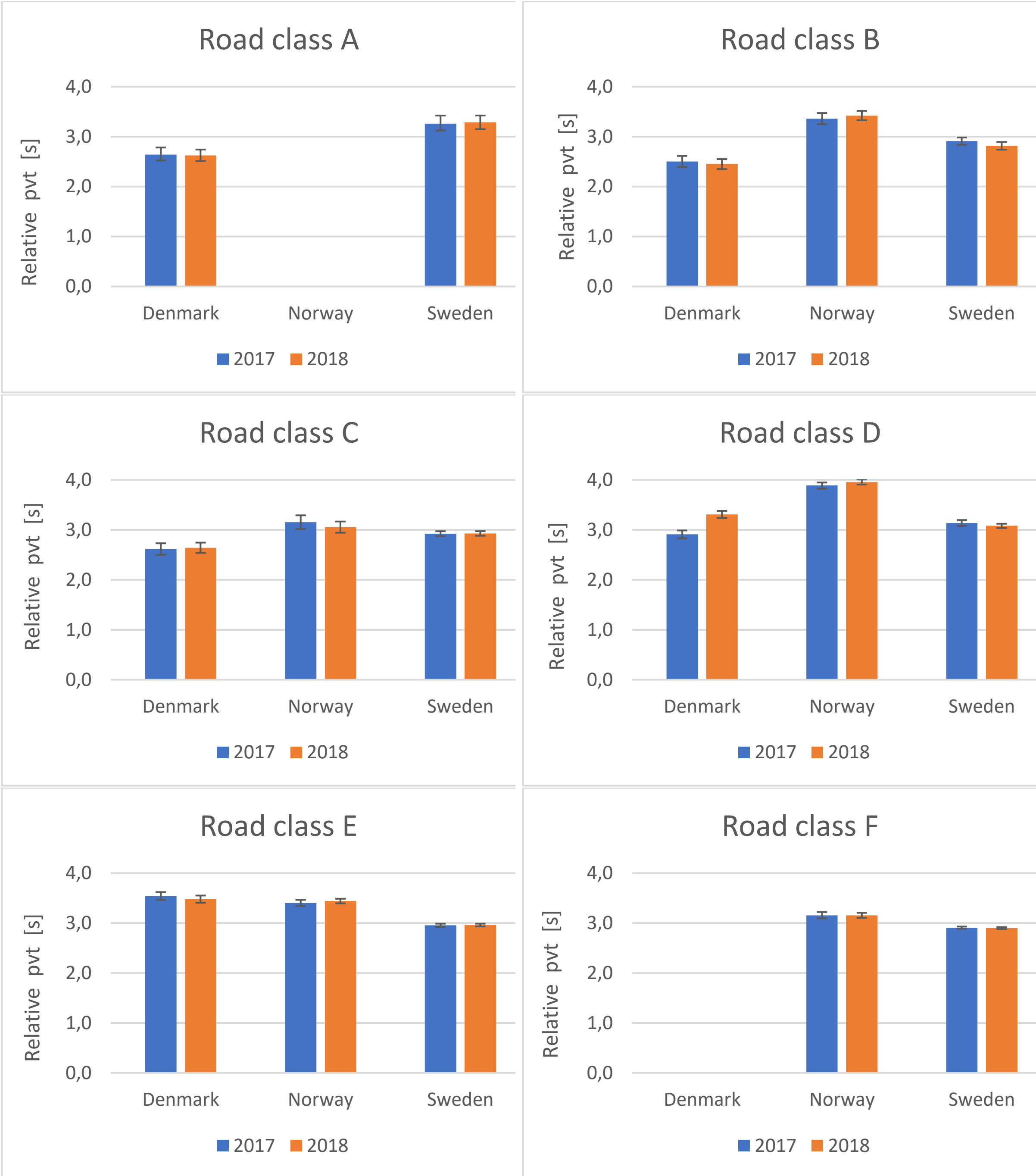

Figure 45. Relative pvt for dry road markings, right edge lines (only white). Comparison between 2017 and 2018 for country and road class.

4.2 Wet road markings

In Table 30 the number of measured wet road markings for 2017 and 2018 is shown. For all countries, the number of wet road markings have increased between 2017 and 2018.

Table 31. Number of wet measured road markings used in the analyses for dry road markings 2017 and 2018.

Road class	Denmark		Norway		Sweden	
	2017	2018	2017	2018	2017	2018
A	9	19				3
B	15	30	12	26	28	35
C	14	27	10	21	67	136
D	28	34	8	21	46	88
E	28	27	14	20	126	146
F			4	2		
Total	**94**	**137**	**48**	**90**	**267**	**408**

4.2.1 Retroreflectivity

In Figure 46, the retroreflectivity for all wet road markings is shown. For both 2017 and 2018, Norway has the highest retroreflectivity for wet roads. Figure 47 shows retroreflectivity for right edge road markings and the pattern is similar.

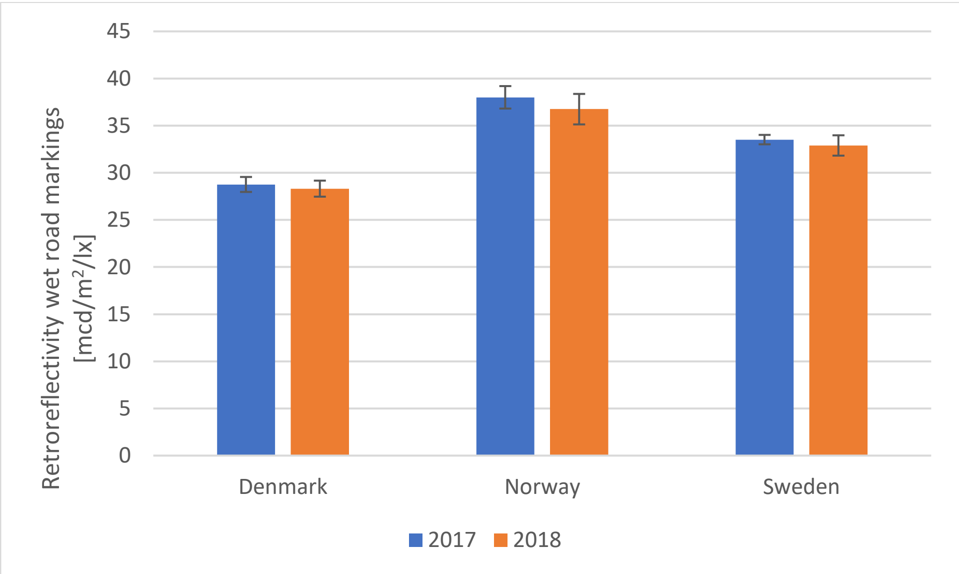

Figure 46. Retroreflectivity for wet road markings. All road markings (white and yellow). Comparison between 2017 and 2018.

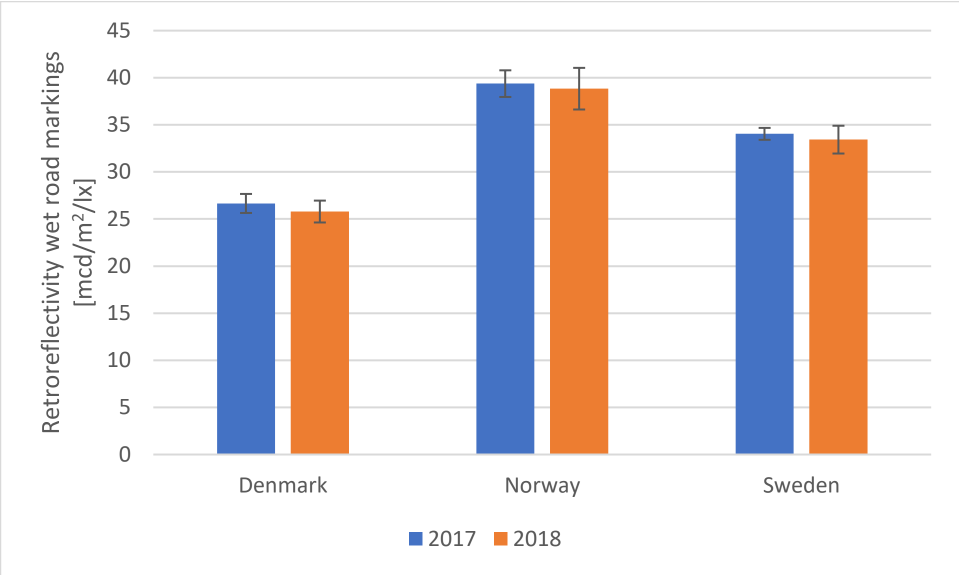

Figure 47. Retroreflectivity for wet road markings, right edge line. Only white road markings. Comparison between 2017 and 2018.

4.2.2 Relative visibility

Figure 48 shows the relative visibility for wet right edge lines in 2017 and 2018. There are only small changes between 2017 and 2018 within each country.

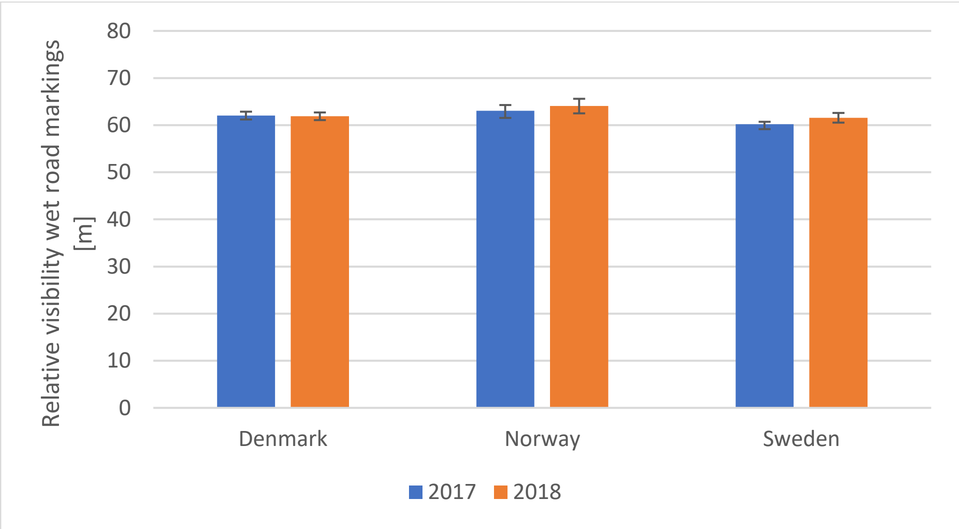

Figure 48. Relative visibility [m] for wet road markings, right edge line. Only white road markings. Comparison between 2017 and 2018.

4.2.3 Relative pvt

Figure 49 shows the relative pvt for wet right edge lines in 2017 and 2018. Similar as for relative visibility there are only minor differences between the years.

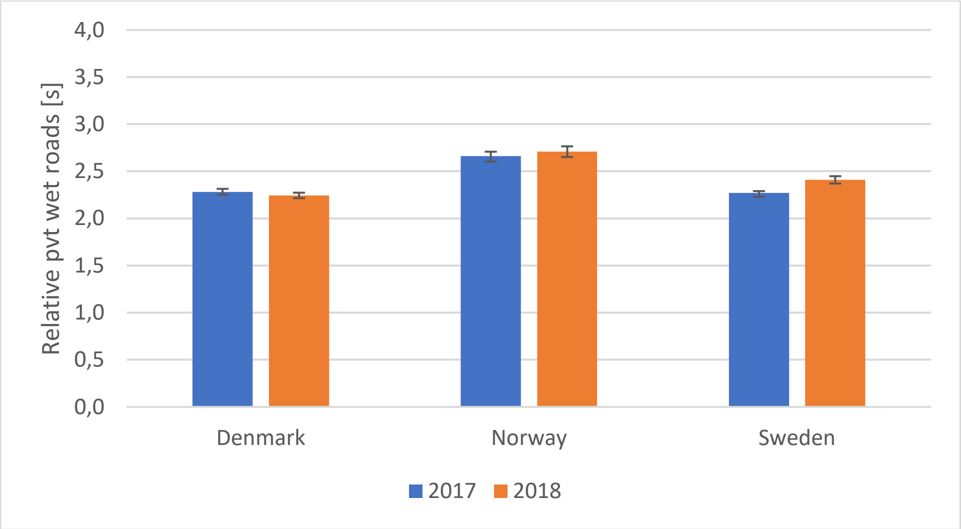

Figure 49. Relative pvt [s] for wet road markings, right edge line. Only white road markings. Comparison between 2017 and 2018.

4.3 TEN-T network

In Figure 50, different performance changes between 2017 and 2018 for the TEN-T road network are shown. On top, retroreflectivity for dry right edge lines are compared between 2017 and 2018 for TEN-T and non-TEN-T roads, in the middle, relative visibility is studied and at the bottom relative pvt is shown. There are only minor differences within countries between the years.

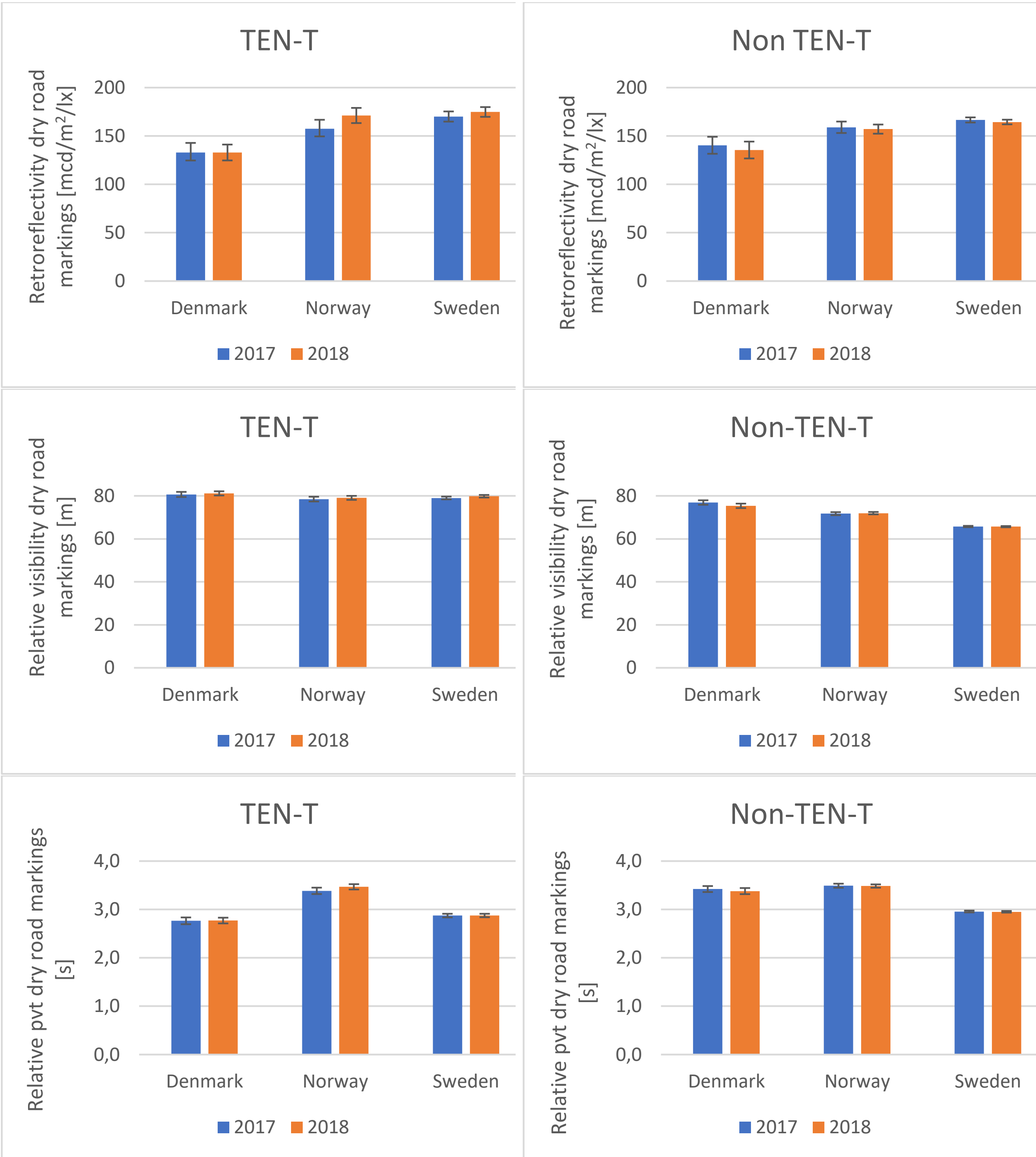

Figure 50. TEN-T and non-TEN-T road network. Retroreflectivity, relative visibility and relative pvt for dry right edge lines. Comparison between 2017 and 2018.

4.4 Cover index

In Figure 51, cover index for all road markings is compared between 2017 and 2018. There are minor differences between the years for road class A, B and C. Sweden shows a significant change towards lower values in road class C, D, E and F and Norway for road class D, E and F.

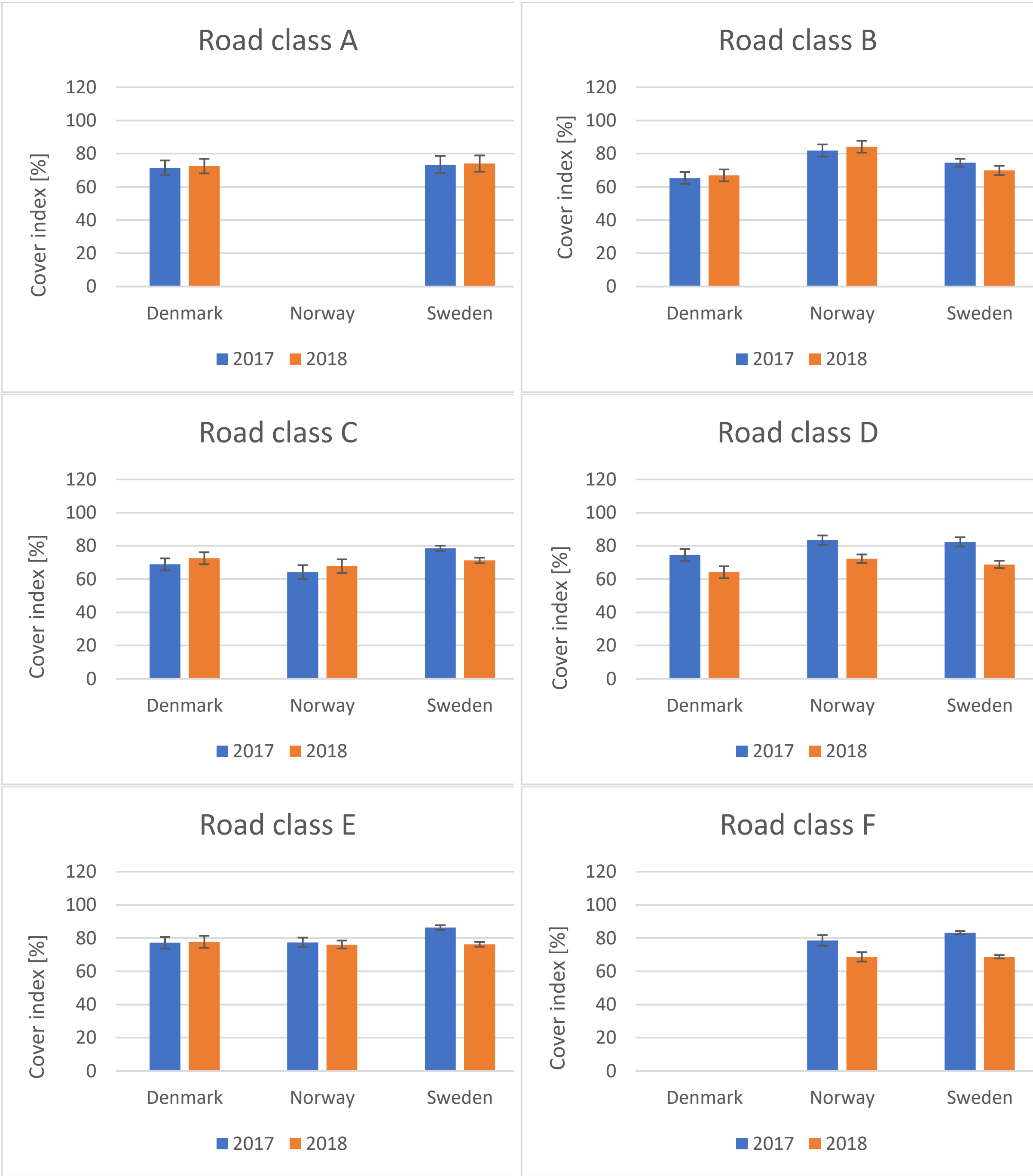

Figure 51. Cover index [%] for all road markings. Comparison between 2017 and 2018.

5 Discussion

The main aim of the Nordic road marking assessment study is to show possible differences in road marking performance between Denmark, Norway and Sweden. Possible differences between road marking performance, dependent on region, country, type of road and AADT (Annual Average Daily Traffic) are studied. A comparison between the TEN-T and the non-TEN-T road network is also made. Furthermore, the aim is to study the road marking quality before and under the introduction of the new certification requirements. Continuous assessments give the opportunity to react and adjust the requirements in the future, if the performance does not develop as expected. Since 2018 is the second year of the project, a comparison between the results for 2017 and 2018 is made. The results from the study are discussed below.

5.1 Results 2018

5.1.1 General

The colour of the permanent road markings is always white, except in Norway where the centre line on two-lane roads and the left edge line on multi-lane roads are yellow. When drawing general conclusions regarding retroreflectivity from the measurements in Denmark, Norway and Sweden, it is important to have in mind that yellow road markings (Norway) in general have about 30 % lower retroreflectivity than white ones. Therefore, when comparing the results in Chapter 3, the overall values in Norway are expected to be lower by approximately 15 - 20 % than in Denmark and Sweden.

The relative visibility of a road marking is dependent on the retroreflectivity multiplied by the area of the marking as Eq. (1) in section 2.3.2 shows. In Table 32, the observed area (based on measured width, type and standard length of the road marking) as well as the typical area (based on country-standards) of the edge line on a road length of 60 m is shown:

Table 32. Observed area (based on measured width, type and standard length of the road marking) and typical area (based on country-standards) of the edge line on a road length of 60 m.

Road class	Country	Observed mean area (m^2)	Typical area (m^2)
A	Denmark	17.1	18 (6 on 3-lane roads)
	Sweden	14.2	18 (12 on 3-lane roads)
B	Denmark	16.7	18 (6 on 3-lane roads)
	Norway	14.0	12
	Sweden	16.1	18 (12 on 3-lane roads)
C	Denmark	14.0	18 (6 on 3-lane roads)
	Norway	15.0	12
	Sweden	12.7	18 (12 on 3-lane roads)

D	Denmark	8.3	6
	Norway	6.6	6
	Sweden	6.1	6
E	Denmark	9.6	6
	Norway	5.9	6
	Sweden	3.7	2-3 (possibly 6)
F	Norway	4.0	6 (possibly 3)
	Sweden	2.7	2-3
Total	Denmark	12.9	
	Norway	7.6	
	Sweden	5.8	

From the figures in Chapter 3 one understands that although the retroreflectivity values of dry road markings in Sweden were rather high, the product of retroreflectivity and area may be low, which is especially evident for right edge lines (see Table 32). This is discussed further below. Regarding lane and centre lines, the area difference in the three countries is less than for edge lines. In Denmark the lane and centre lines are 10 cm wide while in Norway and Sweden they are 10 – 15 cm.

The retroreflectivity of wet road markings is always lower than in the dry condition. This implies also shorter relative visibility distance in the wet condition. Typically, the relative visibility is 55 – 65 metres in the dry condition, while in wet condition, it is 40 – 50 metres.

In the analyses of visibility, the light condition used has always been high beam. The reason for this is that in dipped headlight illumination, the visibility distance will be influenced by the cut-off, which means that the visibility is almost independent of the retroreflectivity of the road marking at distances beyond cut-off.

In the sections below, centre line always refers to the configuration on a straight road. This means 5+10 metres (5 metres line and 10 metres gap) in Denmark, and 3+9 metres in Norway and Sweden.

The relative pre-view-time, pvt, is closely related to the relative visibility distance as shown in Eq. (2) in section 2.3.3. The pre-view-time is often used as a safety measure in night-time traffic; several studies have shown that the driver needs a pvt of more than 2 - 3 s for safe driving (Fors and Lundkvist, 2009). In 80 km/h this means a visibility distance of approximately 45 - 65 metres. However, for reasons mentioned in Section 2.3, the measure used in this study is the relative visibility distance and pre-view-time. Therefore, the pvt values shown in Sections 3.1.3 and 3.2.3 must not be related to the desirable 2 – 3 s.

For practical reasons, the speed used in Eq. (2) is the dominating speed limit of the road. It would have been more appropriate to use the space mean speed of the section of the road where measurements have been carried out, as the actual speed may differ from the speed limit. Actual speed, and consequently pvt, may also vary along the road, depending on e.g. road geometry. Pvt can also, independently of vehicle speed, be influenced by road geometry. Pvt may e.g. be lower on hilly or curvy roads, simply because the road marking isn't visible beyond the hilltop or curve. However, space mean speed data are not available, which means that the speed limit is the best available measure to use. Furthermore, road geometry is not considered when calculating pvt, which means that the actual pvt for a specific road section may differ from the values presented in this report. When "pvt" is used below, it always refers to the relative pre-view-time.

The dominating speed limit is explained in Section 2.3.3 and might differ between countries and road classes. In Table 33, the mean dominating speed limit of the measured road objects in each road class and country is shown. This will influence the relative pvt and explain some of the differences seen in section 3.1.3 and 3.2.3, a higher speed limit will lead to lower relative pvt.

Table 33. Mean dominating speed limit (km/h) of the measured road objects in each road class and country.

Road class	Country	Mean dominating speed limit (km/h)
A	Denmark	114
	Sweden	90
B	Denmark	123
	Norway	92
	Sweden	108
C	Denmark	105
	Norway	100
	Sweden	101
D	Denmark	76
	Norway	69
	Sweden	85
E	Denmark	81
	Norway	79
	Sweden	84
F	Norway	75
	Sweden	81
Total	Denmark	99
	Norway	80
	Sweden	87

5.1.2 Dry road markings

Figure 13 - Figure 15 and Table 7 - Table 9 in Chapter 3 indicate that dry road markings in Norway and Sweden have higher retroreflectivity than road markings in Denmark at a risk level of 5 %. Furthermore, there are significant retroreflectivity differences between the road classes, and the interaction effect is also significant, meaning that the differences between

road classes might differ in the three countries. This is shown in Figure 13; where the retroreflectivity is the highest for Sweden in road class D, E and F, while highest for Norway for road class B and C. Figure 14 shows the results for right edge lines, only. Still, on average, road markings in Sweden have somewhat higher retroreflectivity than those in Denmark and Norway in road class D, E and F. White edge lines in every road class in Denmark have lower values than those in both Norway and Sweden.

Figure 15 is comparable to Figure 14 , but refers to lane (classes A - C) and centre (classes D - F) lines, white markings in Denmark and Sweden, yellow in Norway. The figure shows that lane lines on multi-lane roads in Denmark have lower values than in Norway and Sweden. On two-lane roads in road class D and E, the retroreflectivity of the centre line is somewhat lower in Norway than in Denmark and Sweden, which probably can be explained by the yellow colour of that line.

Regarding differences between the countries and regions it is shown in the cluster analysis that the retroreflectivity is generally the lowest in the Danish, Swedish and Norwegian north-regions and the highest in the Swedish Mid and West regions and the Norwegian East and South regions. None of the regions in Denmark have been clustered in the highest category.

Figure 19 indicates that the relative visibility distance to the dry right edge line is approximately the same on multi-lane roads in the three countries. On most multi-lane roads, the edge line is wider in Denmark and Sweden compared to Norway, but this is to a large extent compensated for by higher retroreflectivity in Norway (see Figure 14). Furthermore, Figure 19 shows that the visibility distance on two-lane roads is longer in Denmark than in Norway and Sweden, especially in road class E. The reason for this is both that the edge line in those road classes may be intermittent in Sweden and Norway, but always continuous in Denmark and that Denmark has wider observed road marking width (see Table 32). Thus, Figure 19 reflects the loss in visibility caused both by the use of an intermittent edge line instead of a continuous one and differences in road marking width. For all road types, Figure 20 shows no large difference in visibility distance of dry lane lines in the three countries.

When comparing relative visibility (Figure 19) and relative pvt (Figure 21) of dry edge lines, some differences can be seen: Denmark has relatively low pvt-values on multi-lane roads and Norway has high pvt values on multi-lane roads in class B and C. This is explained by the high speed-limit on motorways in Denmark, up to 130 km/h, while it is lower in Norway and Sweden. In the same way, the relatively poor pvt on Swedish two-lane road is explained by the fact that many such roads in Sweden have a speed limit of 80 - 100 km/h, while it generally is 80 km/h in Denmark and 70 – 80 km/h in Norway (see also Table 33).

Regarding lane and centre lines, the differences in pvt between the countries are rather small on two-lane roads (road class D, E and F). Danish motorways and multi lane roads (road class A, B and C) show a shorter relative pvt than lane lines in Norway and Sweden.

5.1.3 Wet road markings

As mentioned in section 2.3.1, significant deviations between the results from the mobile measurements and the hand-held measurements according to the standard EN-1436 were seen for some of the test objects during the annual validation of mobile instruments in 2017 and 2018. Deviations up to 25 mcd/m²/lx between the mobile and the standard handheld measurements could be noted and therefore the results for wet road markings should be interpreted with care.

Figure 24 - Figure 27 and Table 17 - Table 19 show the result for wet road markings. The interaction effect (country * road class) is not significant and this indicates that the differences in retroreflectivity is homogeneous over the road classes, which can be seen in Figure 24. In every road class, the retroreflectivity of wet road marking is higher in Norway than in Denmark and Sweden, which is especially pronounced for road class B, C and E. This is remarkable as yellow road markings are included in class E. As for dry road markings, wet road markings in Denmark have lower values than in Norway and Sweden in every road class. Regarding edge lines, the results are shown in Figure 25. In every road class, wet road markings in Norway have higher retroreflectivity than those in Denmark and Sweden. One explanation might be that Norway often has inlaid road markings, a solution seldom used in Denmark and Sweden. It can also be noted that Norway increased the performance requirements for retroreflectivity on wet road markings from 35 mcd/m²/lx to 50 mcd/m²/lx in 2018. However, it is probably too early to note any effect of this increase of performance requirement already in the 2018-measurements.

Figure 26 shows that profiled edge lines in Norway have longer visibility distances than in the other two countries. This is to a large extent explained by higher retroreflectivity. On two-lane roads the edge lines in Sweden show shorter visibility distances than edge lines in Denmark and Norway, although the higher retroreflectivity in Sweden. The explanation for this matter is probably the Swedish intermittent edge line but can also reflect differences in road marking width influencing the area of the road marking (see Table 32).

Figure 27 indicates that pvt of wet edge markings in Norway is higher than in Denmark and Sweden. The explanation is quite simple: High retroreflectivity, large edge marking area and low speed limit means high pvt.

5.1.4 TEN-T road network

A comparison is also made between the Trans-European Transport Network (TEN-T) and other roads. The TEN-T is a network comprised of roads, railway lines, inland waterways, inland and maritime ports, airports and rail-road terminals throughout the 28 Member States. In total, about 32 % of the measured objects in this study belong to the TEN-T network.

Comparing retroreflectivity for dry road markings on the TEN-T road network and the non-TEN-T road network it is shown that there are only minor differences between the TEN-T and other roads in Denmark. However, in Norway and Sweden the retroreflectivity is somewhat higher for the TEN-T network. These differences are significant.

The results for relative visibility show differences between TEN-T and non-TEN-T and in all three countries, the relative visibility is higher for the TEN-T road network. However, studying the relative pre-view-time it is shown that in all countries, the relative pvt is lower on the TEN-T roads. This is probably due to higher speed limits on the TEN-T road network. For Norway and Sweden the differences in pvt between TEN-T and other roads are rather small, while for Denmark the difference is significant and the relative pre-view time is about 0.6 s shorter on the TEN-T roads. This is most likely explained by the fact that in Denmark, the speed limits are much higher on the TEN-T roads than on other roads (around 30 km/h higher).

5.1.5 Cover index

The measure cover index is new and under development. The cover index is measured in % and can have values above 100 % if e.g. a new road marking overlaps with an old road marking. Profiled markings might have values below 100 % even when they are new if the pattern contains unfilled parts, such as a chessboard pattern. Consequently, a cover index of 60 % can represent a partially worn road marking or a new profiled road marking. The ambition for the coming years is to relate the cover index to road marking type (i.e. whether the road marking is profiled or not) to make the results easier to interpret, but this information is not available yet.

The results for cover index are shown in Figure 32 - Figure 36. There is no significant difference in cover index between the countries. However, there is a significant difference between road classes. One explanation could be the different proportions of profiled and non-profiled road markings. Lane and centre lines seems to have a higher cover index than edge lines (Figure 35 and Figure 36). This is difficult to explain, but one reason might be that the first-mentioned road markings are reconditioned almost every year, due to many wheel roll-overs. If so, measurements would have been carried out on almost new lane and centre lines, while the edge lines might have been applied years ago. Another explanation might be that edge lines are profiled to a higher extent than lane and centre lines.

5.2 Comparison 2017 and 2018

Comparing the level of retroreflectivity for 2017 and 2018 for all dry road markings, there are no significant changes for Sweden and Denmark, while for Norway, the retroreflectivity has increased from 154 mcd/m^2/lx to 167 mcd/m^2/lx, the largest differences are seen for Norway in road class B (Motorway or multi-lane roads, 20 000 < AADT ≤ 50 000) and C (Motorway or multi-lane roads, AADT ≤ 20 000), where the retroreflectivity is more than 30 mcd/m^2/lx higher in 2018 than in 2017. Looking at the distribution of retroreflectivity for Denmark, Norway and Sweden 2017 and 2018, the pattern is rather similar within each country.

In the yearly assessment of road markings in Sweden (Nilsson and Tayanin, 2019) the trend for retroreflectivity over the years 2011-2018 was analysed. The results showed a downward trend for the entire country between 2011 and 2015. From 2011, the proportion of road marking length meeting the requirements for dry road markings (> 150 mcd/m^2/lx) has decreased from 69 percent in 2011 to less than 50 percent in 2015. For the last three years the downward trend has ended, and the results seem stable just above 50 percent meeting the requirement 150 mcd/m^2/lx.

Regarding relative visibility and relative pvt for dry right edge road markings there are only minor differences between 2017 and 2018, but Norway has the highest relative pvt.

Studying retroreflectivity for wet road markings, it is shown that Norway has the highest retroreflectivity for wet roads for both 2017 and 2018. There are only small changes in retroreflectivity, relative visibility and relative pvt on wet road markings between 2017 and 2018 within each country.

Looking at the cover index and differences between 2017 and 2018, Sweden shows a significant change towards lower values in road class C, D, E and F and Norway shows the same for road class D, E and F.

6 Conclusions

In Sections 5.1. – 5.2, the retroreflectivity, relative visibility, relative pre-view-time and cover index have been discussed. Regarding these parameters, it is only retroreflectivity that is found in the regulations for all three countries, while cover index is found in the regulations in Norway and Sweden. The retroreflectivity requirement of dry road markings is roughly fulfilled in 50 % of the measured objects. The values are a little bit higher for lane and centre lines, which may be explained by that those lines can have been quite new at the time of measurement. In all, there are no large differences in road marking performance between countries. Some retroreflectivity values are low, e.g. edge lines on motorways in Denmark. However, this is compensated for by a large area, which nevertheless means good relative visibility. The opposite is true for edge lines on Swedish two-lane roads. That is, they have high retroreflectivity, implying good visibility. However, the road marking area is small, thus reducing the relative visibility to shorter distance than for both Danish and Norwegian edge lines.

Regarding retroreflectivity on wet road markings, they have higher retroreflectivity in every road class in Norway than those in Denmark and Sweden. This can probably be explained by the fact that Norway often has inlaid road markings, a solution seldom used in Denmark and Sweden. As mentioned in section 2.3.1, significant deviations were seen between the results from the mobile measurements and the hand-held measurements during the annual validation of mobile instruments in 2017 and 2018 and therefore, the results for wet road markings should be interpreted with care.

There are no requirements for visibility or pvt in the country regulations. It would be desirable to include pvt in the regulations, as it with high probability is a measure related to traffic safety. As mentioned before, many studies have been performed, with the study within COST 331 perhaps being the most reliable (COST 331, 1999). This study consisted of two parts, one carried out in a driving simulator and one as a field study. Both studies showed similar results: when driving conditions are good and simple, the driver needs a pvt value of approximately 2 s. However, a short time must be added, since in a real situation the driver may be disturbed by the surroundings, e.g. oncoming vehicles. A central question appears: How large is that “short time”? This is a tricky but very essential question to answer. As mentioned in Chapter 2.3.2, the model for calculation of visibility is under revision and this work will provide a basis for further research on drivers’ needs under various conditions. With better knowledge it will be possible to take visibility and pvt into account when formulating regulations. For each type of road and for a given speed limit, the requirements on retroreflectivity and road marking area (width and broken/continuous line) can be selected so that the desired levels of visibility and pvt are achieved. Further research on the relationship between drivers’ needs and road marking area and retroreflectivity is thus urgent.

Generally, there is no large difference in road marking performance in the three countries. The only significant differences are the lower visibility of edge lines on two-lane roads in Sweden (especially in class E) and the higher performance of wet road markings in Norway. Other differences are of no or small importance. Looking at country and road class level, there are only minor differences between the results from 2017 and 2018 and the results seem to be rather stable.

Based on 2018 years of measurements, it is not possible to study the effect of the Nordic certification system for road markings since it has just recently been introduced. However, within the last years of the project some effect, hopefully positive, might be possible to register.

References

COST 331 (1999). Requirements for horizontal road marking. Luxembourg: Office for Official Publications of the European Communities. European Commission, Directorate General Transport.

European Standard EN-1436 (2018). Road marking materials – Road marking performance for road users and test methods. BS EN 1436:2018

Fors, C., Johansen, T. C., Lundkvist, S-O. and Nygårdhs, S. (2018). Nordic certification system for road marking materials. VTI Notat 12A-2018. VTI, Linköping, Sweden.

Fors, C., Yahya, M-R. and Lundkvist, S-O. (2015) Road marking assessment 2014. VTI Notat 12-2015. VTI, Linköping, Sweden. In Swedish, summary in English.

Fors, C., Lundkvist, S-O. (2009) Night-time traffic in urban areas – A literature review on road user aspects. VTI Report 605A, VTI Linköping, Sweden.

Lundkvist, S-O., Johansen, T. C., Nielsen, B. (2008) Mobile measurement of road marking performance. VTI Report 611. VTI, Linköping, Sweden. In Swedish, summary in English.

Lundkvist, S-O., Johansen, T. C., Nielsen, B. (2009) Development of Road Marking Tester. Status of RMT Version 2. VTI notat 20 - 2009. VTI, Linköping, Sweden. In Swedish, summary in English.

Montgomery, D., C. (1991) Design and analysis of experiments. John Wiley and Sons.

Nilsson, C., Tayanin, D. (2019) Tillståndsmätningar av vägmarkeringars funktion i Sverige 2018.Ramböll report no 1320014576. In Swedish, summary in English.

Nygårdhs, S. and Lundkvist, S-O., (2004) Road marking assessment in the Nordic countries 2003. VTI notat 44 - 2004. VTI, Linköping, Sweden. In Swedish, summary in English.

Trafikverket (2017). Mobil kontroll av vägmarkering. TDOK 2013:0461 Version 2.0, Trafikverket, Borlänge, Sweden.

Vadeby, A., Kjellman, E., Fors, C. and Lundkvist, S-O. (2018) ROMA. State assessment of road markings in Denmark, Norway and Sweden - Results from 2017. Nord Fou Report 2018-6. Ean number: 9788793689749.

Annex A Results Denmark

Comparison between 2017 and 2018

In Table 34, the number of measured road markings used in the analyses for dry road markings (right edge line) in Denmark is shown for each road class and region in 2017 and 2018.

Figure 52 - Figure 54 compares the results for Denmark between region and road class in 2017 and 2018 as regards retroreflectivity, relative visibility and relative pvt.

Table 34. Number of measured road markings in each road class and region for Denmark, in 2017 and 2018. Right edge lines.

Road class	South		East		North	
	2017	2018	2017	2018	2017	2018
A	4	5	4	5	1	1
B	5	5	5	5	5	5
C	5	5	5	5	4	5
D	10	10	10	10	10	10
E	10	10	10	10	10	9

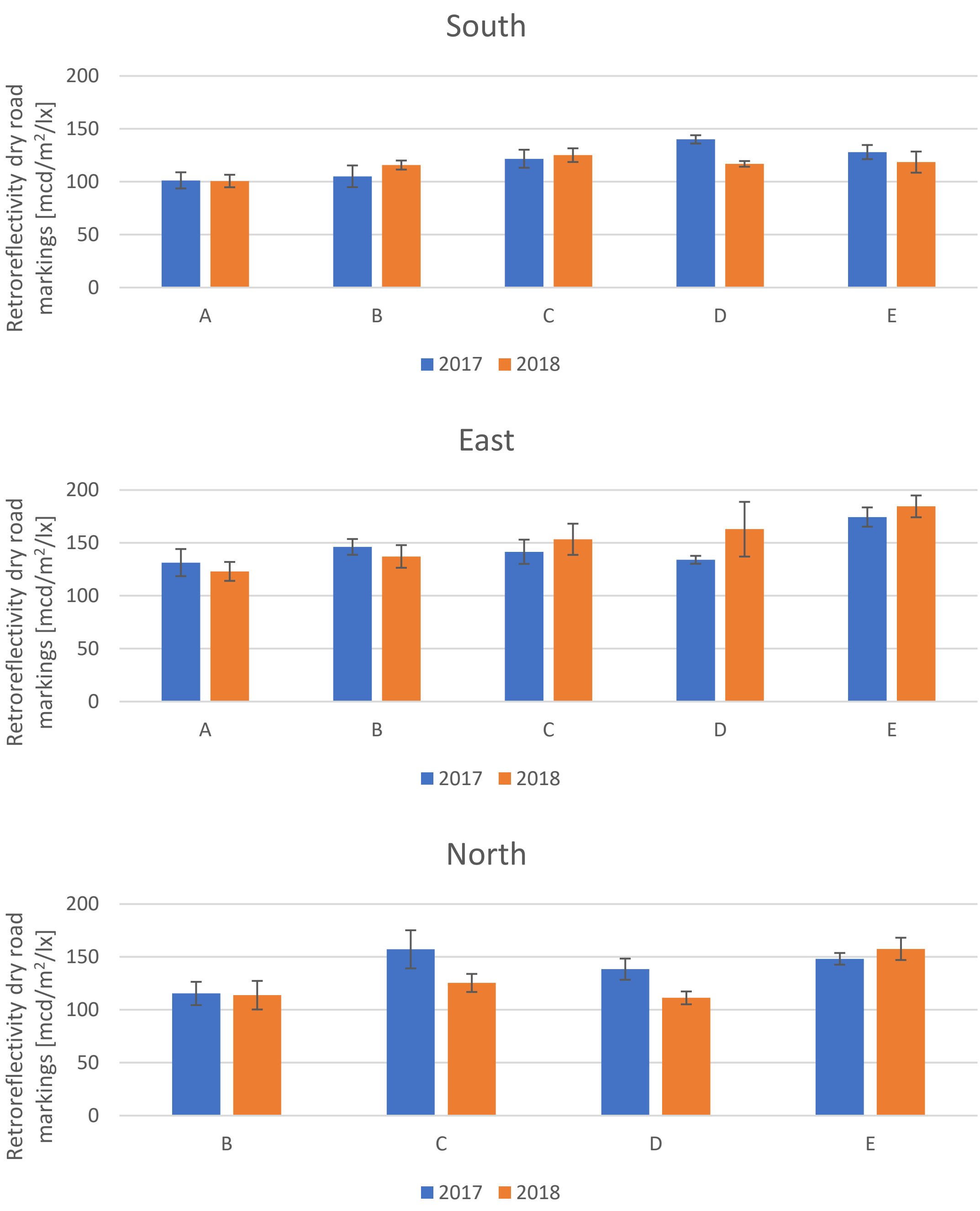

Figure 52. Retroreflectivity for dry road markings in Denmark. Comparison between 2017 and 2018 for region and road class.

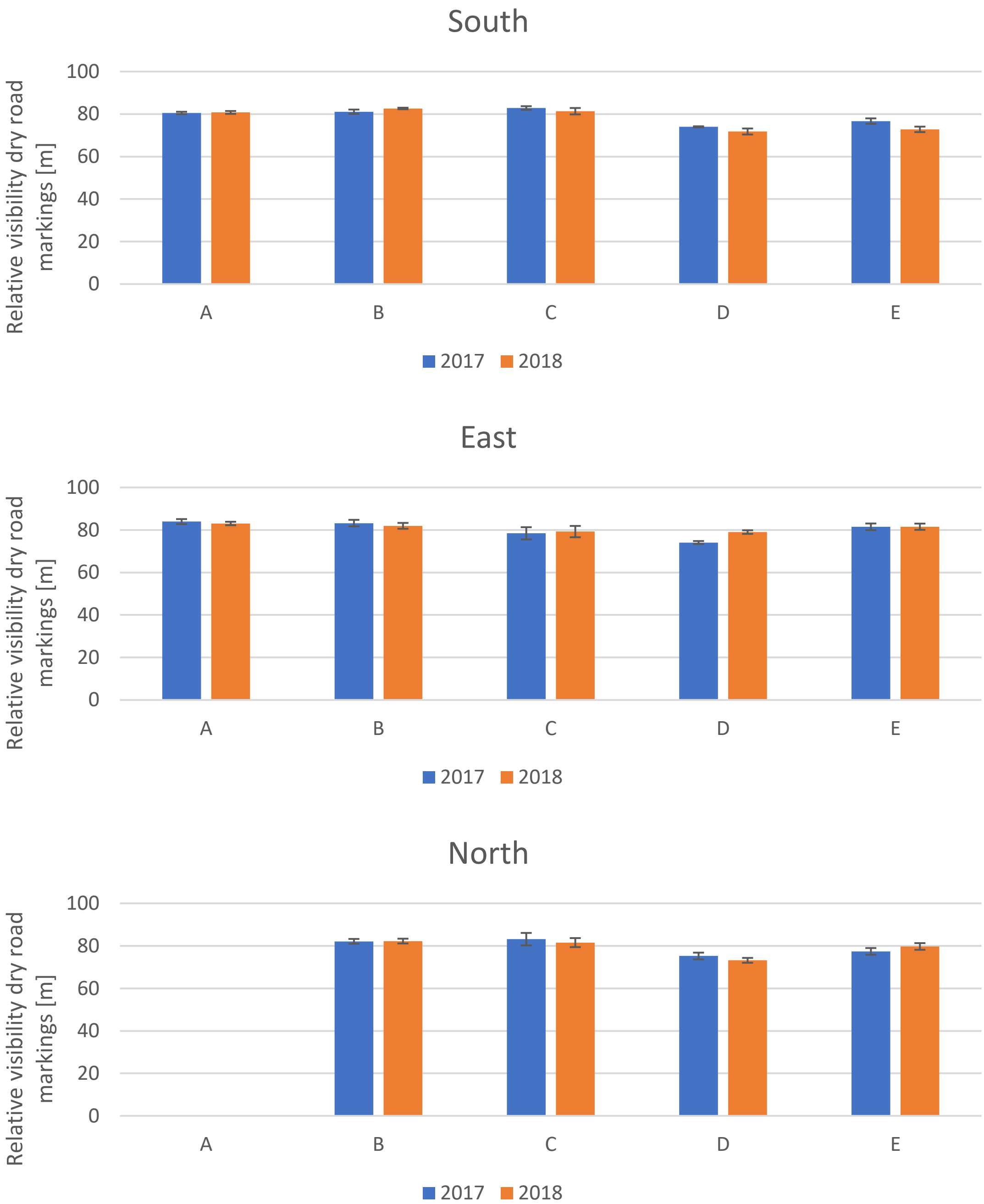

Figure 53. Relative visibility for dry road markings in Denmark. Comparison between 2017 and 2018 for region and road class.

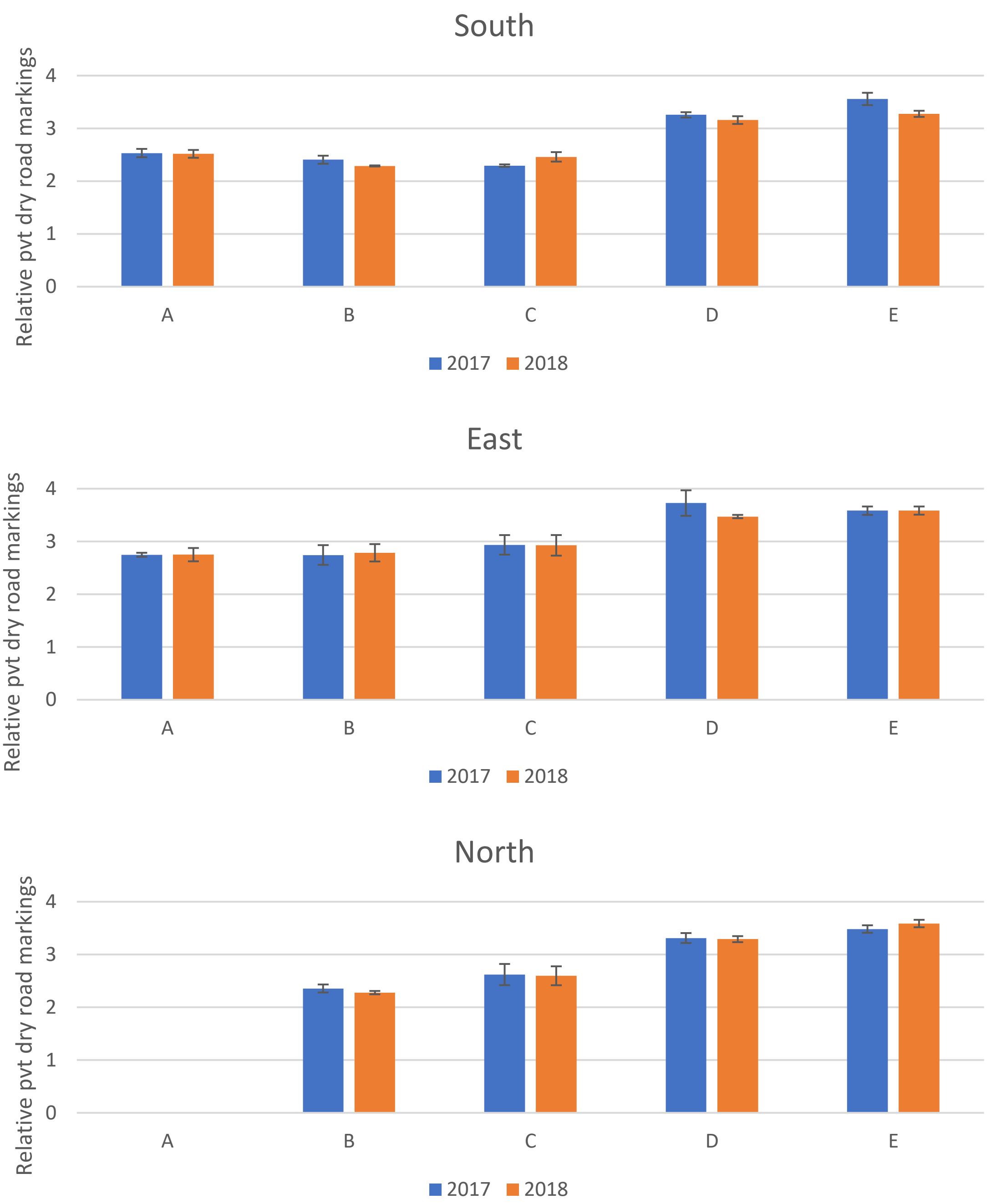

Figure 54. Relative pvt for dry road markings in Denmark. Comparison between 2017 and 2018 for region and road class.

Dry road markings 2018

Retroreflectivity

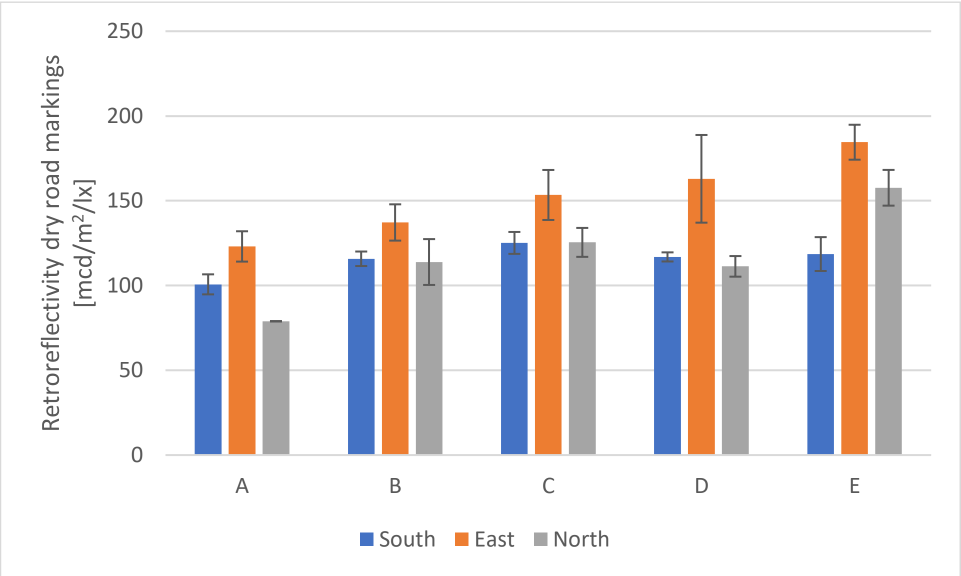

Figure 55. Mean of retroreflectivity right edge line on dry road markings for each region and road class in Denmark.

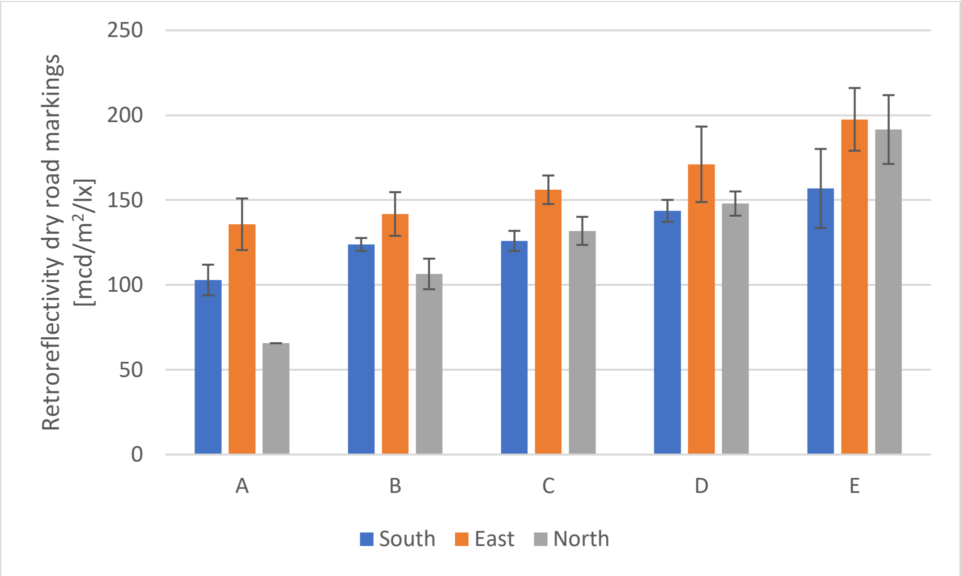

Figure 56. Mean of retroreflectivity in Denmark. Lane line (class A, B and C), centre line (class D, E, and F). Dry road markings for each region and road class in Denmark.

Relative visibility

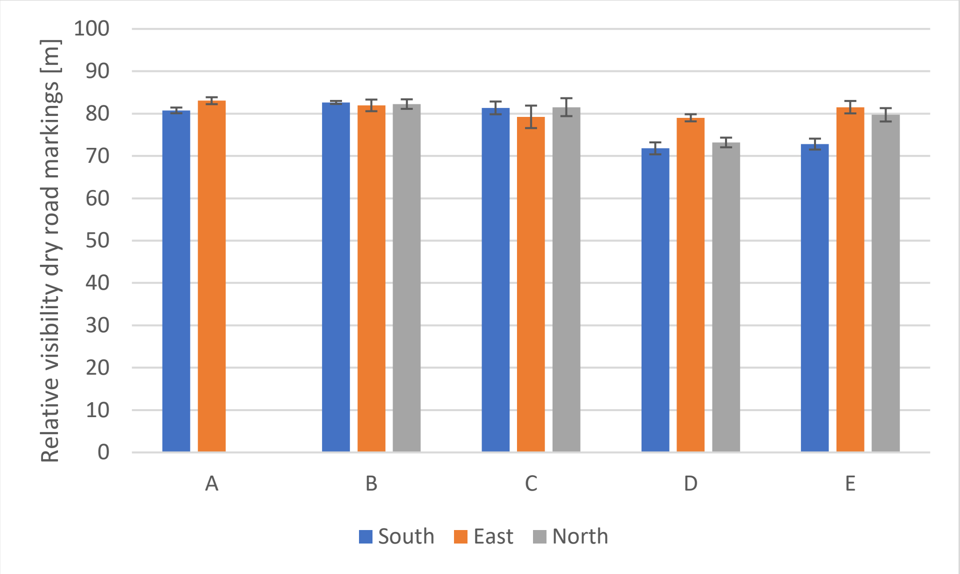

Figure 57. Relative visibility for right edge line for each region and road class in Denmark. Dry road markings.

Relative pre-view-time (pvt)

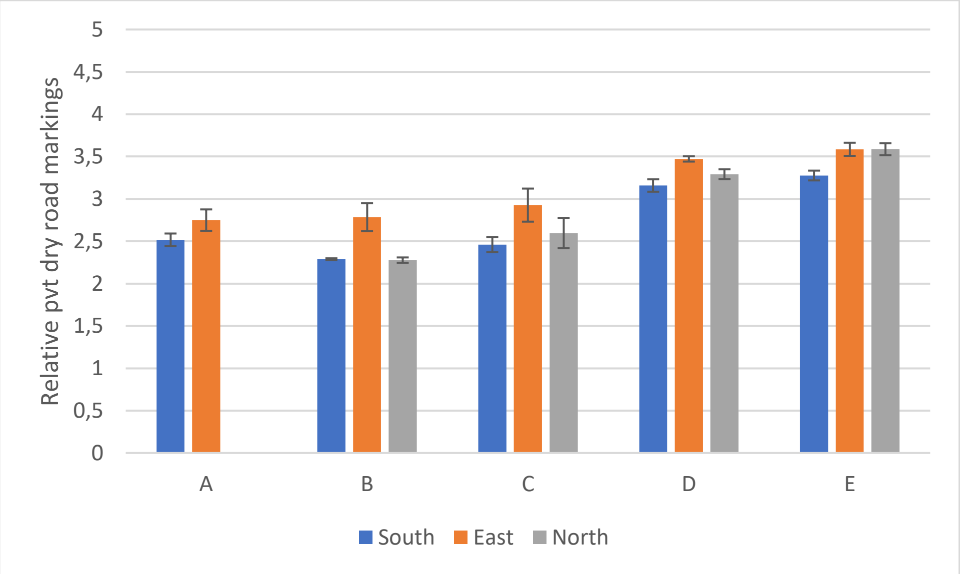

Figure 58. Relative pre-view-time for right edge line for each region and road class in Denmark. Dry road markings.

Wet road markings 2018

Retroreflectivity

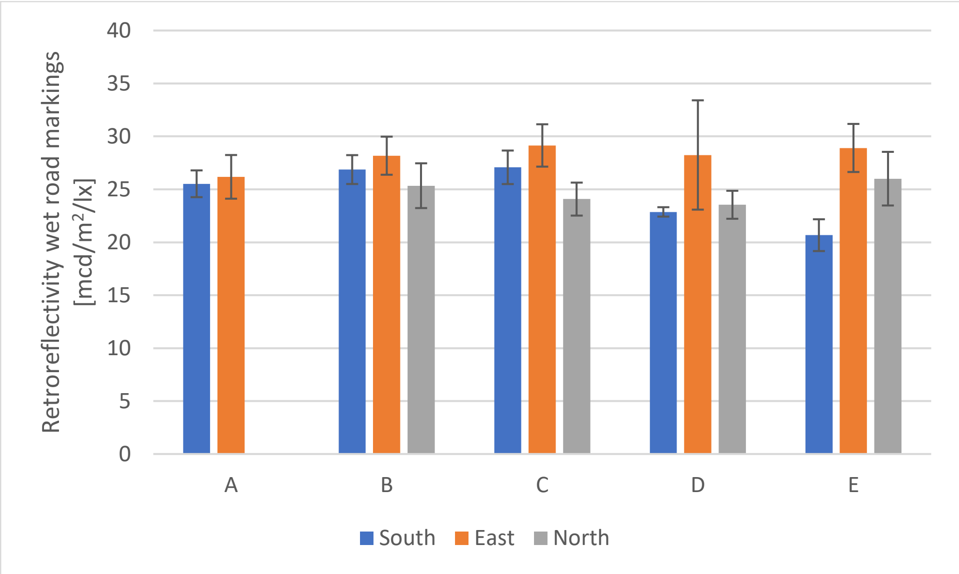

Figure 59. Mean of retroreflectivity right edge line on wet road markings for each region and road class in Denmark.

Relative visibility

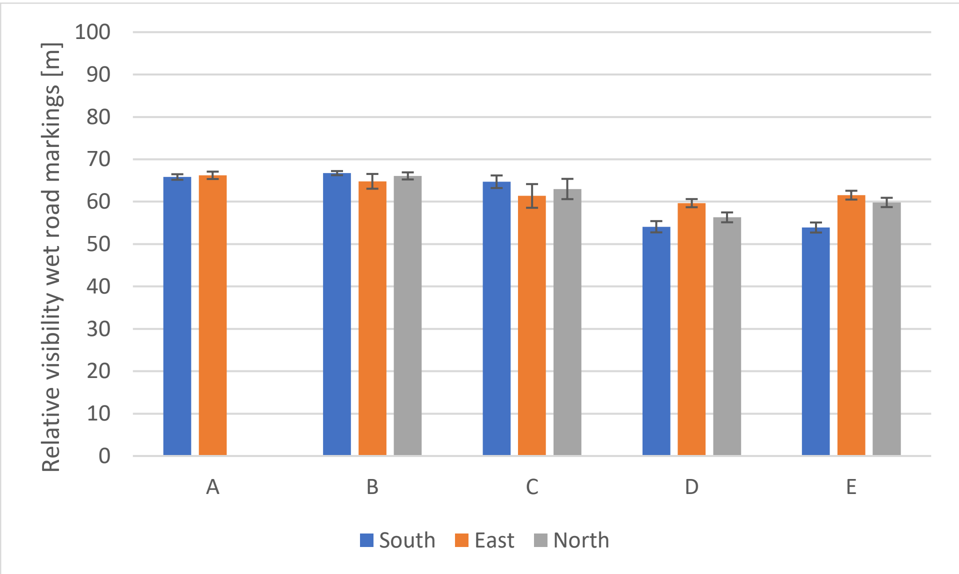

Figure 60. Relative visibility for right edge line for each region and road class in Denmark. Wet road markings.

Relative pre-view-time (pvt)

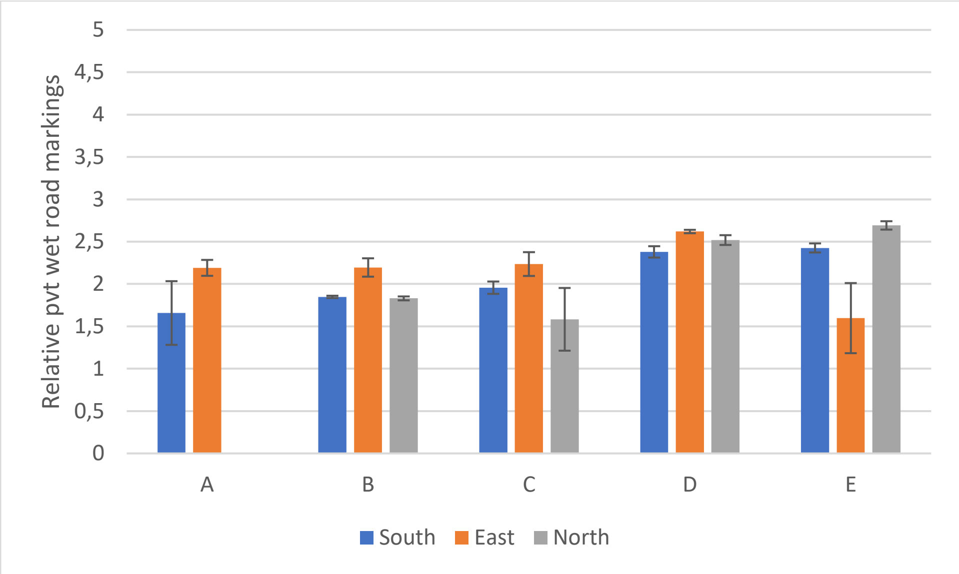

Figure 61. Relative pre-view-time for right edge line for each region and road class in Denmark. Wet road markings.

Cover index 2018

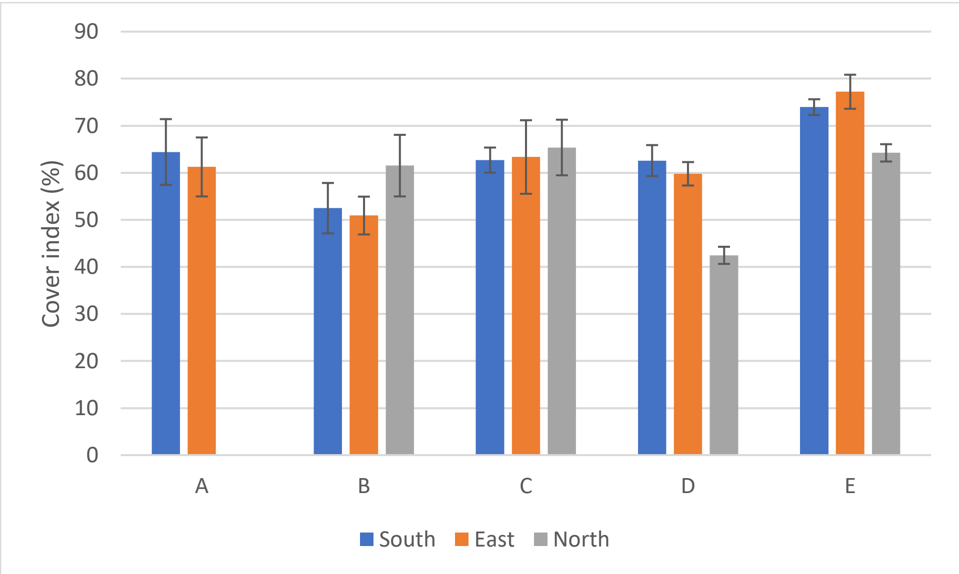

Figure 62. Cover index for each region and road class in Denmark. Right edge line markings.

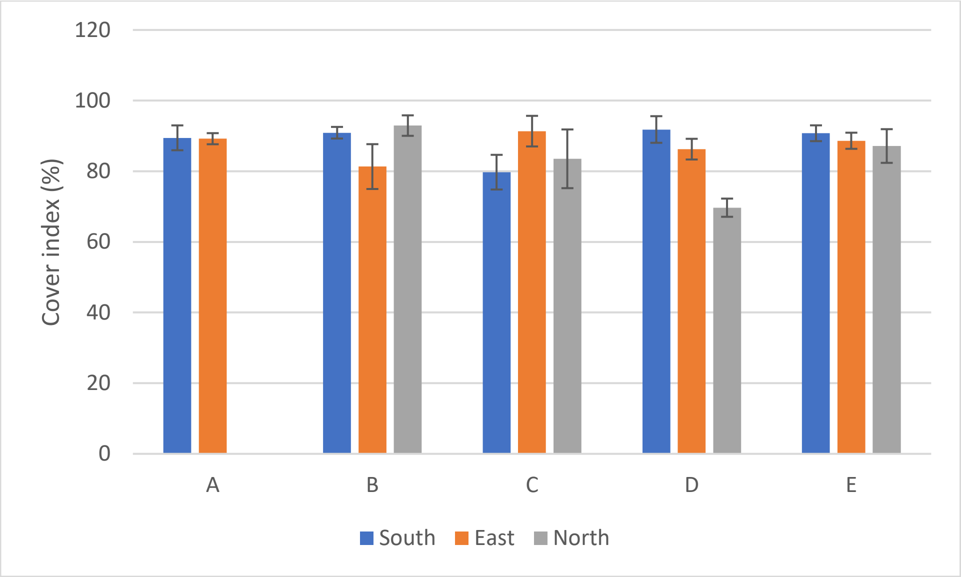

Figure 63. Cover index for each region and road class in Denmark. Lane line (class A, B and C), centre line (class D, E, and F).

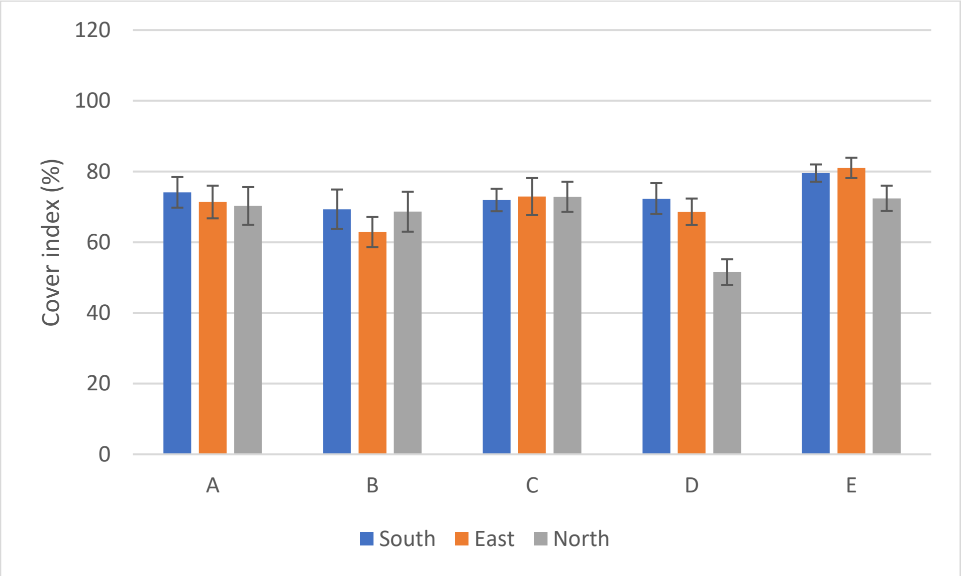

Figure 64. Cover index for each region and road class in Denmark. All road markings (white).

Annex B Results Norway

Comparison between 2017 and 2018

In Table 35, the number of measured road markings used in the analyses for dry road markings (right edge line) in Norway is shown for each road class and region in 2017 and 2018.

Figure 65 - Figure 67 compares the results for Norway between region and road class in 2017 and 2018 as regards retroreflectivity, relative visibility and relative pvt.

Table 35: Number of measured road markings in each road class and region for Norway, in 2017 and 2018. Right edge lines.

Road class	South		West		East		Mid		North	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
B	5	6	3	3	5	6	2	2	0	0
C	4	4	1	1	5	6	1	1	0	0
D	10	12	10	12	10	11	10	12	10	11
E	10	14	9	14	10	14	10	14	10	14
F	10	12	10	12	8	12	9	12	9	12

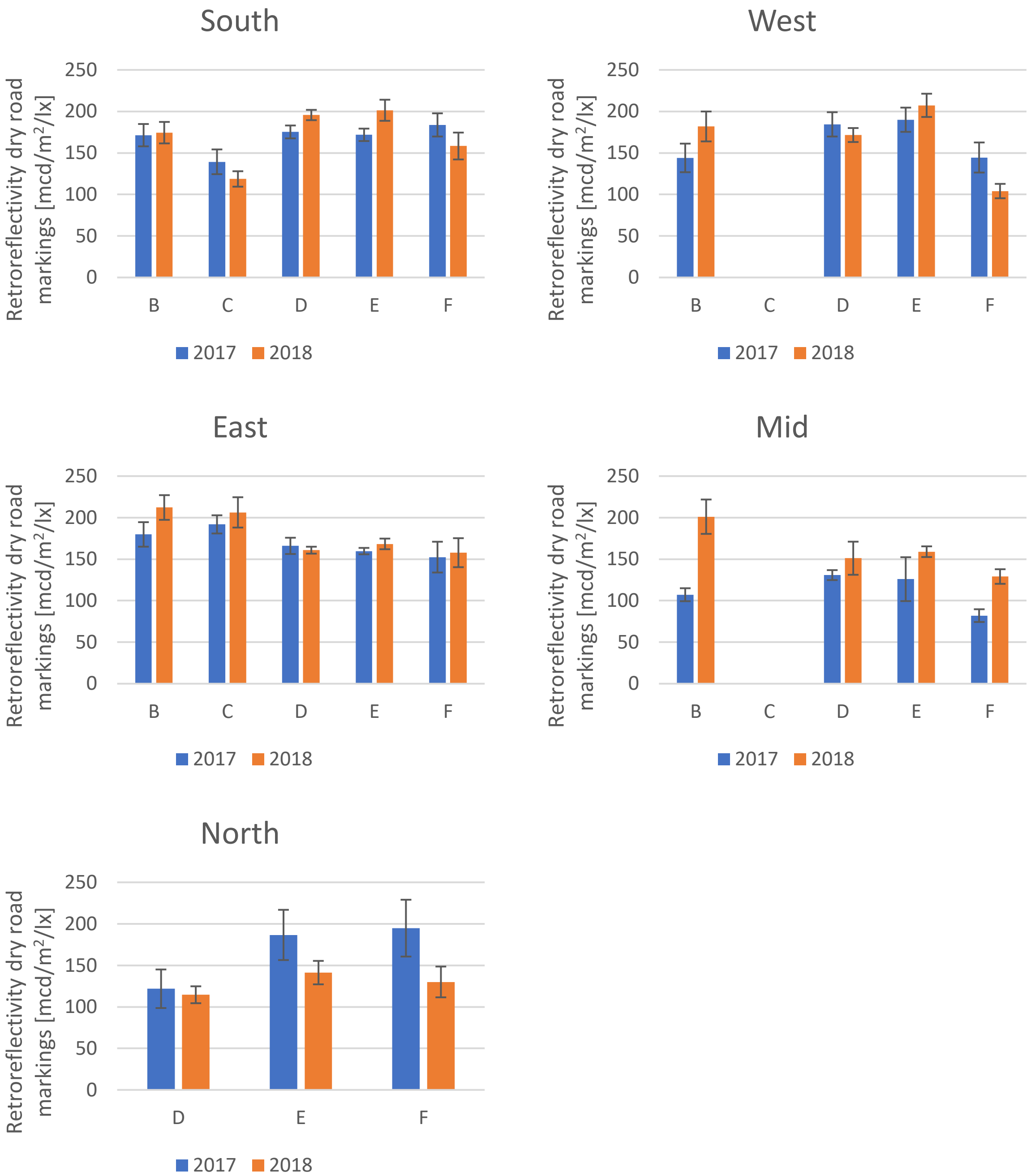

Figure 65. Retroreflectivity for dry road markings in Norway. Comparison between 2017 and 2018 for region and road class.

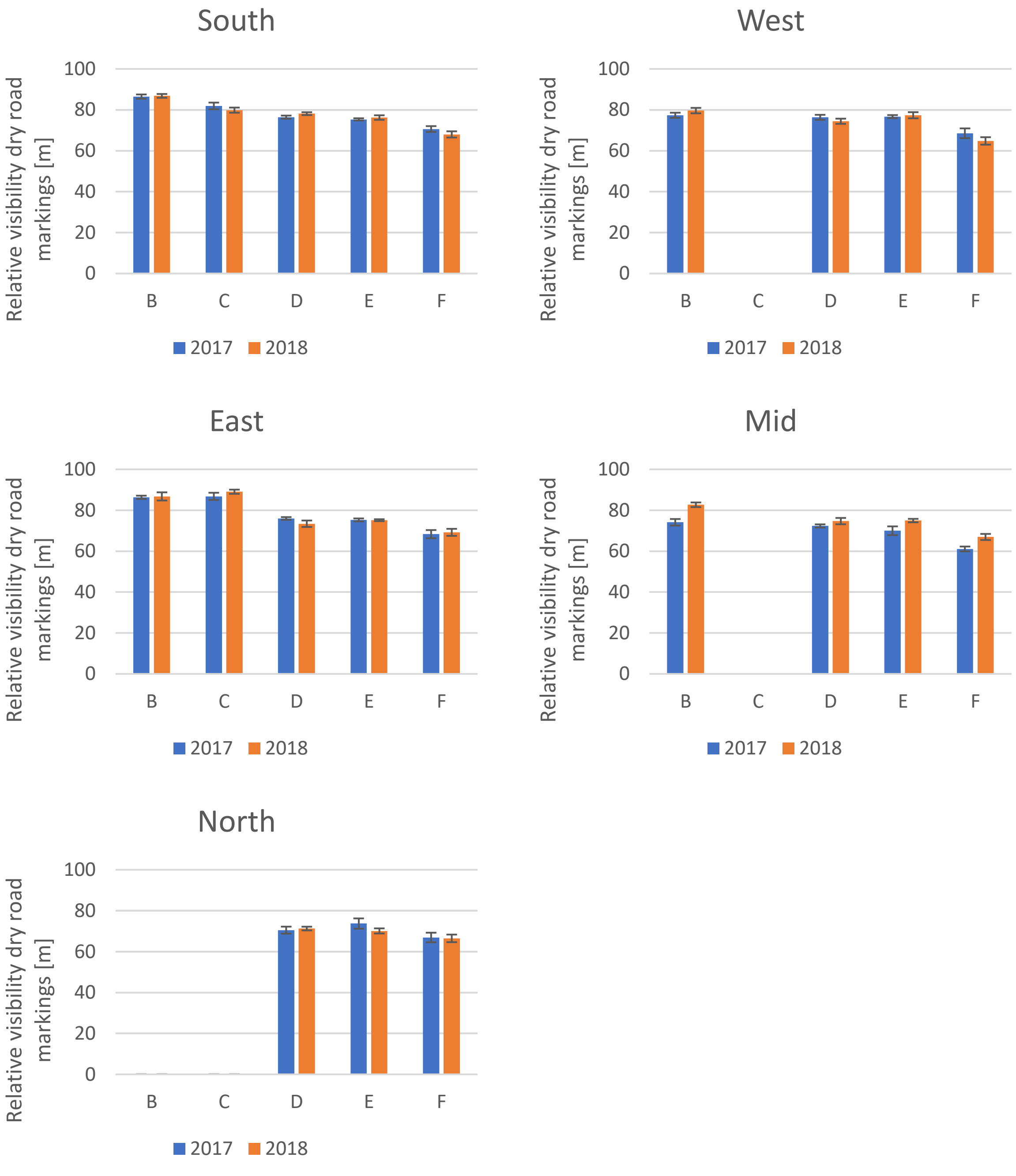

Figure 66. Relative visibility for dry road markings in Norway, right edge lines. Comparison between 2017 and 2018 for region and road class.

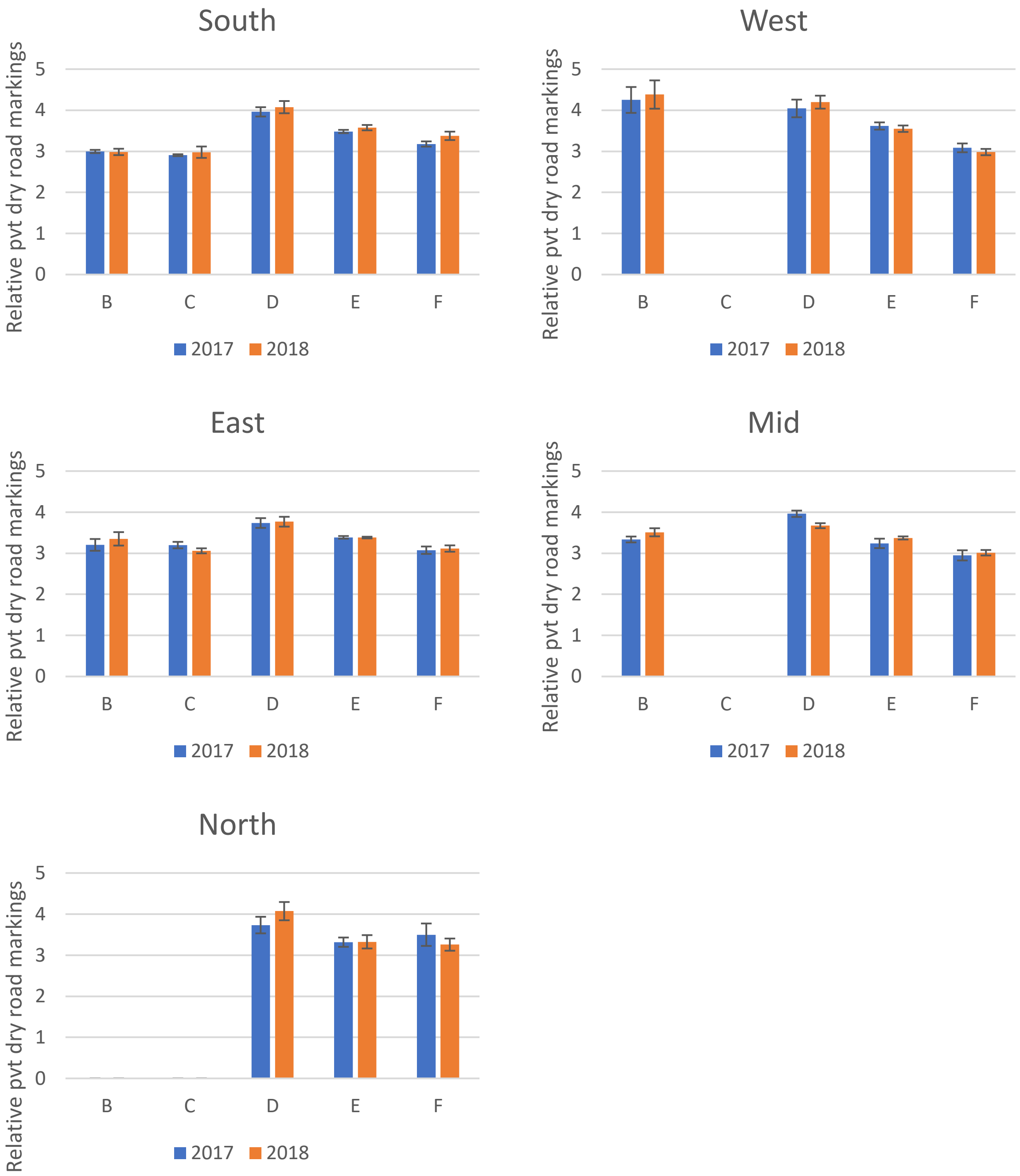

Figure 67. Relative pvt for dry road markings in Norway, right edge lines. Comparison between 2017 and 2018 for region and road class.

Dry road markings 2018

Retroreflectivity

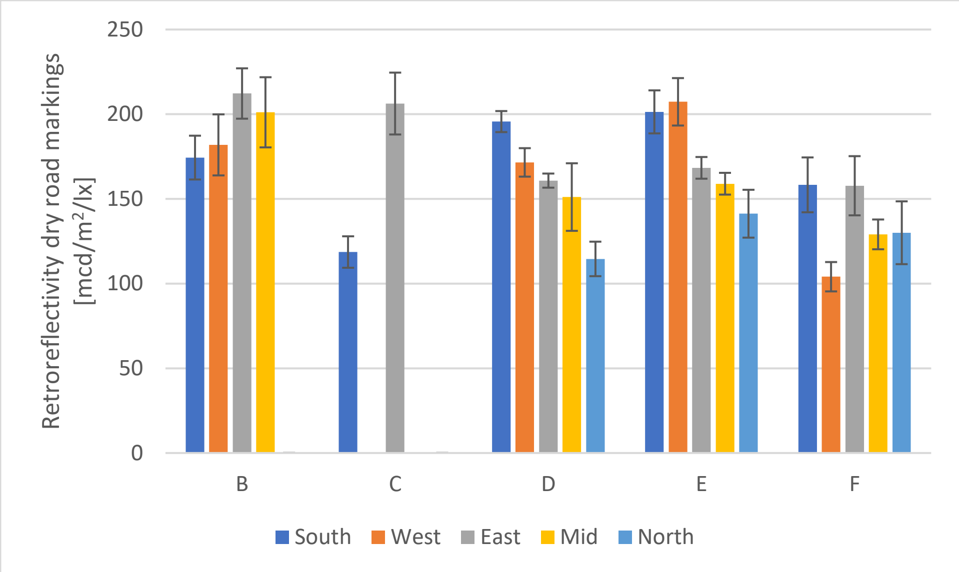

Figure 68. Mean of retroreflectivity right edge line on dry road markings for each region and road class in Norway.

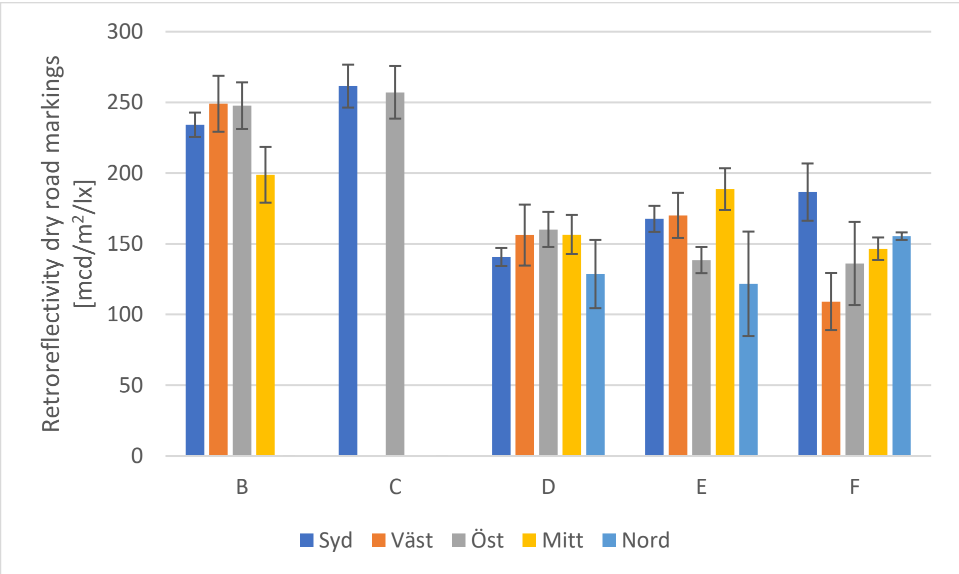

Figure 69. Mean of retroreflectivity in Norway. Lane line (class A, B and C), centre line (class D, E, and F). Dry road markings for each region and road class in Norway.

Relative visibility

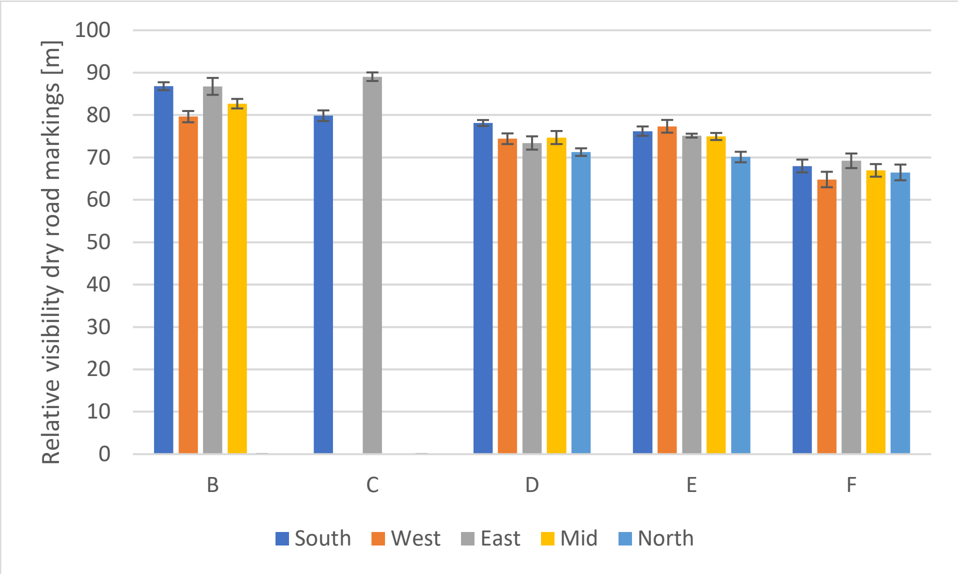

Figure 70. Relative visibility for right edge line for each region and road class in Norway. Dry road markings.

Relative pre-view-time

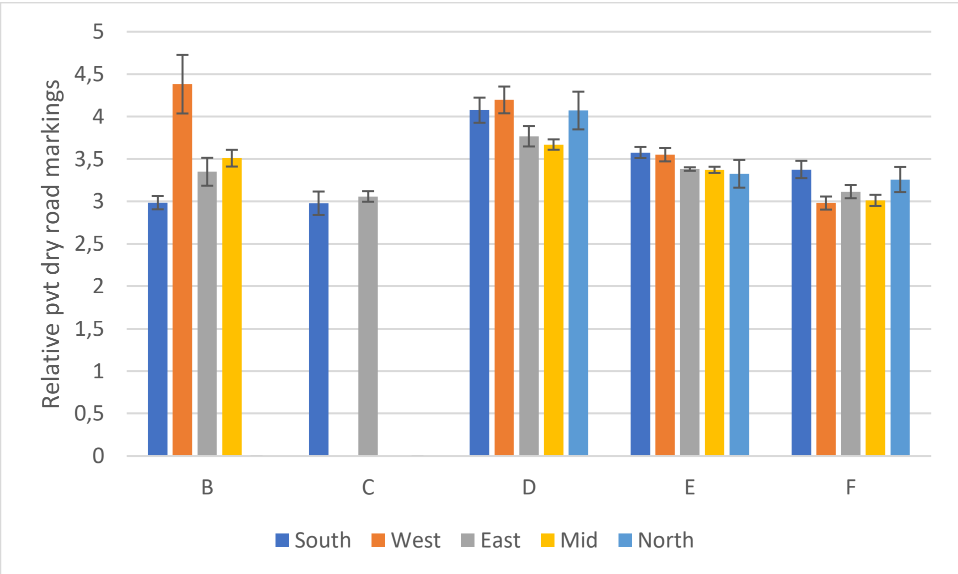

Figure 71. Relative pre-view-time for right edge line for each region and road class in Norway. Dry road markings.

Wet road markings 2018

Retroreflectivity

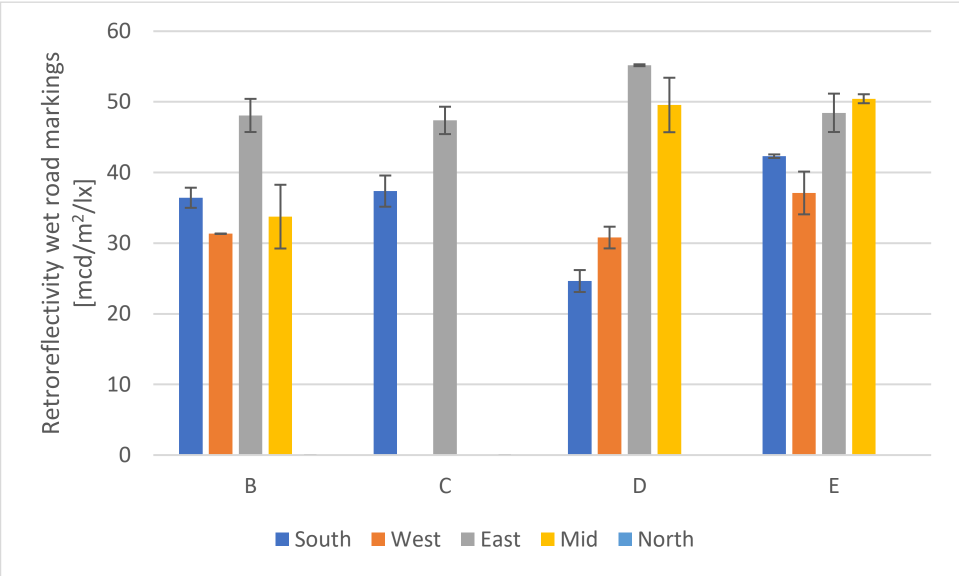

Figure 72. Mean of retroreflectivity right edge line on wet road markings for each region and road class in Norway.

Relative visibility

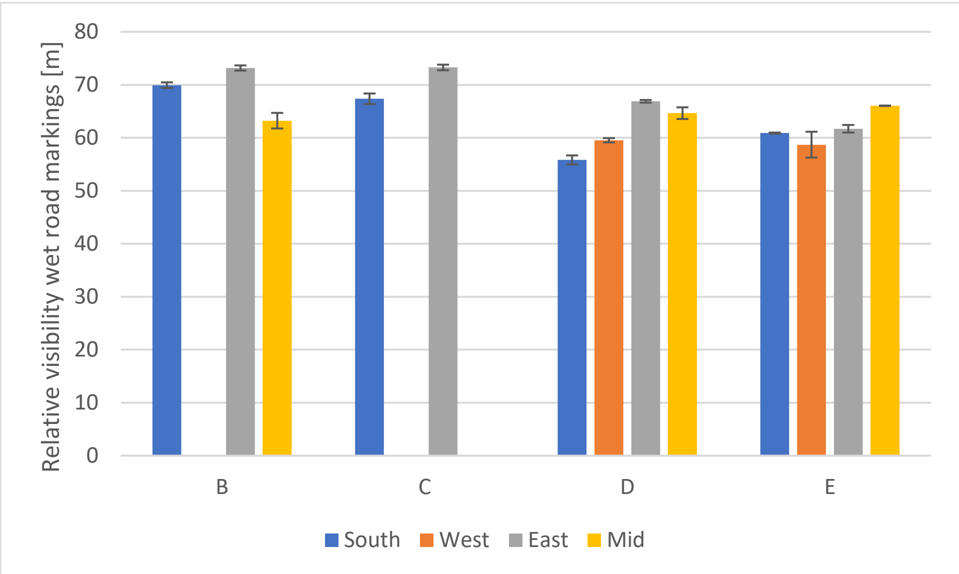

Figure 73. Relative visibility for right edge line for each region and road class in Norway. Wet road markings.

Relative pre-view-time

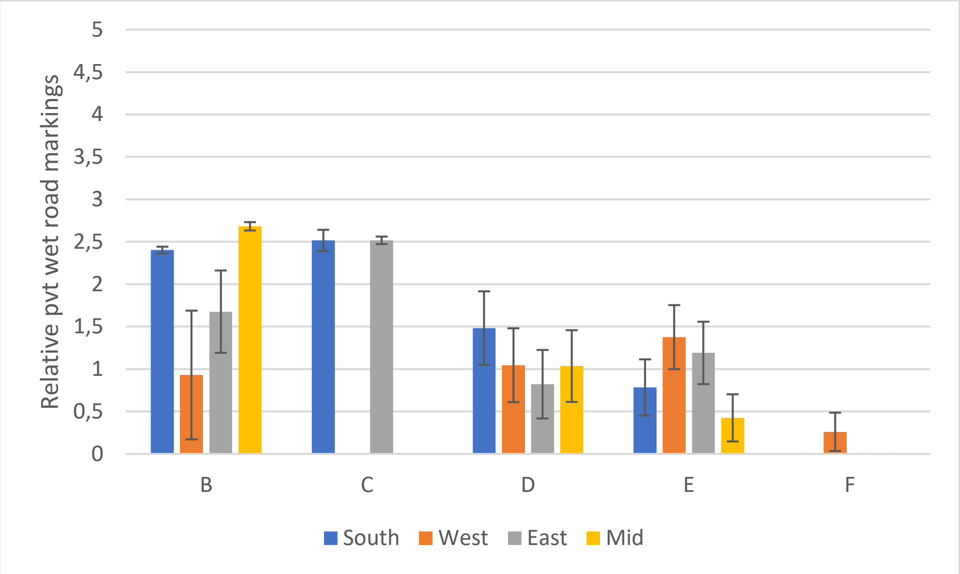

Figure 74. Relative pre-view-time for right edge line for each region and road class in Norway. Wet road markings.

Cover index 2018

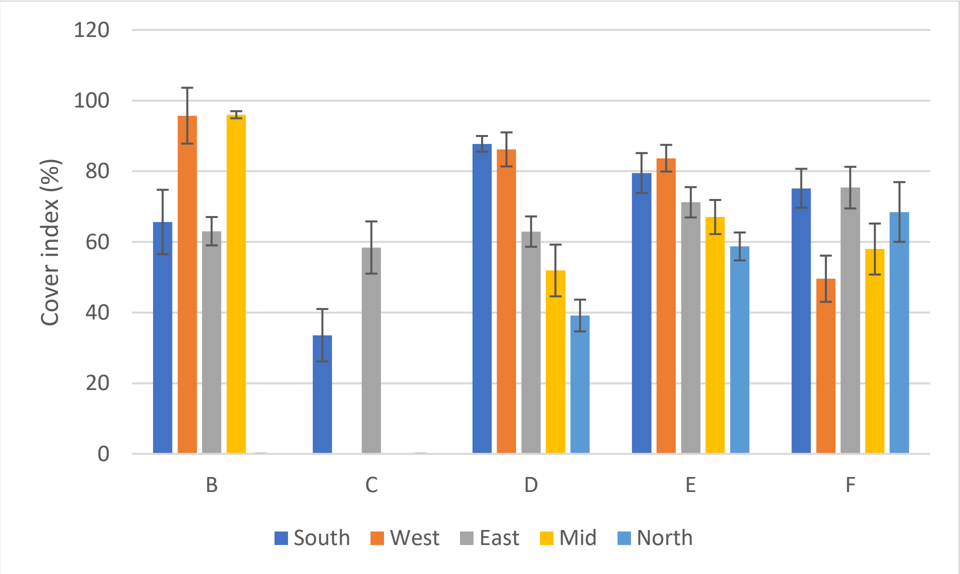

Figure 75. Cover index for each region and road class in Norway. Right edge line (white).

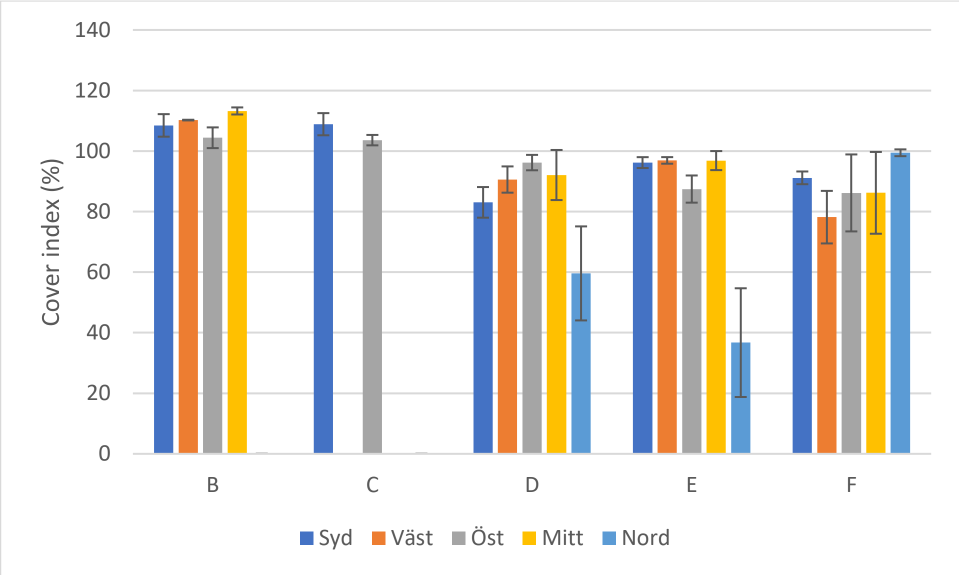

Figure 76. Cover index for each region and road class in Norway. Lane line (class A, B and C), centre line (class D, E, and F).

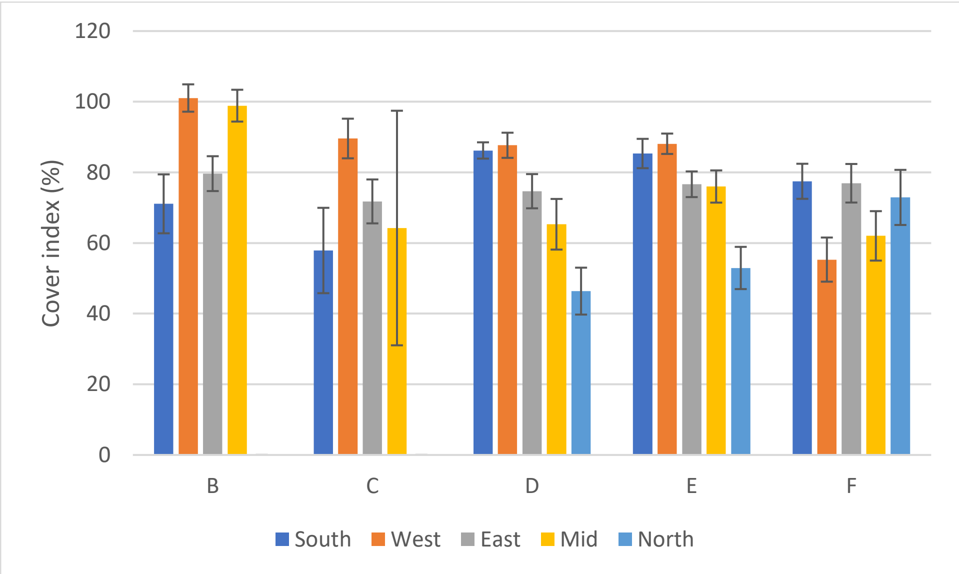

Figure 77. Cover index for each region and road class in Norway. All road markings (white and yellow).

County roads and national roads 2018

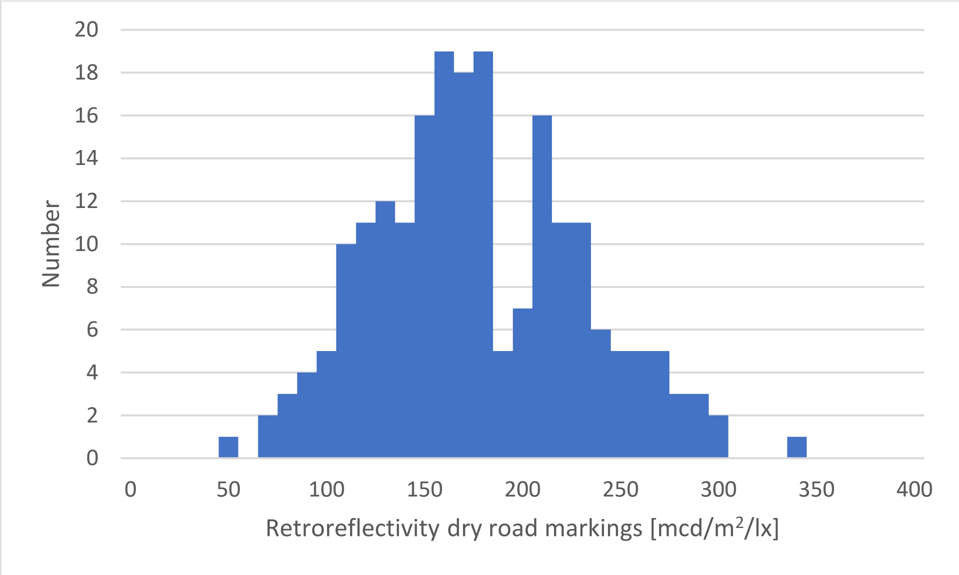

Figure 78 Retroreflectivity for dry road markings in Norway. All road markings, national roads.

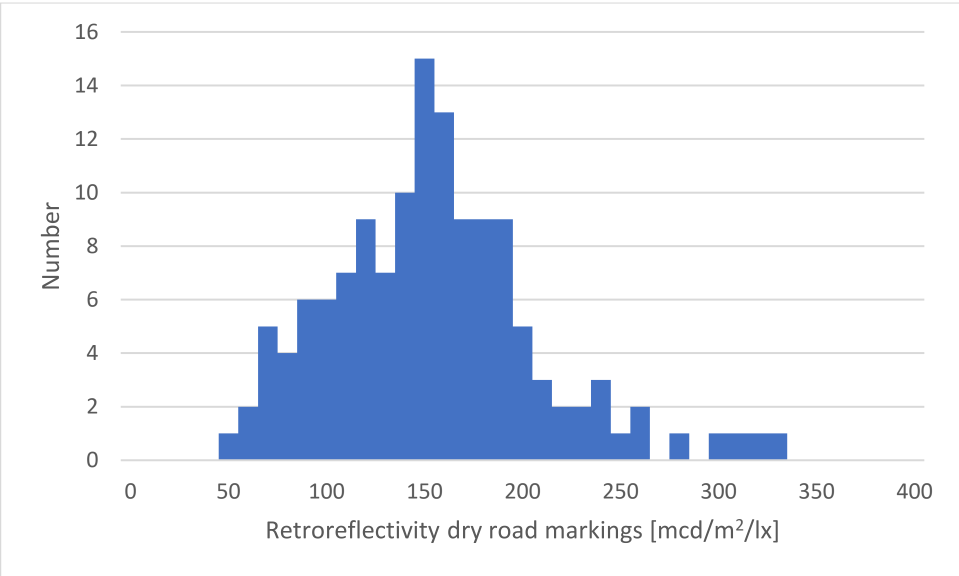

Figure 79. Retroreflectivity for dry road markings in Norway. All road markings, county roads.

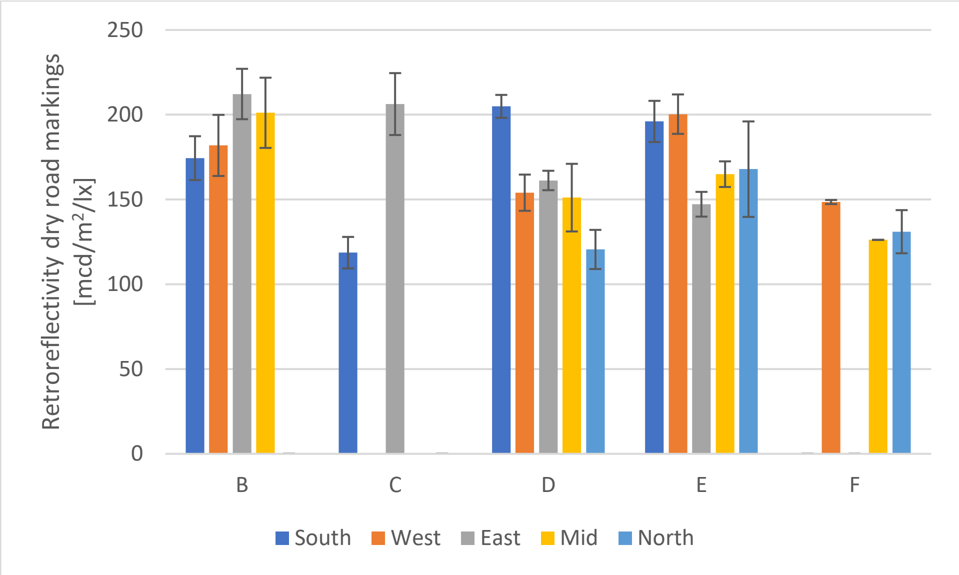

Figure 80. Retroreflectivity for dry road markings in Norway. Right edge line, national roads.

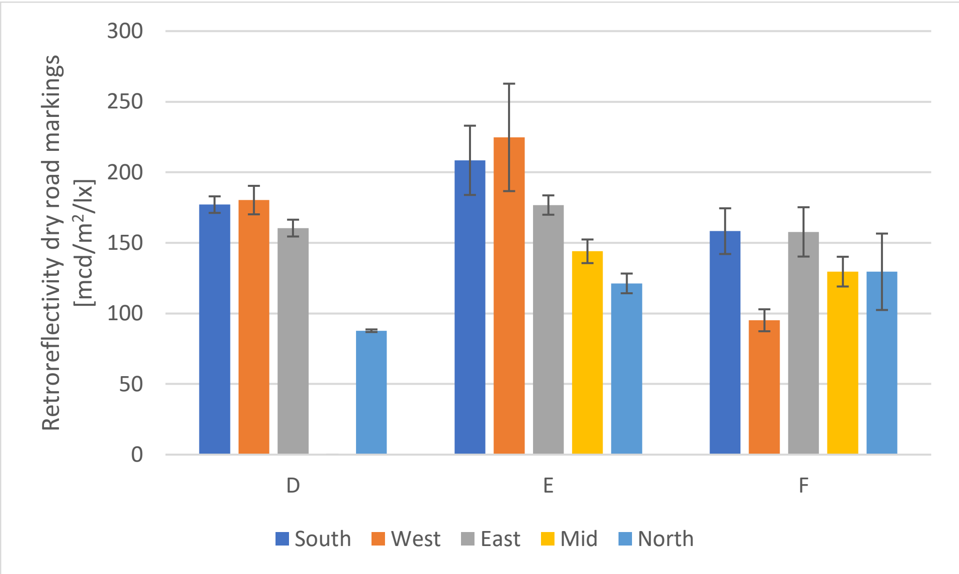

Figure 81. Retroreflectivity for dry road markings in Norway. Right edge line, county roads.

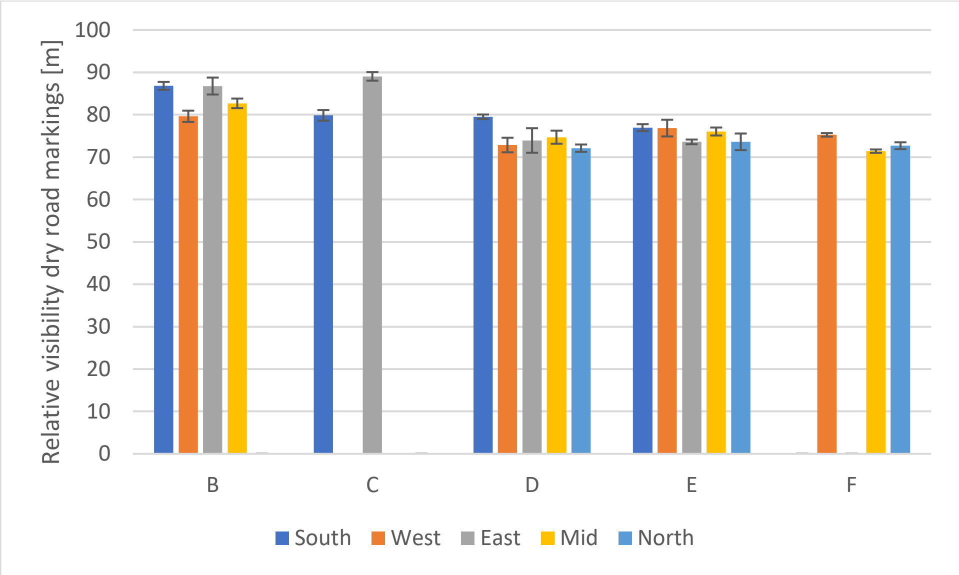

Figure 82. Relative visibility for dry road markings in Norway. Right edge line, national roads.

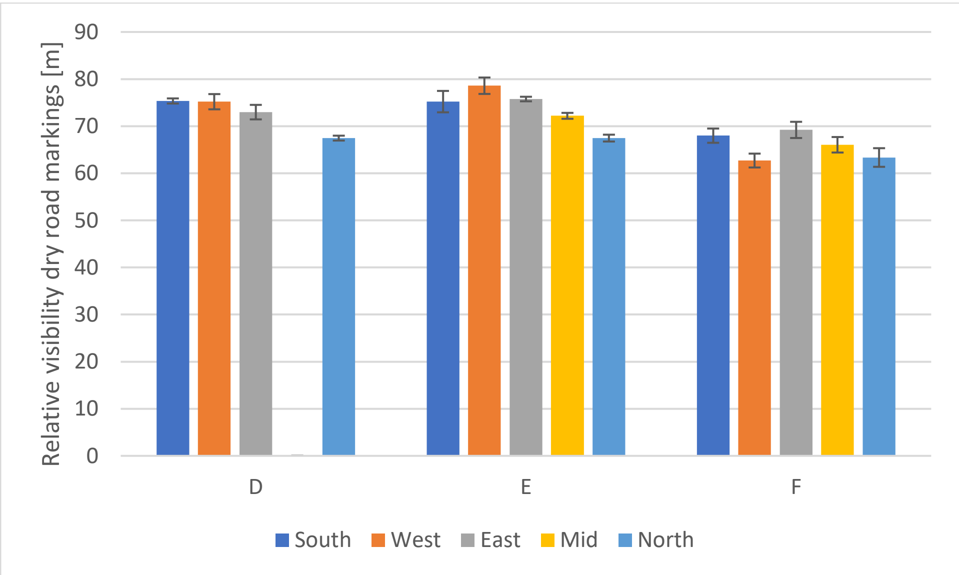

Figure 83. Relative visibility for dry road markings in Norway. Right edge line, county roads.

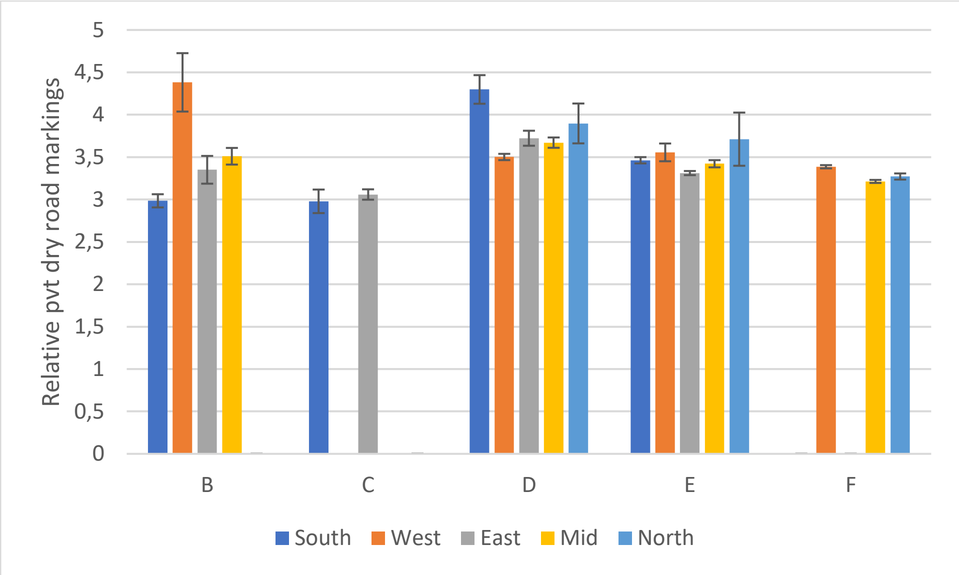

Figure 84. Relative pvt for dry road markings in Norway. Right edge line, national roads.

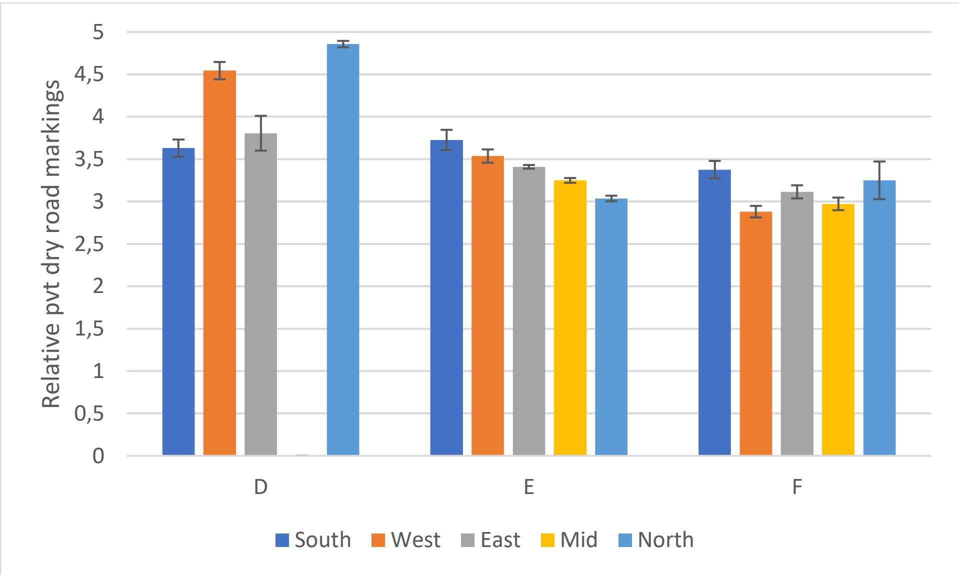

Figure 85. Relative pvt for dry road markings in Norway. Right edge line, county roads.

Annex C Results Sweden

Comparison between 2017 and 2018

In Table 36, the number of measured road markings used in the analyses for dry road markings (right edge line) in Norway is shown for each road class and region in 2017 and 2018.

Figure 86 - Figure 88 compares the results for Sweden between region and road class in 2017 and 2018 as regards retroreflectivity, relative visibility and relative pvt.

Table 36: Number of measured road markings in each road class and region for Sweden, in 2017 and 2018. Right edge lines.

Road class	South		West		East		Stockholm		Mid		North	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
A	0	0	2	2	0	0	5	5	0	0	0	0
B	6	5	8	5	9	8	11	5	1	1	0	0
C	21	21	8	10	23	24	6	6	10	8	7	2
D	16	12	10	26	8	10	10	12	10	11	0	8
E	54	68	31	21	46	42	8	12	37	38	10	16
F	79	69	52	38	76	81	22	25	95	92	69	77

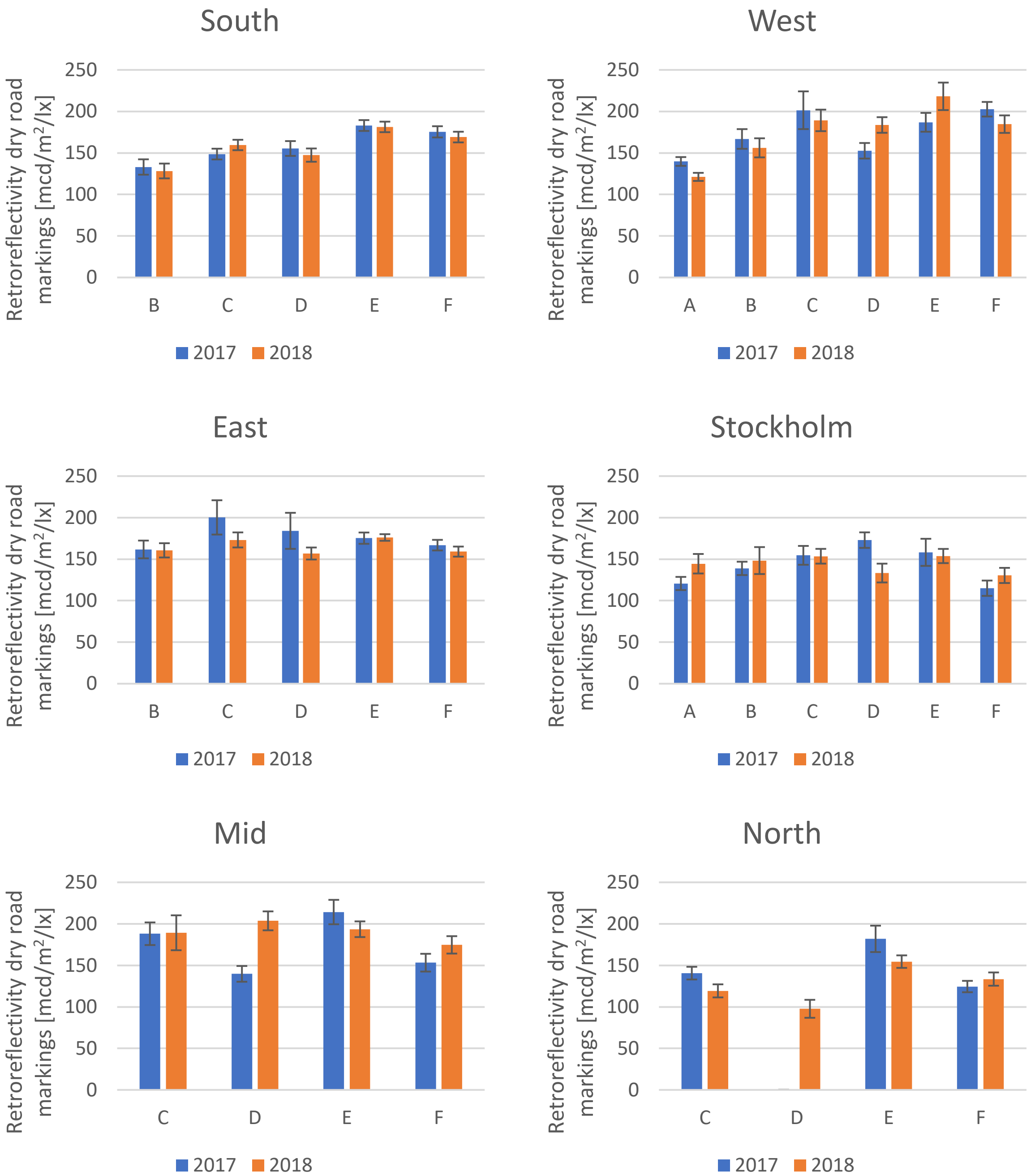

Figure 86. Retroreflectivity for dry road markings in Sweden. Comparison between 2017 and 2018 for region and road class.

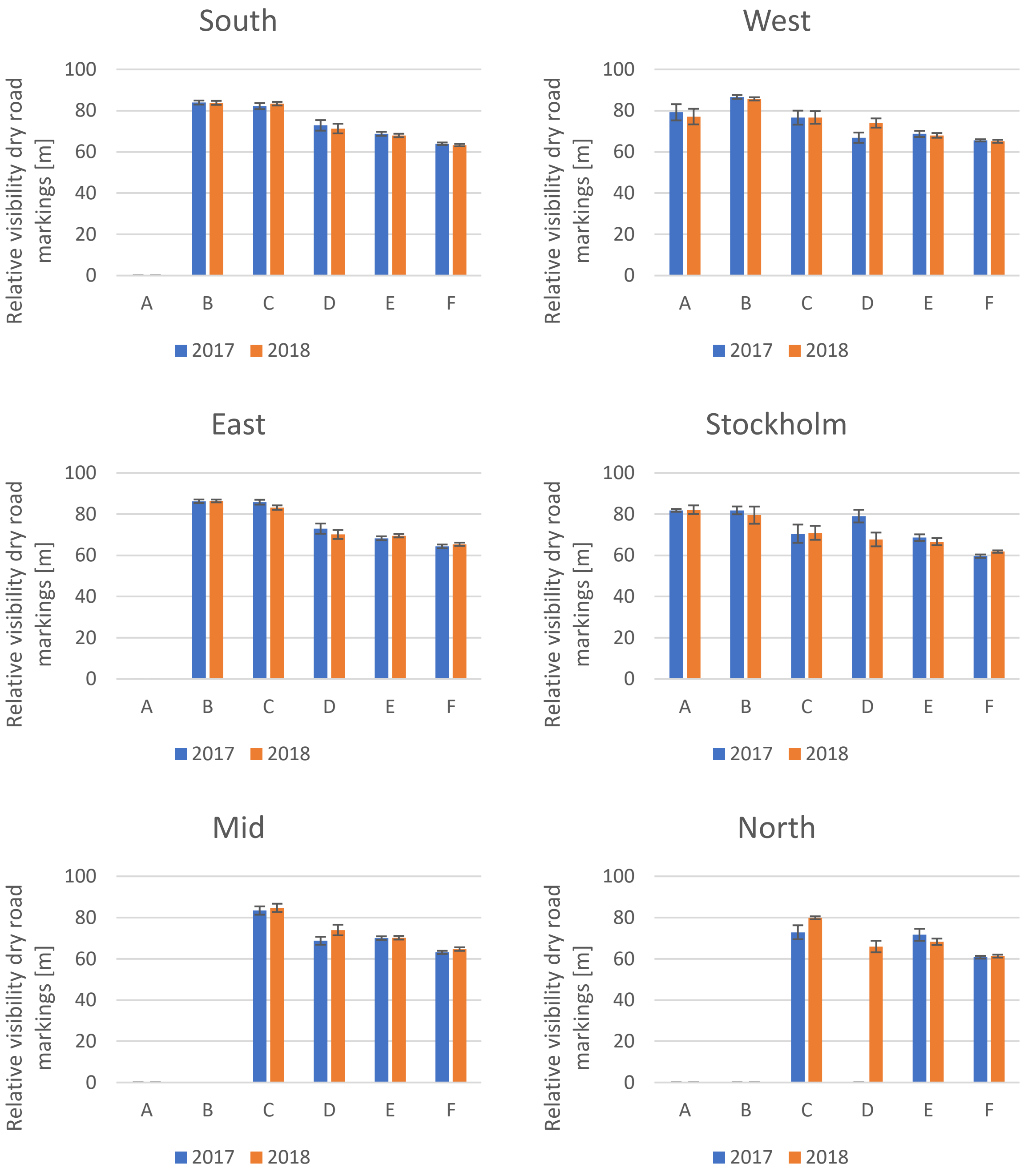

Figure 87. Relative visibility for dry road markings in Sweden, right edge lines. Comparison between 2017 and 2018 for region and road class.

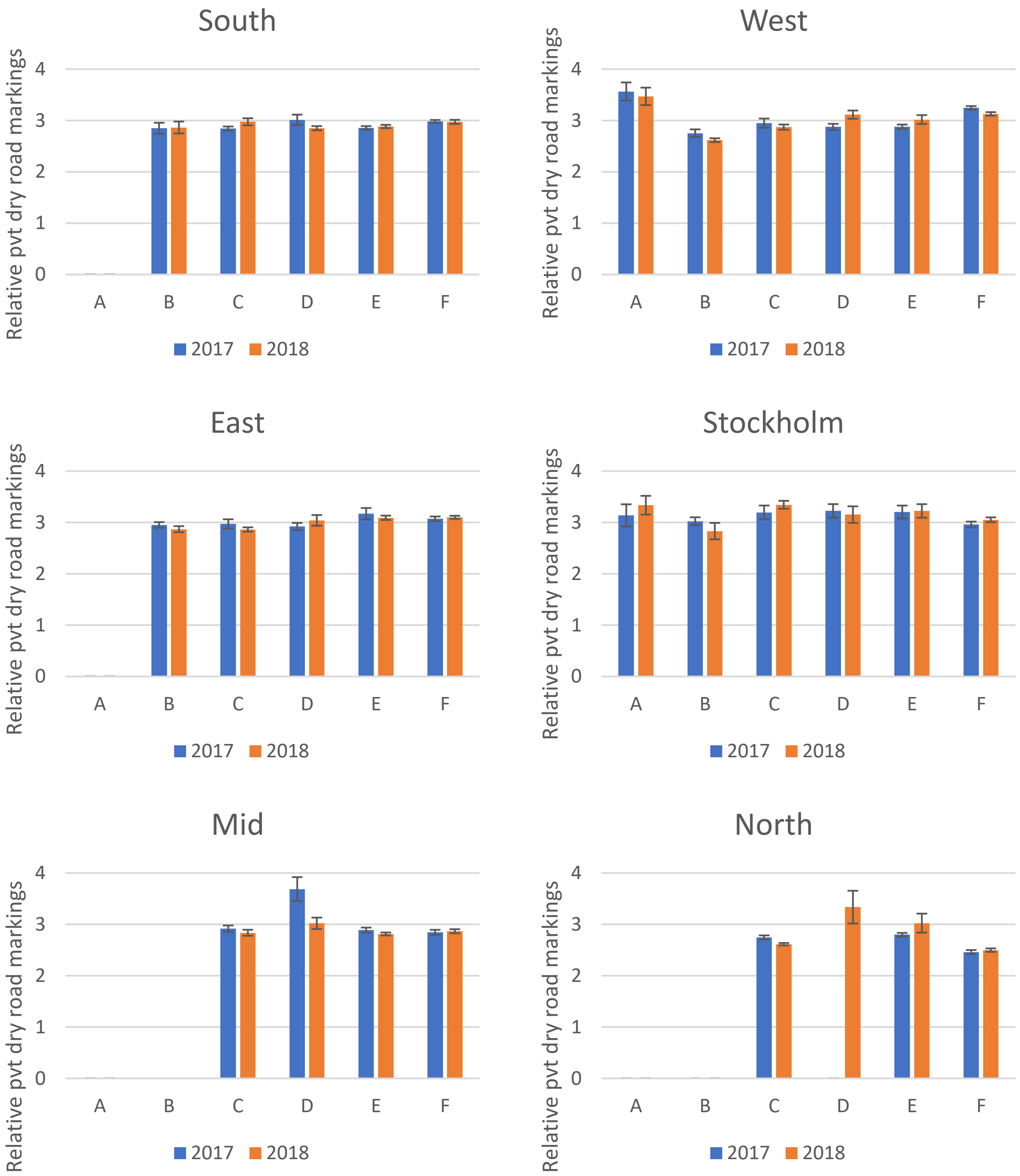

Figure 88. Relative pvt for dry road markings in Sweden, right edge lines. Comparison between 2017 and 2018 for region and road class.

Dry road markings 2018

Retroreflectivity

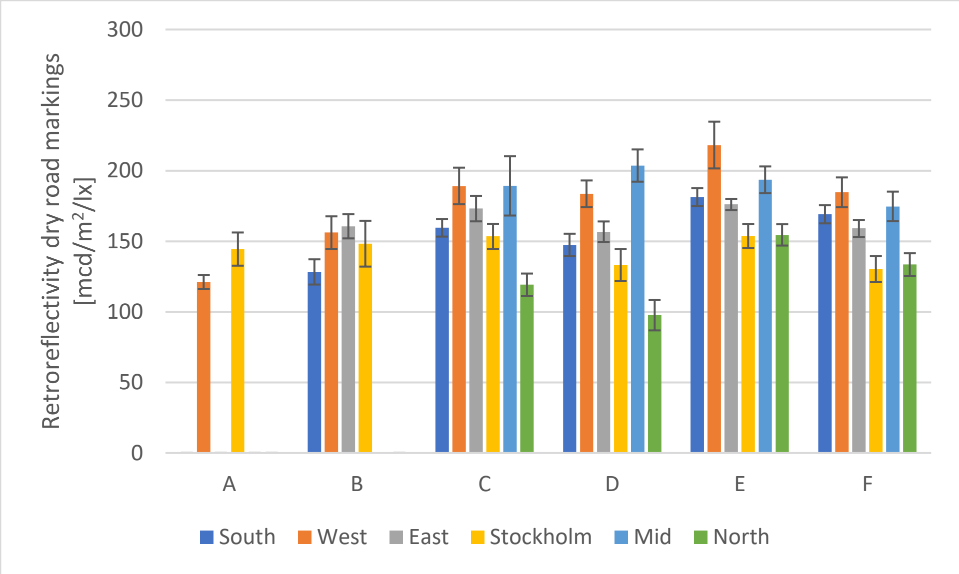

Figure 89. Mean of retroreflectivity right edge line on dry road markings for each region and road class in Sweden.

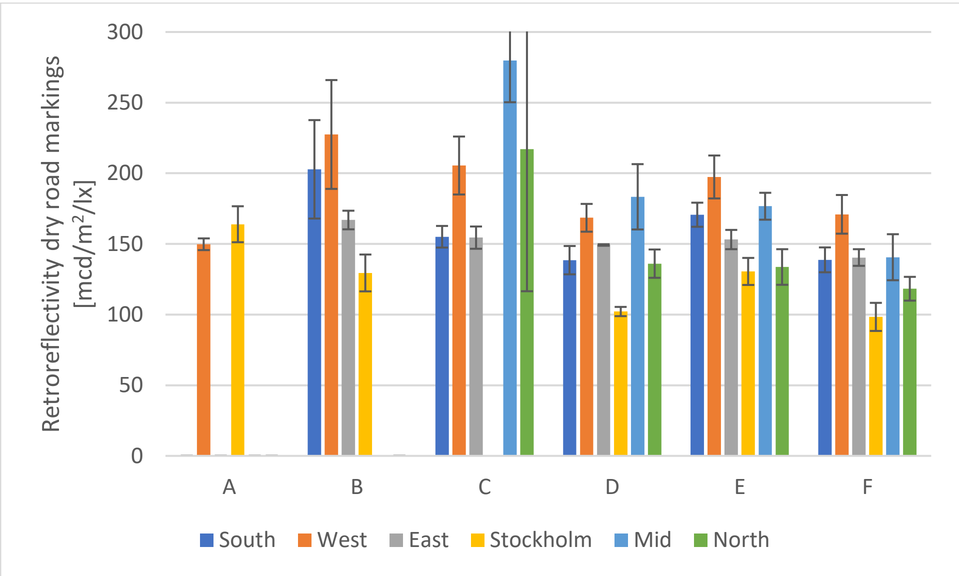

Figure 90. Mean of retroreflectivity in Sweden. Lane line (class A, B and C), centre line (class D, E, and F). Dry road markings for each region and road class in Sweden.

Relative visibility

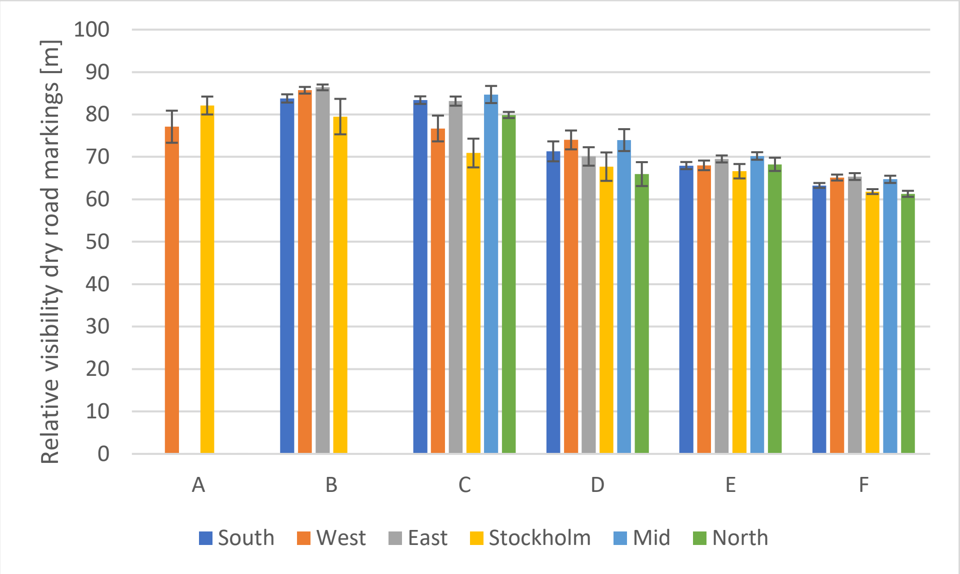

Figure 91. Relative visibility for right edge line for each region and road class in Sweden. Dry road markings.

Relative pre-view-time

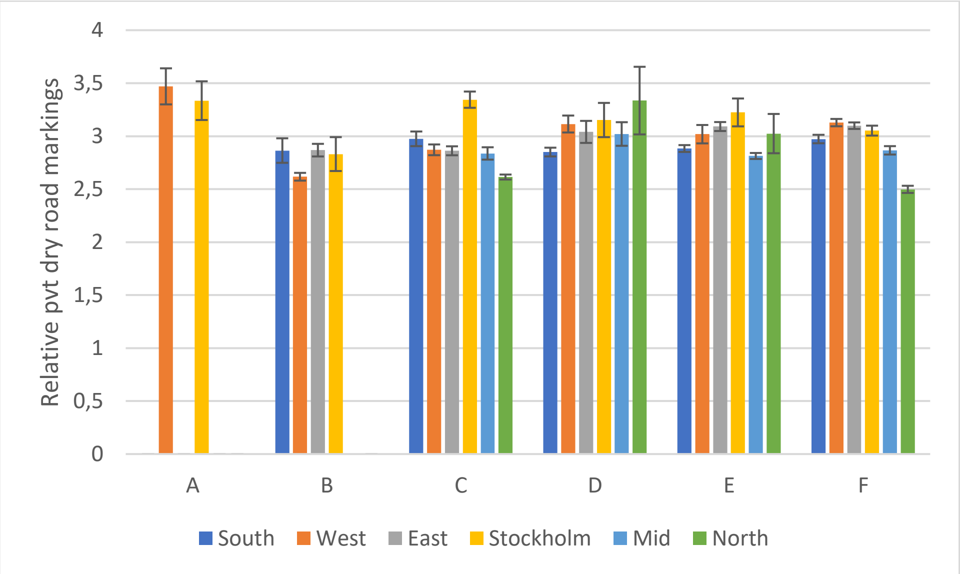

Figure 92. Relative pre-view-time for right edge line for each region and road class in Sweden. Dry road markings.

Wet road markings 2018

Retroreflectivity

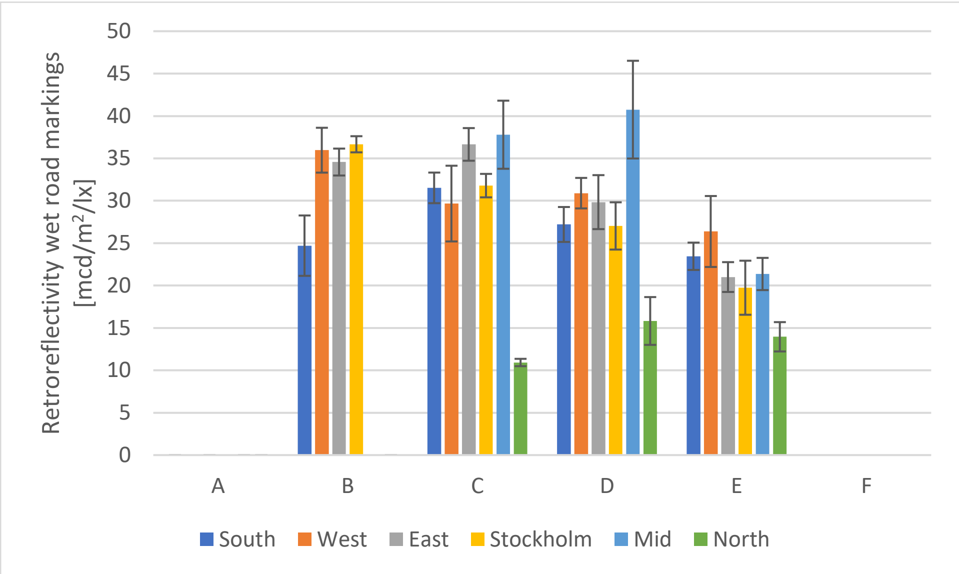

Figure 93. Mean of retroreflectivity right edge line on wet road markings for each region and road class in Sweden.

Relative visibility

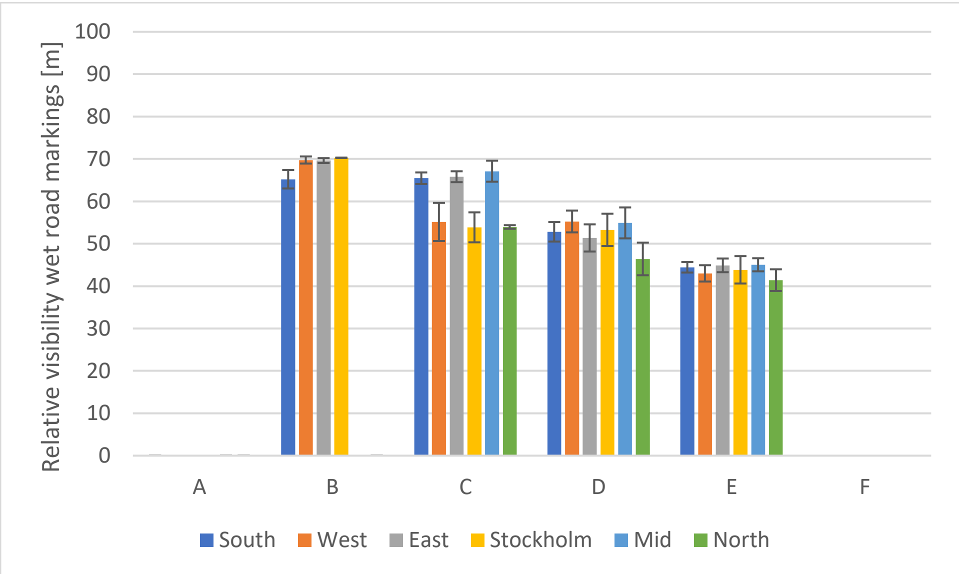

Figure 94. Relative visibility for right edge line for each region and road class in Sweden. Wet road markings.

Relative pre-view-time

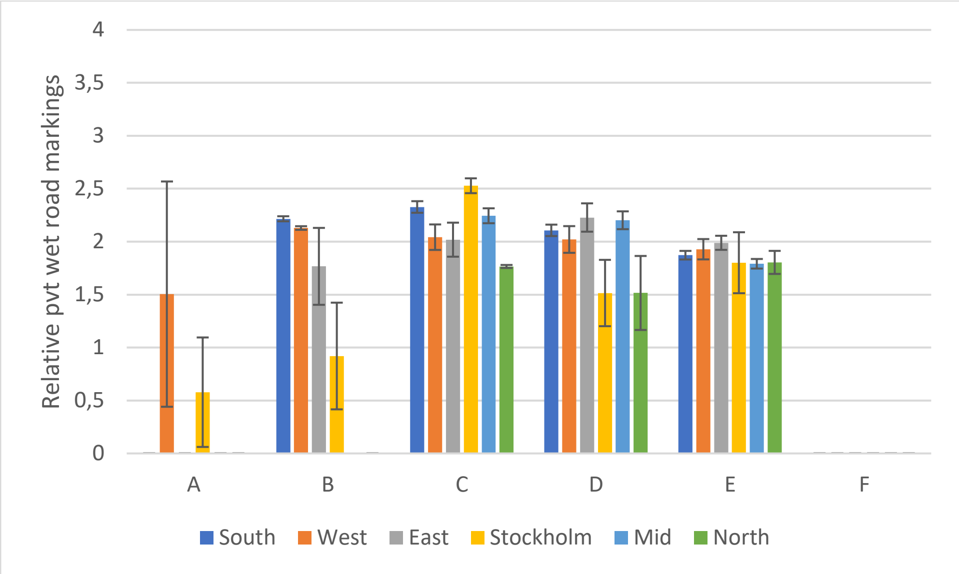

Figure 95. Relative pre-view-time for right edge line for each region and road class in Sweden. Wet road markings.

Cover index 2018

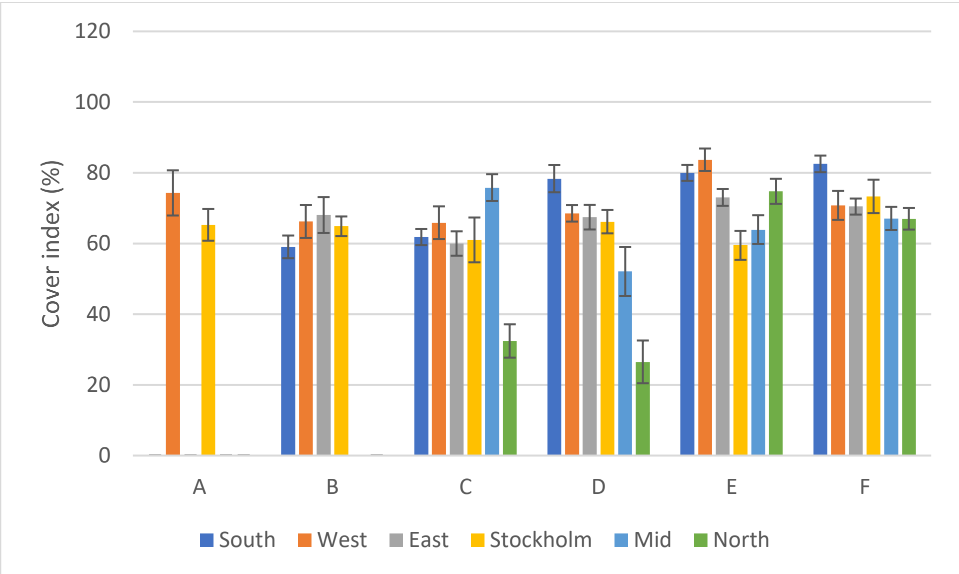

Figure 96. Cover index for each region and road class in Sweden. Right edge line road markings.

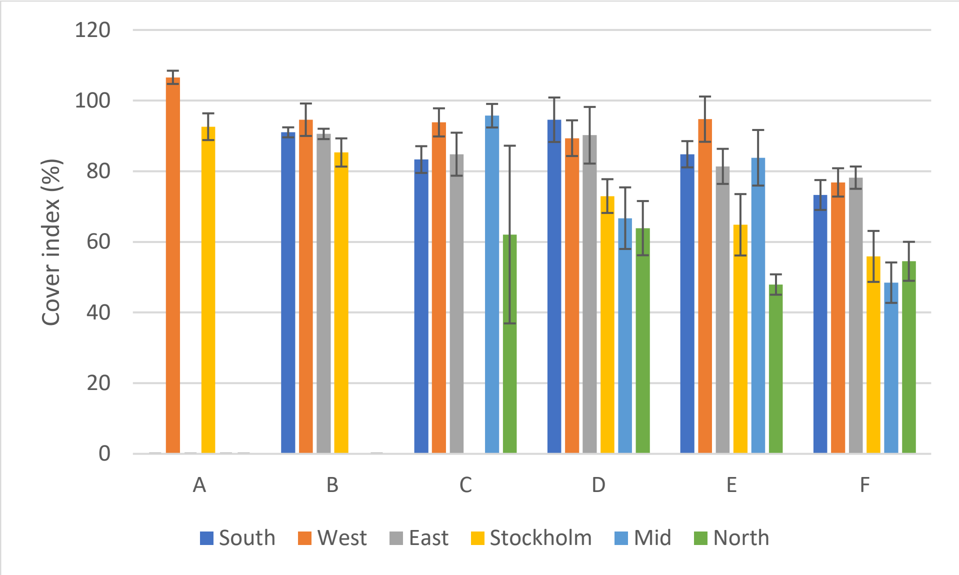

Figure 97. Cover index for each region and road class in Sweden. Lane line (class A, B and C), centre line (class D, E, and F).

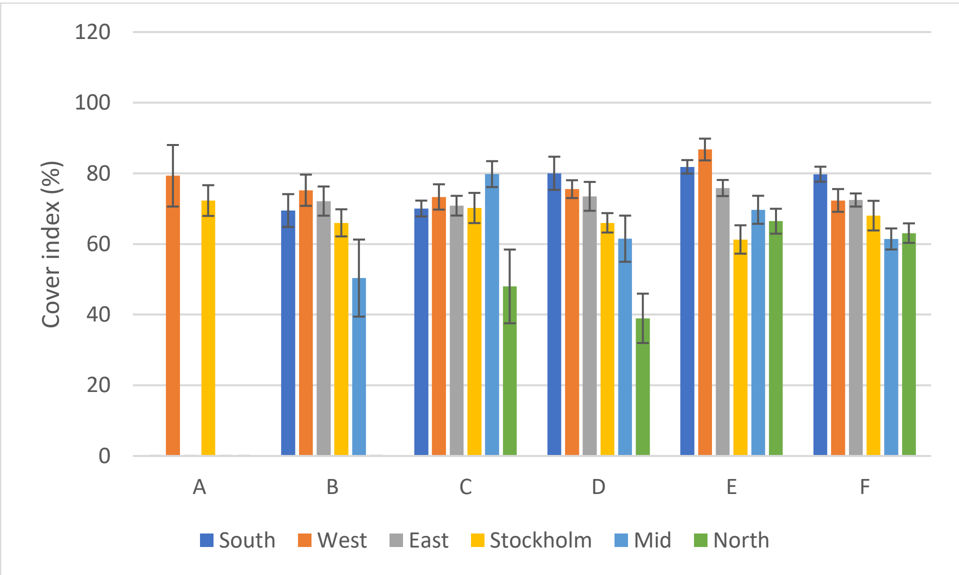

Figure 98. Cover index for each region and road class in Sweden. All road markings (white).

NordFoU

Annex D Results ANOVA

Table 37. Results from ANOVA.

Dependent variable	Independent variable	Degrees of freedom	F-ratio	p-value
Retroreflectivity [mcd/m²/lx] All road markings Dry road markings	Country	2	11.32	< 0.001
	Road class	5	10.85	< 0.001
	Country*road class	8	2.11	0.032
Retroreflectivity [mcd/m²/lx] Right edge line Dry road markings	Country	2	9.09	< 0.001
	Road class	5	6.66	< 0.001
	Country*road class	8	1.61	0.119
Retroreflectivity [mcd/m²/lx] Lane/centre line Dry road markings	Country	2	13.92	< 0.001
	Road class	5	7.2	< 0.001
	Country*road class	8	5.73	< 0.001
Retroreflectivity [mcd/m²/lx] All road markings Wet road markings	Country	2	37.32	< 0.001
	Road class	5	5.06	< 0.001
	Country*road class	7	1.75	0.095
Retroreflectivity [mcd/m²/lx] Right edge line Wet road markings	Country	2	33.94	< 0.001
	Road class	5	1.29	0.266
	Country*road class	7	1.14	0.335
Relative visibility [m] Right edge line Dry road markings	Country	2	10.49	< 0.001
	Road class	5	95.21	< 0.001
	Country*road class	8	4.26	< 0.001
Relative visibility [m] Lane/centre line Dry road markings	Country	2	1.53	0.218
	Road class	5	13.67	< 0.001
	Country*road class	8	5.58	< 0.001
Relative visibility [m] Right edge line Wet road markings	Country	2	10.34	< 0.001
	Road class	5	23.29	< 0.001
	Country*road class	7	3.39	0.002
Relative pvt [s] Right edge line Dry road markings	Country	2	65.77	< 0.001
	Road class	5	44.42	< 0.001
	Country*road class	8	17.35	< 0.001
Relative pvt [s] Lane/centre line Dry road markings	Country	2	21.16	< 0.001
	Road class	5	26.72	< 0.001
	Country*road class	8	4.46	< 0.001
Relative pvt [s] Right edge line Wet road markings	Country	2	80.17	< 0.001
	Road class	5	19.31	< 0.001
	Country*road class	7	18.25	< 0.001
Cover index [%] All road markings	Country	2	2.13	0.12
	Road class	5	4.70	< 0.001
	Country*road class	8	1.84	0.066
Cover index [%] Right edge line	Country	2	1.17	0.311
	Road class	5	5.68	< 0.001
	Country*road class	8	1.78	0.077
Cover index [%] Lane/centre line	Country	2	9.00	< 0.001
	Road class	5	5.34	< 0.001
	Country*road class	8	1.47	0.165

Table 38. Mean levels and standard error for Denmark, Norway and Sweden. The mean levels are estimated marginal means and adjusted for unbalance in the design.

Variable	Denmark	Norway	Sweden
Retroreflectivity, all road markings, dry [mcd/m²/lx]	144 (4.0)	167 (3.4)	162 (2.6)
Retroreflectivity, right edge line, dry [mcd/m²/lx]	130 (6.4)	165 (5.1)	160 (4.4)
Retroreflectivity, lane/centre line, dry [mcd/m²/lx]	143 (6.6)	186 (6.0	162 (4.3)
Retroreflectivity, all road markings, wet [mcd/m²/lx]	28 (0.9)	37 (1.6)	33 (1.1)
Retroreflectivity, right edge line, wet [mcd/m²/lx]	26 (1.1)	38 (2.2)	33 (1.5)
Relative visibility [m], right edge line, dry	79 (0.7)	77 (0.6)	75 (0.5%
Relative visibility [m], lane/centre line, dry	63 (0.6)	63 (0.5)	63 (0.4)
Relative visibility [m], right edge line, wet	62 (0.8)	64 (1.6)	62 (1.1)
Relative pvt [s], right edge line, dry	2.9 (0.04)	3.4 (0.03)	3.0 (0.03)
Relative pvt [s], lane/centre line, dry	2.3 (0.05)	2.8 (0.04)	2.6 (0.03)
Relative pvt [s], right edge line, wet	2.2 (0.03)	2.7 (0.06)	2.4 (0.04)
Cover index [%], all roads	71 (1.7)	74 (1.4)	72 (1.1)
Cover index [%], right edge line	62 (2.5)	65 (2.0)	67 (1.6)
Cover index [%],lane/centre line	87 (2.9)	94 (2.6)	83 (1.9)

Annex E Distribution of retroreflectivity and relative visibility right edge line

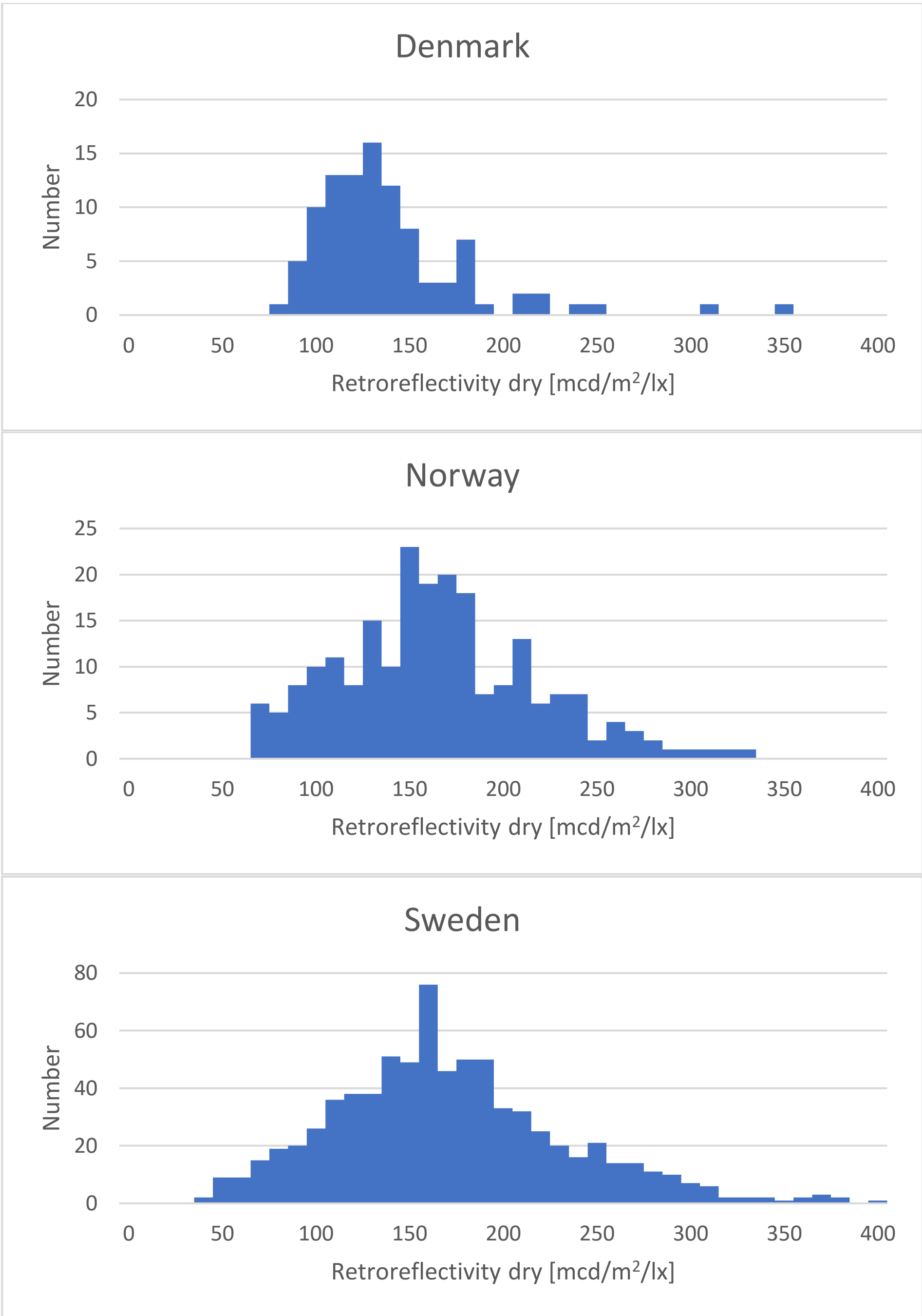

Figure 99. Distribution of dry right edge line retroreflectivity [mcd/m^2/lx].

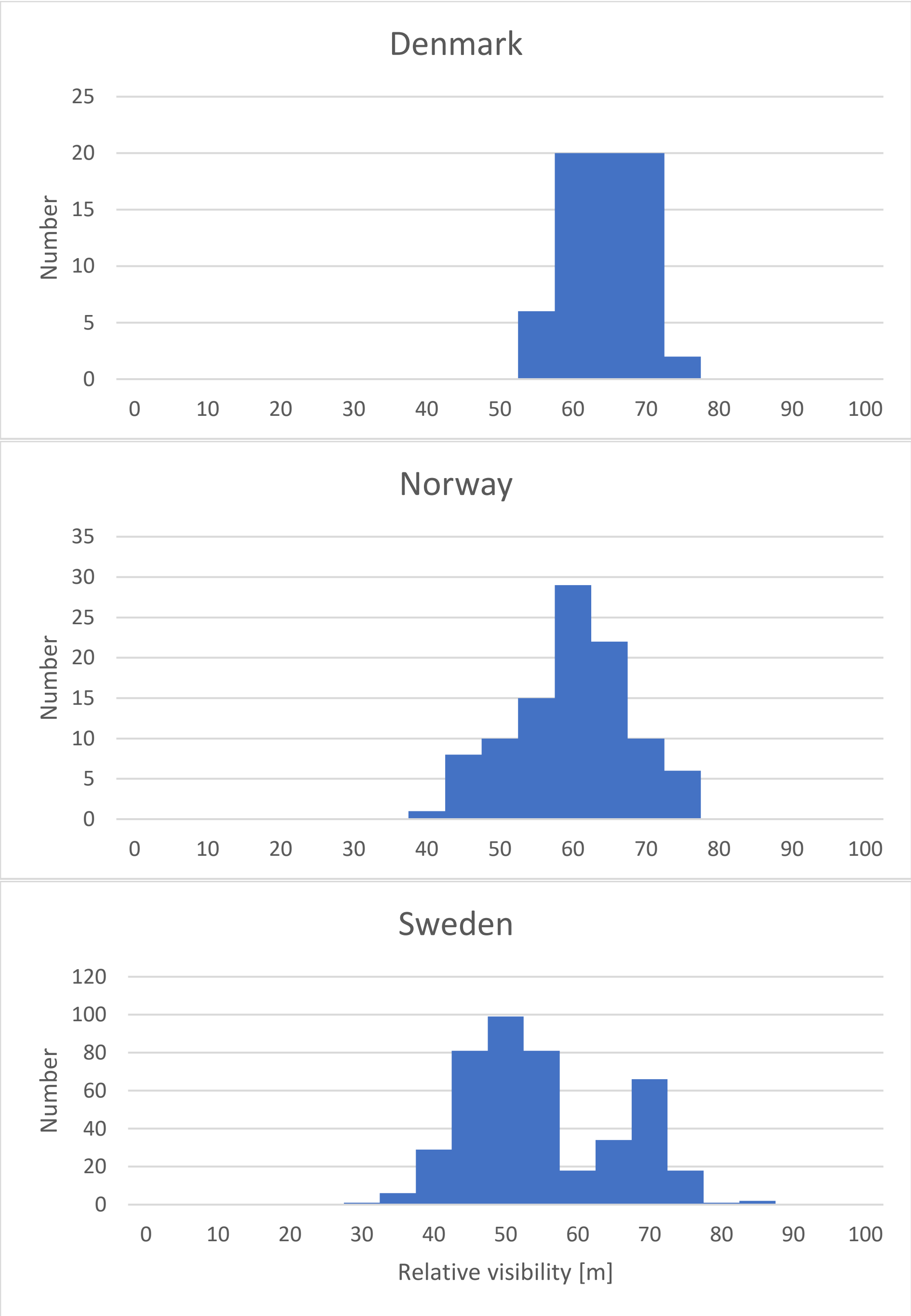

Figure 100. Distribution of relative visibility of dry right edge lines.

NordFoU

CVR nr.: 35272704
Nordfou.org
Havnegade 27
1058 København K