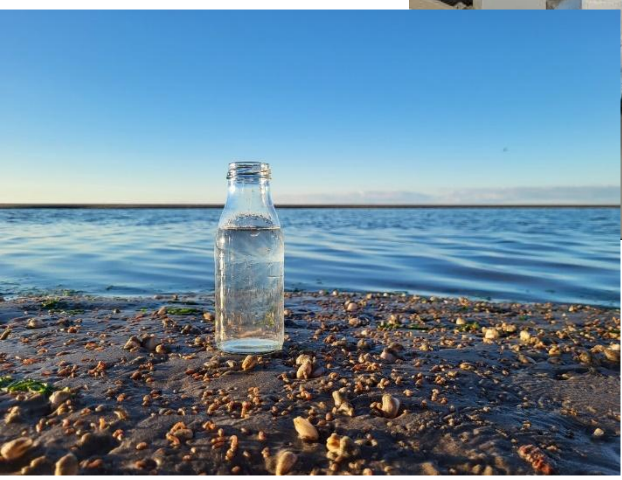
Entry to the Stockholm Junior Water Prize Netherlands 2025

drinking water production Ameland

Desalination of seawater with electrodialysis



Martijn Ridder & Sjoerd Kiewiet

Netherlands

Acknowledgements

First of all, we would like to thank Mr Santema, our teacher, for supervising our profile paper. In addition, our thanks goes to Ir. Kecen Li, who helped us by making his setup (with which he conducts his own research) available. He also provided us with valuable guidance during our research and contributed his thoughts. We would also like to thank Rouèl Gnodde for contacting researchers and helping us find out which question we preferred to tackle. Dear reader, in front of you is a short summary of the profile paper on the possibility of desalinating seawater around Ameland. Enjoy reading it!

Summary

Ameland is an island with unique challenges and opportunities in drinking water production. An increasing demand for drinking water due to growing tourism and a growing permanent population creates challenges. The current drinking water supply largely relies on freshwater bubbles under the island and water brought in from the mainland via pipes. However, this approach is fragile and not fully sustainable. Therefore, this paper investigated whether electrodialysis metathesis (EDM) could contribute to a self-sufficient and future-proof drinking water system for Ameland.

First, samples were taken from the North Sea and the Wadden Sea around Ameland. The chemical composition of the water was analysed using ion chromatography (IC) and inductively coupled plasma (ICP). The EDM plant separated salt ions from seawater by passing them through specific membranes that allow only certain ions to pass through. To make the water meet Dutch drinking water standards, a double treatment was carried out. The experiment showed that EDM removed 95.7% of ions from the seawater after one hour of treatment. A second treatment has not been practically tested. However, based on calculations and assumptions, a second treatment is expected to bring the salt ion content below the legal standards for drinking water. EDM appears to be a good tool in converting seawater into drinking water. The study concludes that EDM is a promising technique for producing drinking water from seawater on Ameland. The road to a self-sufficient drinking water system is still long and has many obstacles, but this research shows that with the right innovations and knowledge, it is possible.

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Introduction

We, Martijn Ridder and Sjoerd Kiewiet, were born and raised on Ameland. While searching for a subject for our school project, we came across the need to supply drinking water from outside Ameland. This led to the question: Can the production of drinking water also be done on Ameland itself? Drinking water is important for our daily lives. Our drinking water must be safe and therefore meet quality requirements. For instance, it must not contain too much salt and dangerous substances such as Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) must not be present in large quantities. In the Netherlands, 1.117 billion m^3 of drinking water is supplied annually. Per person, we use 128.1 Litres per Day. (Ministry of Infrastructure and Water Management,

2023) Of this, 60% is prepared from groundwater and 40% from surface water. (Drinking Water Quality, 2023) Despite a decline of almost 8% in daily water consumption per capita, drinking water consumption across Friesland has increased by as much as 18% over the past eight years. (Wetter foar letter Drinking water strategy Fryslân 2050, 2021)

This creates additional required drinking water production. Friesland's drinking water strategy for 2050 mainly assumes the production of drinking water using fresh groundwater. This is because it is currently easier to process than brackish or even salty groundwater. However, there is talk of the special situation where Ameland gets a third of its water consumption from a freshwater bubble under the island. This is supplemented by rainwater that infiltrates the dune sand. However, the balance between the use of nature's plants and animals and drinking water for consumption must be guaranteed for a sustainable cycle on the islands. Because the bubble under Ameland is not large enough to provide Ameland residents with drinking water all year round, water is transported under the Wadden Sea with a water pipeline. By increasing the production of drinking water on the mainland, Ameland will not experience a shortage of water as long as the water pipeline is in use. However, we are looking at how to future-proof the drinking water supply on the Wadden Islands. This includes looking at innovations in the water chain. (Wetter foar letter Drinkwaterstrategie Fryslân 2050, 2021) (Whole parafraph).

This study investigated whether electrodialysis can be a possible and sustainable innovation to make Ameland's drinking water production self-sufficient and future-proof by desalinating the surrounding seawater. This will involve a trial of a plant suitable for removing ions in brackish water. By carrying this out not with brackish water but with salty seawater, it can be investigated whether this method works for desalinating the North Sea and/or Wadden Sea. For this, it is first necessary to investigate which ions are specifically present in the sea around Ameland. These data are important to determine the method by which the ions will be removed, but also to be able to map the decrease of these ions

Desalination methods

On Ameland, 200,000 m^3 of water per year is extracted from groundwater from the dunes. Of this, 100,000 m^3 per year comes from the dunes in Buren, and 100,000 m^3 per year comes from the dunes in Hollum (two villages on Ameland). As the annual demand is higher, in addition to its own production, drinking water is supplied by so-called mudflats from the production location Noardburgum to Ameland. Water consumption on Ameland increased in 2009 from about 8,300 m^3 in the quiet month of November when there is little tourism to over 48,000 m^3 in the summer when tourism is at its peak. (Start of drinking water plant on Ameland, 2009) The current two production sites cannot handle this pressure in summer. To relieve them, water is brought in from the mainland. A report by the University of Wageningen states that in 2013, this amounted to another 330,000 m^3 per year. (Peters, 2013) The 20-kilometre pipelines laid in 1981 help ensure that during the peak of residents' numbers in summer, the water supply is maintained. Thus, if the own sites are unable to meet the need, there is an urgent need to switch to water from a production site elsewhere. With rising tourism and more permanent residents on the island, other technological developments are being sought to future-proof water production on Ameland. (Wetter foar letter Drinking water strategy Fryslân 2050, 2021) To prevent future incidents, one possibility is to increase drinking water production on Ameland to the required 550,000 m^3 per year. However, a water production site on Ameland that is completely independent of supply from external sites must also be able to scale up and down when the need for drinking water demands it. Indeed, the difference in demand between November and July is very large. In addition, the Netherlands is drying out, thus reducing the national freshwater supply. This in turn affects nature, biodiversity and drinking water sources. (The water transition: what is it? And 4 other questions, 2021) Another source for our drinking water is a possible alternative to using groundwater. To realise a self-sufficient drinking water system on Ameland, there is one very obvious suggestion: seawater. However, it is then necessary to remove a large part of the salt ions from the water. This process is very laborious and expensive. However, desalinating seawater is not new. In many (dry) places around the world, it is already used as a source of drinking water. One example is a large desalination plant in Saudi Arabia. At this place, 50% of the total drinking water is currently produced from seawater. This amounts to 1.9 m^3. Membrane filtration is used for this purpose. (Nijholt, 2022) In Israel too, 585 billion litres are desalinated in the same way every year, this amounts to 80% of Israel's total drinking water needs. (Nijholt, 2022) So the possibilities of membrane filtration are already there. Belgium is also testing the extraction of drinking water from seawater present in large quantities. This has been done using Closed Circuit Reverse Osmosis (CCRO) technology and Sonix ED technology. (Nijholt, 2022) In reverse osmosis, seawater is forced through a membrane by means of high pressure. The membrane is made so that only the relatively small pure water molecules can pass through. The ions then remain suspended in the filter and the purified water passes through the filter. This therefore, separates the water from the ions. (see figure 2) In doing so, under pressure of 70 bar, approximately an efficiency of 85-95% is achieved and requires a current of about 6-8 KWh/m^3. (Ultra-high recovery 3-stage seawater desalination, 2024) (see figure 3) A disadvantage of reverse osmosis is that there is a high counteracting force due to the seawater, this counteracting force is called osmosis and with seawater is about 25 bar. This high counteracting force is caused by the high salt content of 35 g/L. The 25-bar osmosis means that at least 25 bars of pressure must be applied to get any water through the membrane at all. In addition to the high pressure, the residual flow with a high ion content must be processed. This can be evaporated or processed into solids with chemicals, for example. The filters must also be cleaned, often with chemicals, to desalinate the next load of seawater. (Wageningen university & research, November 2022)

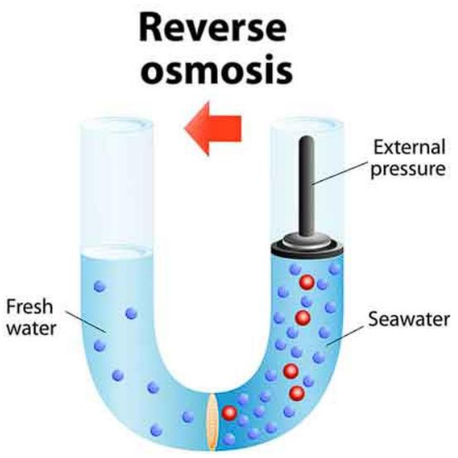


Figure 1: Schematic overview of a Reverse Osmosis system (Pure Aqua inc., 2025)

Electrodialysis and Electrodialysis Methathesis

Electrodialysis is an electrochemical process that uses the electrical charge of ions. Salt water consists of water with salts dissolved in it. When these salts dissolve in water, they are separated into two different ions. A salt always consists of one or more positively charged and one or more negatively charged particle(s). For example, when you dissolve table salt (NaCl) in water, you get a solution containing positively charged sodium ions and negatively charged chloride ions. The solution of table salt in water looks like the following:

$$NaCl\ (s) \rightarrow Na^{+}\ (aq) + Cl^{-}(aq)$$

Electrodialysis (ED)

In electrodialysis, a continuous stream of salt water is energised with a negatively charged electrode (cathode) placed at one end and a positively charged electrode (anode) at the other. The positive ions (cations) are attracted to the negatively charged cathode and the negative ions (anions) are attracted to the positively charged anode. Alternating anion-elective membranes (AEM) and cation-elective membranes (CEM) are placed between the cathode and the anode. Salt water is continuously passed between these membranes. The anion-selective membranes allow only anions to pass through and the cation-selective membranes only cations. The feed stream of salt water is then separated into two types of streams. The anions will migrate through the AEM towards the anode and then be stopped by the CEM. On the other side of the CEM is another feed stream and from it the cations migrate through the CEM towards the cathode and are then stopped by the AEM. This thus creates a current with a high concentration of ions (concentrate). The ions from the streams next to it have thus migrated to the concentrate. A stream with a low concentration of ions (diluate) is thus created in the streams next to the concentrate. After possibly several steps, this diluate then has the required salt content and is usable as drinking water.

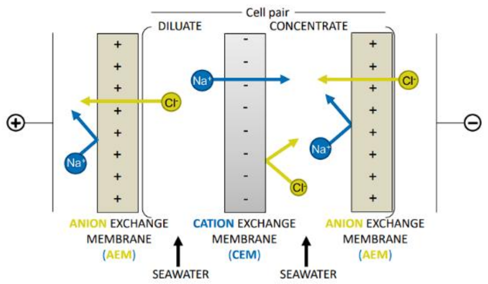


Figure 2: Schematic overview of electrodialysis desalination (Doornbusch, 2020)

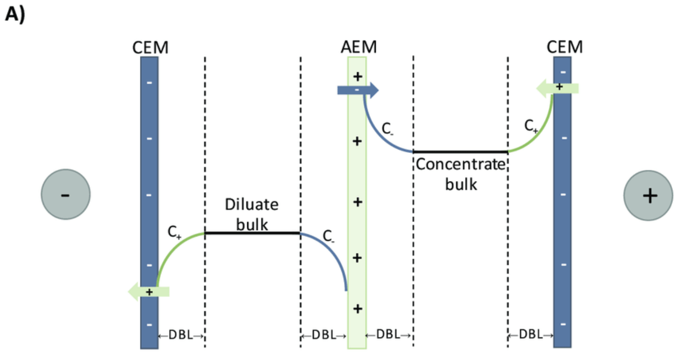


Figure 3: Schematic overview of electrodialysis system (Sciencedirect, 2020 June 15)

When there is a lot of transport between membranes, a layer with very little salt is formed on the membrane in the dilutant flow. This phenomenon is also called *concentration polarisation*. The point where the salt concentration of this layer reaches zero is called the LCD. At this point, energy consumption becomes much higher. (Doornbusch,2020)

At a higher salt concentration of the diluate stream, the LCD is lower. This also makes the degree of desalination higher. (Doornbusch, 2020)

Electrodialysis Methathesis (EDM)

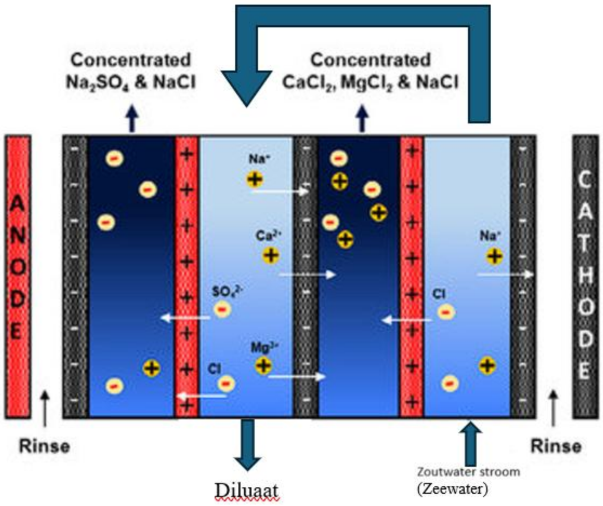


*Figure 4: Schematic over view of electrodialysis metathesis (*Prado de Nicolás, A. K.-G.-G., 2022)

EDM is a method of electrodialysis that, unlike conventional ED set-ups, does not use cation- and anion-selective membranes. EDM uses mono selective membranes: membranes that allow only a particular ion to pass through. The stream of salt water first passes two monoselective membranes: one membrane that lets only Na^+ through (mCEM) and one membrane that lets only Cl^-through (mAEM). Next to the mCEM is an AEM that passes all anions and next to the mAEM is a CEM that passes all cations. So in the stream where first almost all Na^+ ions migrated to, now all cations migrate to. And in the stream to which almost all Cl^- ions have migrated, all anions are added. So two concentrated streams are formed: one Na-type and one Cl-type with diluate streams in between. The Na-type stream contains Sodium ions and anions. The Cl-type stream contains Chloride ions and cations. These four streams are repeated several times side by side in an EDM stack.

The usefulness of these two concentrated streams is to prevent the formation of 2:2 salts and promote the formation of 2:1 salts and 1:2 salts. 2:2 salts are salts that have the ratio of cations: anions 2:2 such as: $CaSO_4$and $CaCO_3$. Both ions have a charge of 2 (negative and positive). So 1:2 salts are salts such as: Na_2SO_4. 2:1 salts are salts such as: $CaCl_2$. (Li, 2022)

1:2 and 2:1 salts are more soluble in water than 2:2 salts. So with more 1:2 and 2:1 salts, more salt can be dissolved in water and hence the maximum salt concentration of the concentrates is higher. Thus, less water is needed for the concentrate.

Advantages and disadvantages

Standard Electrodialysis:

The difference between ED and EDM is that EDM uses two different streams of concentrate. The advantage of these two different streams of concentrate is that there is less 'scaling' which is a problem in ED. Scaling is the precipitation of poorly soluble salts. These are the 2:2 salts mentioned in sub-question one. Because the concentrates in EDM contain more 1:2 and 2:1 salts and fewer 2:2 salts than in ED, the maximum salt concentration of the concentrates is higher. Thus, less water is needed for the concentrate and hence more water is needed for the diluate. The water extraction in EDM is thus higher than in ED.

Reverse Osmosis:

Another method widely used for desalinating seawater is Reverse Osmosis (RO). In RO, the salt water is forced through a water-permeable membrane under high pressure. The ions in the water are stopped by the membrane and you are thus left with potable water. RO also involves the problem of scaling. In RO plants, chemical antiscalants are added to counteract scaling. However, these chemicals are harmful to the environment. By preventing scaling in the manner of EDM, there is no need to add other chemicals. Another disadvantage of RO is that it uses high pressure. This causes mechanical wear and tear. EDM operates at atmospheric pressure and thus does not suffer from mechanical wear. (Doornbusch, 2020)

An advantage of RO is its relatively low energy consumption. When desalinating seawater, an energy consumption of 2 kWh/$m^3$is possible in modern advanced RO plants. Our results showed that to produce the potable water by EDM requires about 11.15 kWh/$m^3$for the first treatment. After a second EDM treatment, the seawater is potable according to Dutch regulations. It is expected to cost about 15 kWh/m^3in total. A disadvantage of EDM is therefore that energy consumption is relatively high. However, if this energy can be generated by, for example, solar panels, wind turbines or other sustainable ways of energy generation, it is a lesser problem.

Quality requirements for drinking water in the Netherlands.

Before we started the research, it was important to know the quality requirements of our drinking water. Drinking water used in the Netherlands must meet hundreds of strict standards and many controls. In few countries are these requirements as high. In addition, many of the 10 drinking water companies in the Netherlands apply even stricter values to ensure they stay (well) within the legal rules. 'Tap water is thus more strictly controlled than food in the Netherlands.' (Drinkwaterplatform, 2024)

All national requirements are described in the Dutch Drinking Water Decree, valid from 12 January 2023. These requirements are based on the European Drinking Water Directive. This not only addresses the parameter conditions of certain substances but also specifies how often water must be checked and when water is considered drinking water. The data relevant to this study are shown in the table below. (Drinking Water Decree, 2024) (DIRECTIVE (EU) 2020/2184 OF THE EUROPEAN PARLIAMENT AND COUNCIL. on the quality of water intended for human consumption, 2020)

Table 1

Maximum permissible values for drinking water of the ions we examined.

	European Drinking Water Directive	Dutch drinking water decree
Sodium	200 mg/l Indicator parameter	150 mg/l Aesthetic parameters
Chloride	250 mg/l Indicator parameter	150 mg/l Operating parameter
Sulphate	250 mg/l Indicator parameter	150 mg/l Aesthetic parameters
Magnesium	No limit[1]	No limit[1]
Calcium	No limit[1]	No limit[1]
Potassium	No limit	No limit

[1]If drinking water is produced by demineralisation or softening, calcium and/or magnesium salts may be added to reduce negative effects.

Besides the substances sodium, chloride and sulphate, there are also ions that have no fixed upper limit, such as magnesium and calcium. These substances are needed in certain quantities in drinking water precisely because they have positive effects on health. Calcium, for example, is good for bones. Too many of these ions, on the other hand, cause scale because the water is heated and, together with air, is converted into lime ($CaCO_3$) . Water companies are lowering the levels of magnesium and calcium in some locations to ensure consumers are less inconvenienced. However, the Dutch Drinking Water Decree does set a minimum hardness, this is measured by the amounts of Magnesium and Calcium. The lower limit is set by the drinking water decree at 5.6 dH (German degrees). The upper limit is 12.5 dH at most drinking water suppliers. Should the water produced from seawater be too hard, Magnesium and Calcium ions will have to be removed. If dH is too low these minerals should be added additionally. The water that is currently extracted on Ameland, and therefore provides part of the water consumption, contains fewer ions than the legal requirements. To ensure that the implementation of this project does not lead to a reduction in water quality on Ameland compared to the 'old' system, the aim will have to be to match and, if possible, improve these values. (Pb. Buren , 2024) (Pb. Hollum Reinwater outgoing, 2024) (For table with values see Dutch report table 5). (Pb. Buren , 2024) (Pb. Hollum Reinwater outgoing, 2024) (For table with values see Dutch report table 5)

Research questions

To what extent can desalinating seawater around Ameland through electrodialysis metathesis (EDM) provide a self-sufficient drinking water system on Ameland? In order to study this, we divided this research question into two sub questions:

1. In what concentrations are ions present in the water of the North Sea and Wadden Sea near Ameland?
2. To what extent is it possible to reduce the content of the ions studied to drinking water levels in seawater by electrodialysis?

Hypothesis

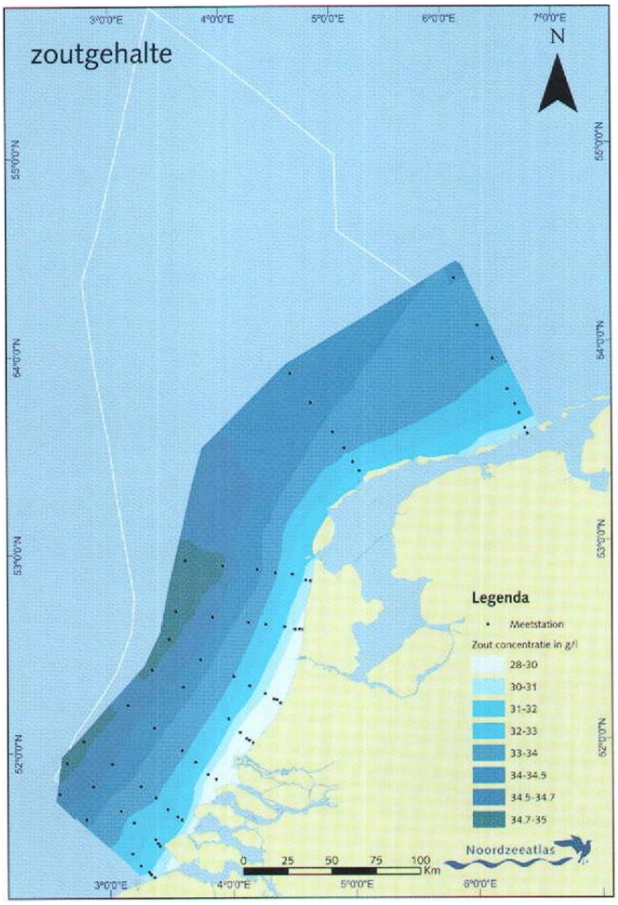


Figure 5: Map showing salt concentrations in the North Sea (Noordzee-atlas, 2004)

Sub-question 1 In what concentrations are ions present in the water of the North Sea and Wadden Sea near Ameland?

The total salt concentration of the water of the North Sea and Wadden Sea near Ameland

is expected to be about 31 g/L. This is according to data from the 2004 North Sea Atlas. From the map, you can read that the salt concentration near the Ameland coast is 31-32 g/L. As you get closer to the coast, the salt concentration decreases (Figure 2). Since the seawater used for this test was collected from the coast, it is expected that it is actually closer to 31 g/L.

Sub-question 2

After consulting with expert Kecen Li at Wetsus, it was clarified that previous experiments with the laboratory EDM stack showed that water extraction was 90%. This was for brackish water. It is expected that water extraction of around 90% is also feasible for seawater.

Material and method

subquestion 1 In what concentrations are ions present in the water of the North Sea and Wadden Sea near Ameland?

To carry out the study on the possibility of removing salt ions from seawater using EDM, it is first necessary to determine which ions are specifically present in seawater around Ameland. One possible method for this is a literature review.

It is known from the 1992 North Sea Atlas that the salinity in the North Sea along the coast of the Netherlands, Germany, Denmark and Norway is about 25 g/L. around Scotland, however, it is 35 g/L. According to this source, the salinity along the coast of

Netherlands, among others, is influenced by the flow of (fresh) river water that mixes with salty seawater along the coast. Besides the North Sea, the Wadden Sea also forms a large part of the water around Ameland. To carry out the study as realistically as possible and investigate both the North Sea and the Wadden Sea as possibilities, the choice was made to first analyse the substances in the seawater. For this purpose, one litre from the North Sea (Buren beach) and one litre from the Wadden Sea (Nes Marina) were taken to the lab at Wetsus. Using IC (*Ion Chromatography*) and ICP *(Inductively Coupled Plasma*), it is possible to examine exactly which ions are present in the seawater. After the study, this analysis will then have to be repeated to clarify the influence of electrodialysis on the seawater around Ameland.

IC and ICP are methods for detecting ions. Here, IC detects sodium and chloride. ICP detects the ions; potassium, magnesium, calcium and sulphate. As the IC and ICP equipment have a limited range, the content of ions in seawater must be adjusted accordingly. For seawater, the ion content must first drop quite a bit to fall within the range. Therefore, the seawater is first diluted a thousand times, so it falls within the range. The method describes exactly how this is done (appendix).

Subquestion 2 To what extent is it possible to decrease the content of the ions studied in seawater by electrodialysis metathesis.

Due to limited time, the choice was made to conduct the EDM experiment with North Sea water. This was chosen because the values between North Sea and Wadden Sea show no significant difference. In addition, it is expected that a possible EDM installation will be placed more easily in the North Sea than in the Wadden Sea. This is simply because the sea is deeper and does not have problems with there being too little water at low tide. But also because it is less strictly regulated. This is because the area is not included in the UNESCO world heritage list.

Before the number of ions in solution can be measured, it must first be calculated whether the expected amounts of ions are within the range of the IC and ICP machines. To calculate this, an assumption is made based on previous experiments with the same EDM stack. 90% Of ions are expected to be removed.

The calculations involve calculating whether the equipment will then be able to measure the ions. (Elaborations in Appendix 16) Calculations show that sodium and chloride will have to be diluted 1000 times. (Appendix 17) The remaining substances will have to be diluted 500 times. These calculations are also done for the sodium-type and chloride-type solutions. Here, sodium and chloride should be diluted 2000 times and potassium, magnesium, calcium and sulphate 500 times. (Appendix 18) After checking values for the IC and ICP equipment, the EDM experiment can be performed. The water remaining after the experiment is desalinated by EDM for an hour. The liquid taken every 15 minutes has to be analysed in the lab. for this, it is diluted according to the above data. From this follows data, with this the realistic desalination percentage is calculated (full data appendix 3).

Results

Subquestion 1

To avoid measurement errors, the analysis is done in triplicate and then the mean is calculated. For the exact results of IC and ICP, see annex 1. The average values are incorporated in the following table. The calculations of these can be found in the appendix (Annex 6). The results can be seen in appendix 14.

So these data are calculated on seawater that has first been diluted 1000 times. to calculate the data for actual seawater, the numbers are multiplied by 1000. The notation is then in g/l. (Annex 15)

Then the values are converted from mg/l to mol/l for the calculations. This is done according to the data for substances with their corresponding masses (g/mol) (Annex 7).

Quantity of ions in North Sea water in mol/l

	After	K	Mg	Ca	Cl	SO4
1.	0,413	0,011	0,045	0,009	0,480	0,023
2.	0,412	0,011	0,045	0,009	0,468	0,023
3.	0,420	0,011	0,046	0,009	0,485	0,023
Average	0,415	0,011	0,045	0,009	0,478	0,023
Deviation	0,003	0,000155	0,000183	5,54E-05	0,006268	0,000132

Table 2

These calculations were also carried out using the values for the Wadden Sea. To avoid measurement errors, the analysis is performed in triplicate and then the mean is calculated. For the exact results of IC and ICP, see Annex 1.

Table 3

Amount of ions in Wadden Sea water in mol/l (calculations Annex 8+9)						
	After	K	Mg	Ca	Cl	SO4
1.	0,409	0,011	0,046	0,009	0,480	0,024
2.	0,425	0,011	0,047	0,009	0,480	0,024
3.	0,419	0,011	0,047	0,009	0,480	0,024
Average	0,418	0,011	0,047	0,009	0,480	0,024
Deviation	0,006	0,000111	0,000549	8,87E-05	0	0,000229

All the salts are neutral and the seawater should also be neutral. However, when you add up the weighted charge of all these tested ions, you do not get 0. Take row 1 for example. The charges of the ions are as follows:

$[Na] + [K] - [Cl] + 2([Mg] + [Ca] - [SO4])$ = 0,408879 + 0,010964 - 0,479508 + 2(0,046081 + 0,008908 - 0,023515) = 0,003283

That leaves 0.003283 mol. There must therefore still be negative particles in the water to arrive at a neutral charge. These negative particles can be explained by phosphate (PO_4^{3}) and nitrate (NO_3^-), which occur in small quantities in seawater. Formulas can be used to calculate the amount of moles of these particles. Annex 21 shows the values for these missing charges

Subquestion 2 To what extent is it possible to decrease the content of the ions studied in seawater by electrodialysis metathesis.

The resulting data is summarised in Table 4 and 5.

Table 4

Sodium	**Potassium**	**Magnesium**	**Calcium**	**Chloride**	**Sulphate**
97%	>99%	93%	96%	98%	74%

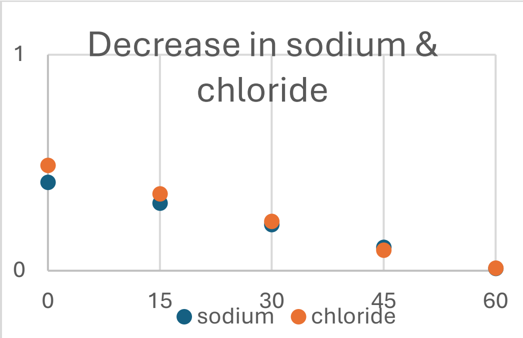
Table 5

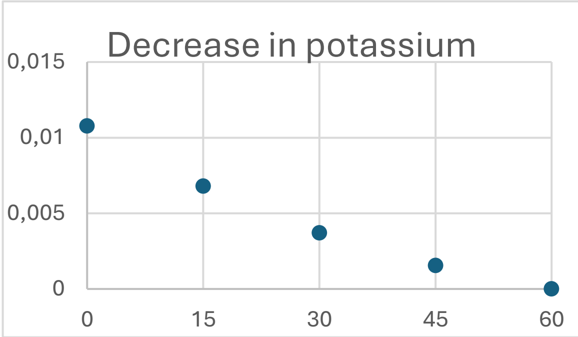
Total dissolved salt for EDM	**30.77036 g/L**
Total dissolved salt after	1.320073 g/L

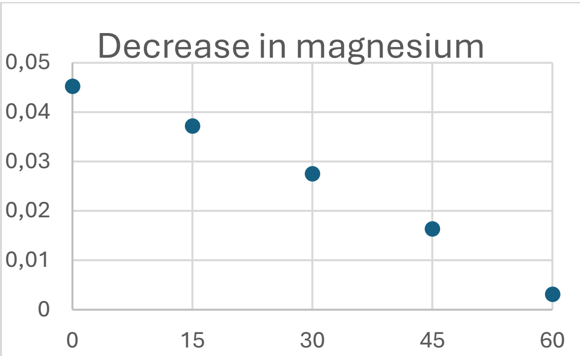
$$total\ percentage\ decrease: \left(1 - \frac{1{,}320073}{30{,}77036}\right) \times 100 = 95{,}7\%$$

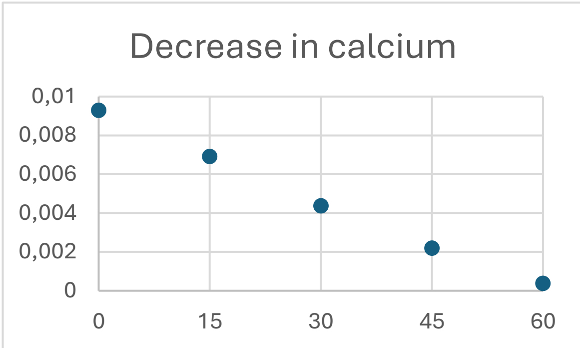
The corresponding graphs are then the following (figures 6 to 10):

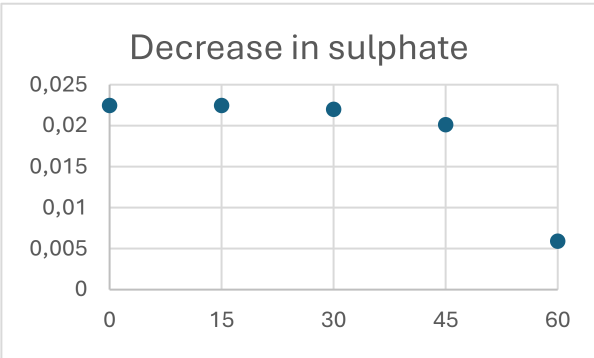
Here, the vertical axis is mol/L and the horizontal axis is time in minutes.











One-hour EDM results are (mg/L);

Table 6

Sodium	Potassium	Magnesium	Calcium	Chloride	Sulphate
240	<20	154	30,8	420	379

These values still do not meet the requirements. Therefore, the EDM treatment will have to be performed again with a lower voltage. This treatment is expected to achieve another 95.7% reduction based on previous results with the same stack. Accompanying this expected efficiency are the following data (calculations in Annex 13):

The expected results of a second-hour EDM are (mg/L);

Table 7

Sodium	Potassium	Magnesium	Calcium	Chloride	Sulphate
10,32	<0,86	6,622	1,324	18,06	16,297

These levels of ions do meet the requirements for drinking water in the Netherlands. After a second treatment with EDM, the North Sea water is therefore expected to be suitable for use as drinking water. Besides the flow of North Sea water being desalinated, there are also two streams where ions from the desalinated water end up, the Sodium-type and Chloride-type (the tables can be found in table 15 and 16 of our Dutch report).

The energy consumption required for this is written out in full in Annex 5. Below is the summarised version. (The calculations are in Annex 12)

After one hour, the total energy consumption is 11.51825 kWh/m3. Since another hour is needed, the total expected energy based on previous trials with the same *stack* and expert insight comes to 15 kWh/m3. This is not yet proven and is therefore an estimate.

Conclusion

In conclusion, electrodialysis metathesis is a promising way to make Ameland self-sufficient in drinking water in the future. EDM is sustainable because it does not use chemicals. It uses only electricity.

Sub-question 1: The hypothesis to sub-question 1 is not rejected because the values of ions found in the North Sea and Wadden Sea are 30.77 g/L. This number corresponds to the expected value of 31 g/L.

Sub-question 2: is rejected because our study showed that the ion content decreased by 95.7%. This is even more than the previously expected 90%.

Discussion

In our study, we only looked at the salts in seawater. However, there are many other substances in seawater such as biomass. So it is not yet known what problems, if any, can arise when natural seawater is used for EDM. More research will have to be done in the future

A possible explanation for the higher efficiency (95.7% instead of 90%) is that the *stack* is mainly used for brackish water research. This water has a salt content of 3 g/L. This is as much as 10 times lower than seawater. The lower the salinity, the higher the LCD. This can also be seen in the results of G.J. Doornbusch's research (see Figure 13).

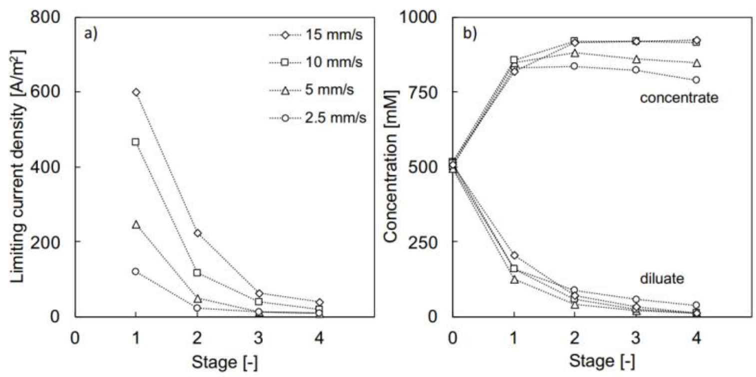


Figure 11: Graphs showing the relation between LCD and salt removal (Doornbusch, 2020)

'The decrease in LCD scales with the decrease in salt removal per stage. As a consequence, the highest current densities and highest desalination degrees are observed in the first and the second stage'. (Doornbusch, 2020)

The higher the salinity, the lower the LCD and thus the higher the degree of desalination. Since our seawater has a higher salinity than the brackish water studied earlier, the degree of desalination is also expected to be higher.

According to the 1992 North Sea Atlas of the Ministry of Transport, Public Works and Water Management/ North Sea Directorate, the salinity of the North Sea varies in summer and winter. Therefore, samples of sea water should be taken at several times during the year.

In addition, producing drinking water using the EDM method requires a large amount of energy. This study did not consider methods to generate this energy in a 'green' way. Also, it is not known who will have to pay for the investment of this energy or the energy itself. These factors are important to make a realistic plan for the future. This also requires follow-up research.

Finally, there are many other harmful substances in seawater. For example, a high percentage of PFAS is known to be present in the sea, but substances such as nitrate, pesticides and medicine residues (Drinking Water Platform, 2022) also pose a danger. In this study, no substances were investigated other than; sodium, potassium, magnesium, chloride, sulphate and calcium. A major difference with drinking water extraction from groundwater is that when using seawater, there is no metre-long natural filter present in the form of sand and other soil layers. Moreover, groundwater contains virtually no oxygen, as a result it does not contain bacteria and viruses (Drinking Water Platform, 2024). Thus, an actual implementation of seawater desalination should also consider these dangers to drinking water quality.

The electricity needed for the process currently costs a relatively large amount of money and effort. However, if this energy can be sustainably obtained by, for instance, solar panels, windmills or other methods of sustainable energy generation, the high energy costs will no longer be a problem, because cheaper energy can be switched to.

Table 8

time(min)	0	15	30	45	60
kJ	0	4,023	8,326	14,320	41,466
kWh	0	0,001	0,002	0,004	0,012
kWh/m3	0	1,117	2,313	3,978	11,518

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