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Current Status and Future Outlook of Refrigeration Systems Employed in Norwegian Vegetable Storages

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ABSTRACT

Approximately one-third of food produced is lost or wasted (FAO, 2022), and the current food system is a major user of energy, natural resources, and accounts for nearly one-third of global GHG emissions (Crippa et al., 2021). Refrigeration plays a vital role in mitigating losses of perishable food, such as vegetables, in the post-harvest storage and distribution stage. This paper describes the structure of the Norwegian vegetable and potato storages, with a particular focus on refrigeration. A survey was conducted among 290 producers, operating a total of 594 storages, representing 37% of the stored volume of vegetables. Only 48% of the surveyed storages employ refrigeration systems (covering 59% of the stored volume). R134a and R400-refrigerants are most common (55%), albeit a trend towards natural refrigerants are observed for newer systems. A mismatch between required and installed cooling capacity was observed for the surveyed storages. Knowledge on best practice has been shared with stakeholders.

Keywords: vegetable storage, refrigerated warehouses, refrigerants, food loss mitigation

1. INTRODUCTION

In order to cater for population growth and evolving food habits, EU estimates that world food production needs to double by 2050 (EU, 2022). At the same time, we must reduce the environmental impact of food production, including but not limited to reducing GHG emissions. Besides emissions related to production itself, food waste further increases the environmental impact. A study within the EU estimated that the global warming potential (GWP) of food waste accounts for 16% of the domestic food utilization (Scherhaufer et al., 2015). To mitigate food waste (including resources utilized during the production) refrigeration plays a vital role, especially for perishable foods such as vegetables. A traditional and effective preservation method for prolonging shelf life of vegetables is to reduce the temperature levels throughout all stages from post-harvest storage, to processing, distribution, and domestic use. However, mechanical refrigeration systems inherently carry emission sources. Refrigerant leakage, which may be as high as 15-20% annually for industrial systems (Evans, 2012) , contributes to direct emission if high-GWP refrigerants are used. Furthermore, a mismatch between refrigeration capacity and demand will in many cases lead to inefficient energy use of the system, which is an indirect emission source dependent on primary energy supply. A transition towards low-GWP refrigerants is necessary and ongoing through regulations such as the EUs F-gas directive and the Kigali Amendment to the Montreal protocol. Natural refrigerants, such as CO_2, NH_3 and hydrocarbons, are advocated by many researchers as a viable route solving emission issues related to both direct and indirect sources (Hafner and Ciconkov, 2021; Lorentzen, 1995).

2. METHODOLOGY

2.1. Survey

A survey was sent out to Norwegian producers of vegetables and potatoes in 2020 and received 290 complete responses. A total of 594 storages were operated between these producers. By comparing self-reported gross storage volumes against data from national statistic agencies, this study accounts for 64% of the total stored volume of vegetables and 28% volume of potatoes. Summarized, the study is estimated to account for 37% of the total stored volume in Norway.

Producers were surveyed on descriptive data of their storage(s) (e.g. total volume, type(s) of vegetable(s), location), refrigeration system (e.g. capacity, refrigerant, issues) and investment plans (e.g. new storages, refrigeration systems). Questions could be either answered as multiple choice or open-ended, depending on type of question. A translated example: *"Do you experience issues keeping a low and stable temperature in the storage(s)"?* with choices *"Yes"*, *"Sometimes"* and *"No"*.

2.2. Data handling and analysis

Thermal load calculations for each storage in the survey was performed based on data from the survey (storage size, storage period, vegetable type, geographical location) using a spreadsheet tool developed for this particular purpose. The tool accounts for product heat including respiration and transpiration, heat transmission through storage building envelope, heat loss by opening and closing of doors, heat from fans and defrosting of evaporators.

Handling and analysing of survey data, and thermal calculations were done in MS Excel.

3. CURRENT STATUS

3.1. Structure of storages within survey

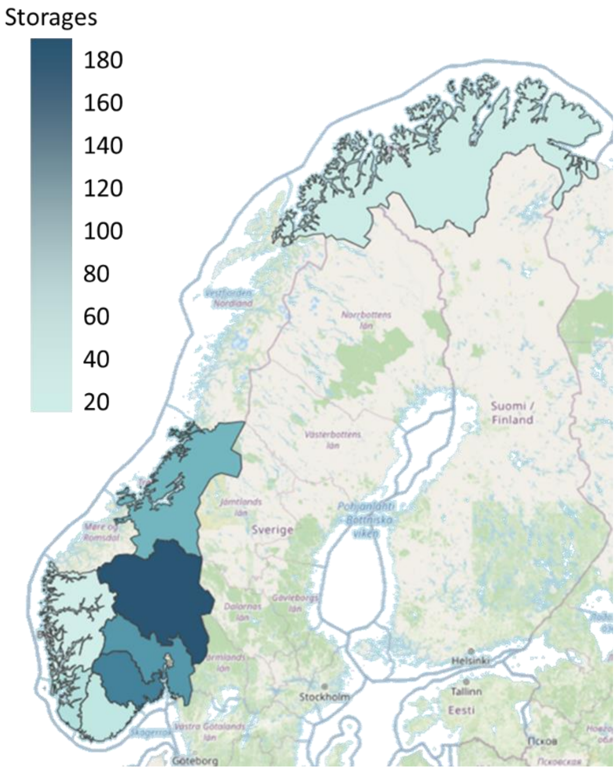


Figure 1: Choropleth map showing number of storages (within survey respondents) in each county

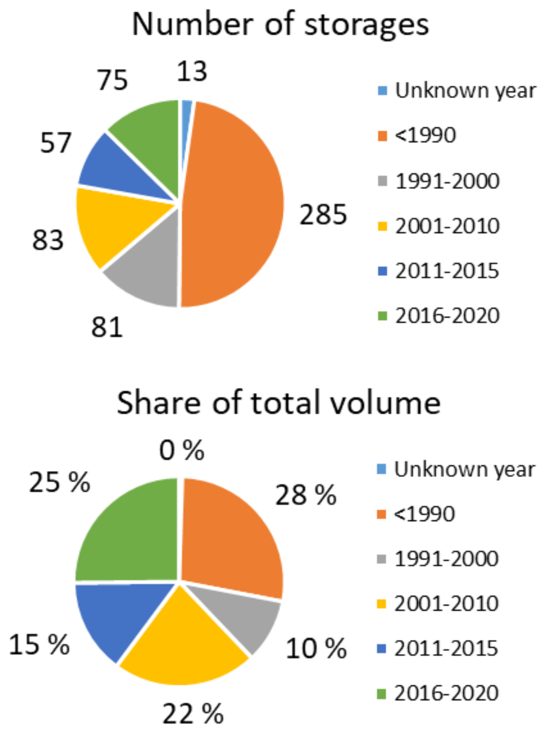


Figure 2: Top: Number of storages within survey by age (construction year). Bottom: Share of total volume by age of storage building

Figure 1 shows a choropleth map of where the storages within the survey are located by county. Only three counties are not included in the data (Nordland, Møre & Romsdal and Oslo). Almost half of the storages within the survey (48%) are 30 years or older, but accounts only for 28% of the total storage volume (see Figure 2). The reverse trend can be seen with newer storages: 22% of storages have been built since 2011 and accounts for 40% of storage volume. The average storage volume is significantly larger for newer storages, including some super-sized storages (>3000 tonnes) built the last decade. Average volume for storages built during the last 5 years are 603 tonnes, compared to 174 tonnes for storages older than 30 years.

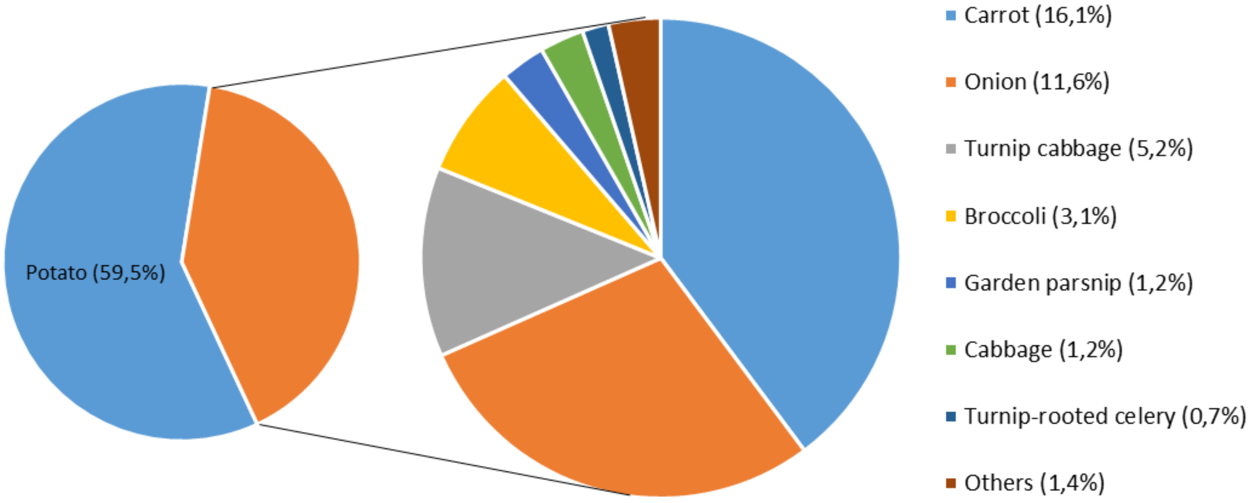


Figure 3: Representation of different types of vegetable groups within the survey

Figure 3 shows the representation of different groups of vegetable sorted by storage volume within the survey, and as shown, potatoes are by far the largest group followed by carrots and onion. Note that some storages are designed to hold more than one type of vegetable, but in the dataset, they are coded by the main vegetable group as reported by producers.

3.2. Refrigeration

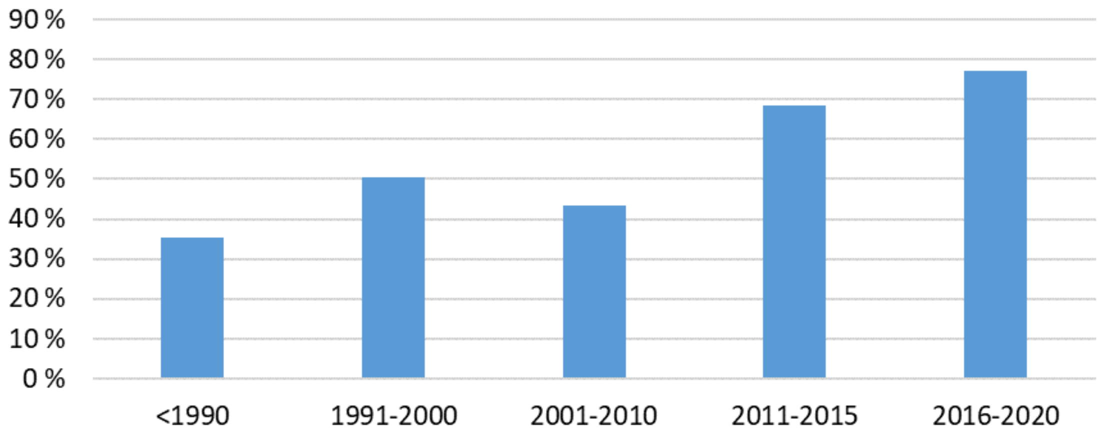


Figure 4: Share of storages with refrigeration equipment grouped by age of building

48% of the 594 storages have installed refrigeration equipment. These storages account for 59% of the total storage volume. Figure 4 shows the share of storages with refrigeration grouped by building age, revealing that the newer storages (>2011) are mostly equipped with refrigeration systems (buildings with unknown building year not shown).

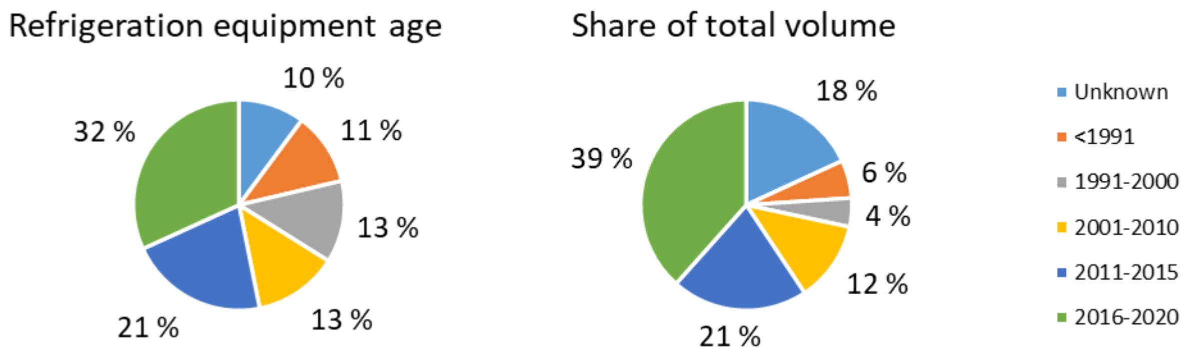


Figure 5: Data on refrigeration equipment. Left: Share of refrigeration systems grouped by age of system. Right: Share of total refrigerated storage volume grouped by age of refrigeration system

Furthermore, Figure 5 shows that the newer refrigeration systems hold a larger share of the total refrigerated storage volume. This indicates that newer storages tend to be both larger and equipped with refrigeration systems.

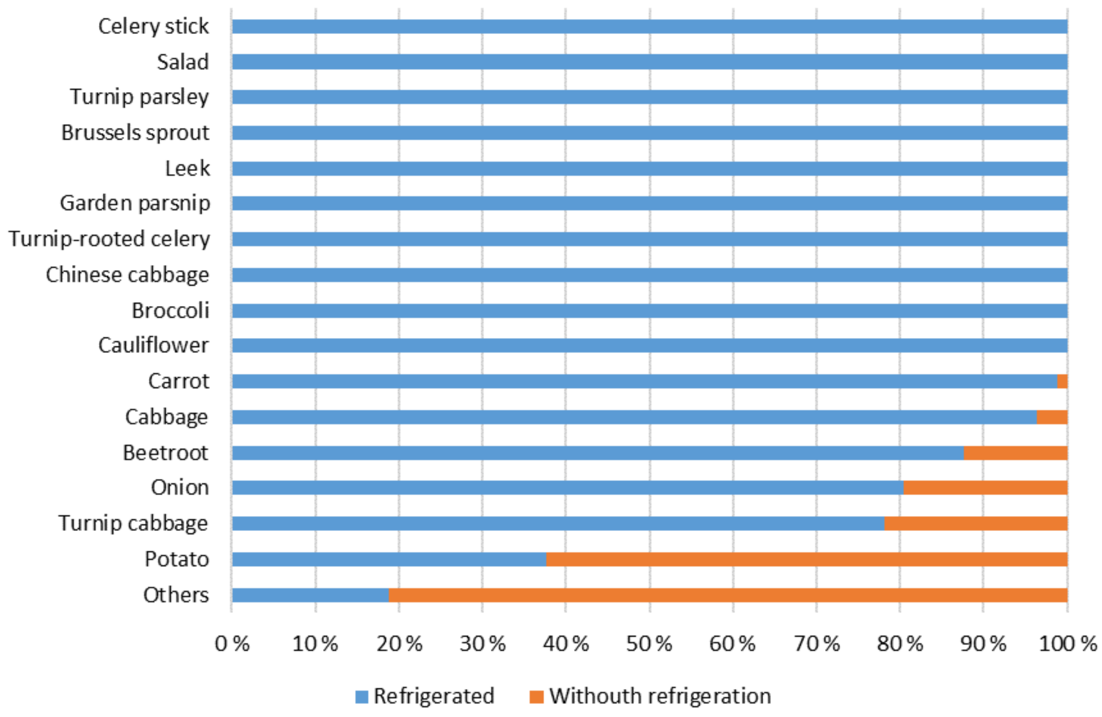


Figure 6: Share of storage volume that is refrigerated, grouped by type of vegetable

As can be seen in Figure 6, it is mainly storages for potato, turnip cabbage and onions that are operating without refrigeration. Part of the reason why potato storages are non-refrigerated is that they require higher storage temperatures (4-10 °C) and many of the storages being geographically located in cold-climate areas. However, communication with the producers showed that there is an increasing interest in refrigeration equipment due to warmer winters. When asked if there were issues related to reduce and maintain storage temperature, almost 80% of storages without refrigeration reported "Yes" and "Sometimes", while for storages with refrigeration the share answering the same was 27%.

3.3. Refrigeration capacity

Utilizing the spreadsheet tool developed for the purpose, specific refrigeration demand for each storage in the survey was calculated. The following graph shows the results from these calculations, averaged for selected groups of vegetable. Note that these calculated values are only valid for the storages within the survey, as they are based on local weather data and processing parameters (harvest period, wound healing etc.).

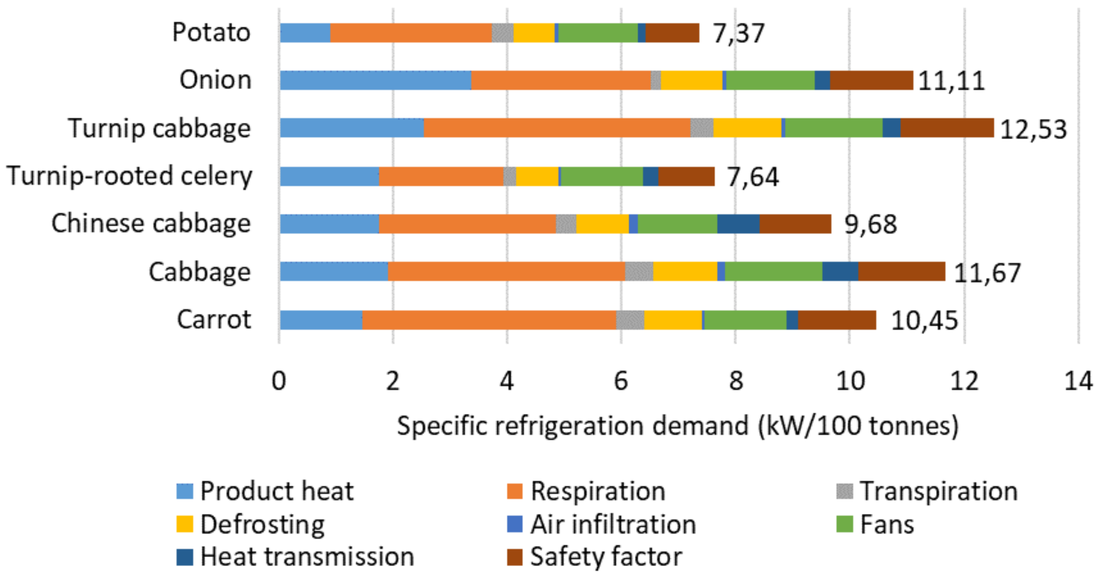


Figure 7: Calculated specific refrigeration demand for selected groups of vegetable

When asked to report installed refrigeration capacity in the survey, the authors received answers from 184 of the producers. However, obviously faulty reporting required the authors to limit the sample to contain only reasonable answers, i.e., only considering values between 0-50 kWh/100 tonnes. Reported values ranged from 0.6-675 kWh/100 tonnes of commodity.

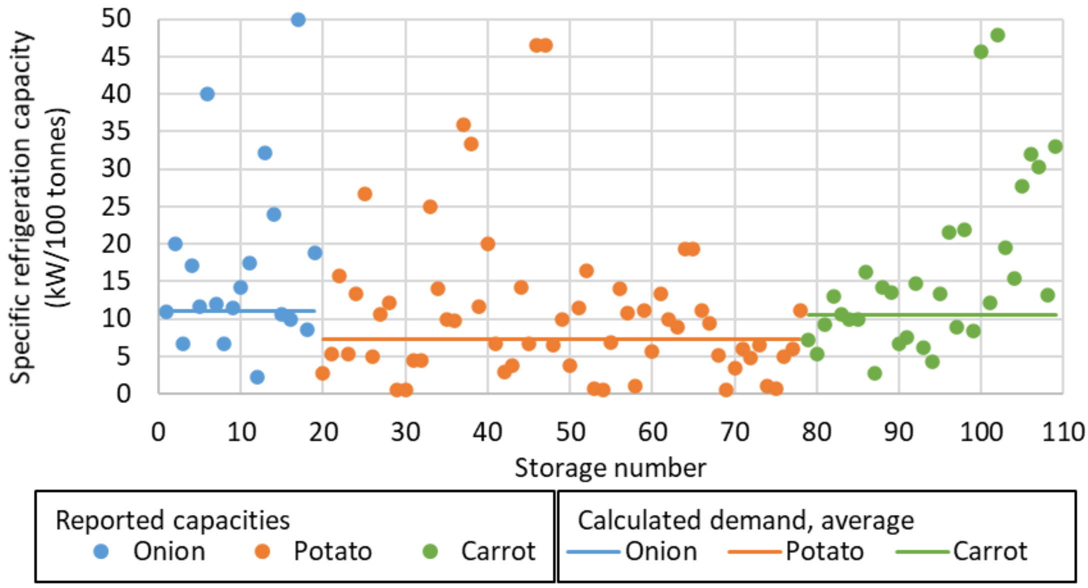


Figure 8: Specific refrigeration capacity (reported values) and calculated refrigeration demand for onion, potato and carrots

In Figure 8 the reported (valid) capacities can be seen for onion, potato and carrot storages, including the calculated refrigeration demand. The figure reveals, in many cases, a significant mismatch between capacity and demand. Some of these mismatch cases can be explained by using different tools and methods for load calculation. It is also a known practice for some vendors to apply a 'better safe than sorry'-strategy when dimensioning refrigeration systems which may explain some of the seemingly oversized systems. The drawback of this strategy is the poor performance which typically occurs at part load operation, which would constitute to most of the running hours.

3.4. Refrigerants

Storage owners were asked to report on which refrigerant was employed in the refrigeration systems, resulting in 213 (of 286) answers.

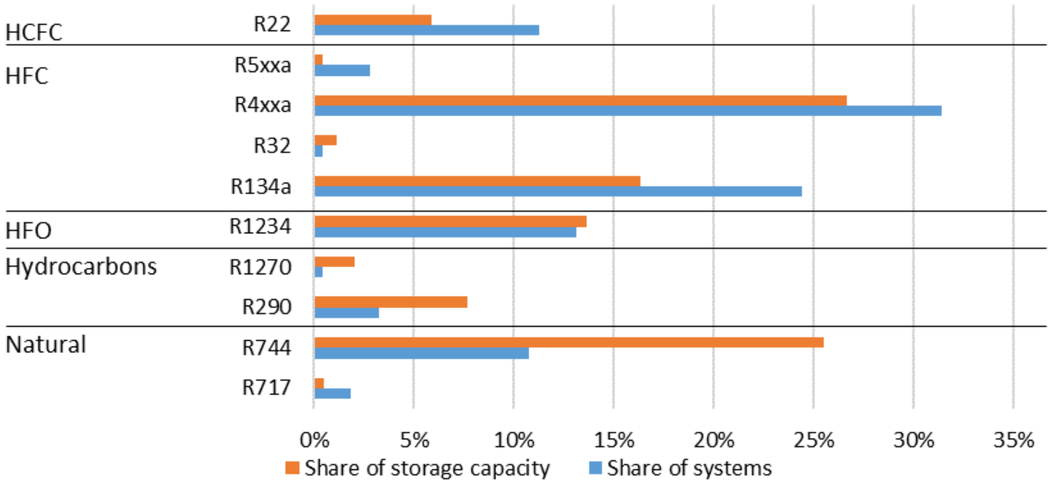


Figure 9: Share of systems (blue) and share of total storage volume (orange) within survey by type of refrigerant.

The first thing to notice is that there are still a number of systems employing the phased-out HCFC R22, which besides having a high GWP also constitutes a threath to the ozone layer (ODP > 0). As there is a ban on refilling with R22, these systems will likely be replaced with either new systems or employed with replacement refrigerants as they break down. Furthermore it is interesting to compare the share of systems vs share of total storage volume for the different refrigerants, which reveals that albeit natural refrigerants only covers ~13% of the systems, they cover 26% of the storage volume. Hydrocarbons also cover a larger share of storage compared to share of systems. This indicates that these modern and climate friendly (very low-to zero GWP) refrigerants are more likely to be found in larger storages. This is confirmed by survey data: while the average system was built in 2008, natural systems were built on average in 2015, compared to 1988 for R22 systems (see Table 1).

Table 1: Average installation year of refrigeration system, grouped by refrigerant type

Average installation year of refrigeration system	
HCFC	1988
HFC	2008
HFO	2016
Hydrocarbons	2010
Natural	2015

Systems employing HFC, and in particular refrigerants from the R4xxa-family holds the largest share, both measured in number of systems and volume. Given current regulations taking place through EUs F-gas regulation and the Kigali Amendment to the Montreal Protocol, in which many countries have committed to reduce production and consumption of HFCs, it is likely that also several of these systems will have to transition towards more climate friendly solutions, albeit within a longer time horizon. The weighted average GWP for systems in this survey was calculated to a value of 1521.

4. FUTURE OUTLOOK

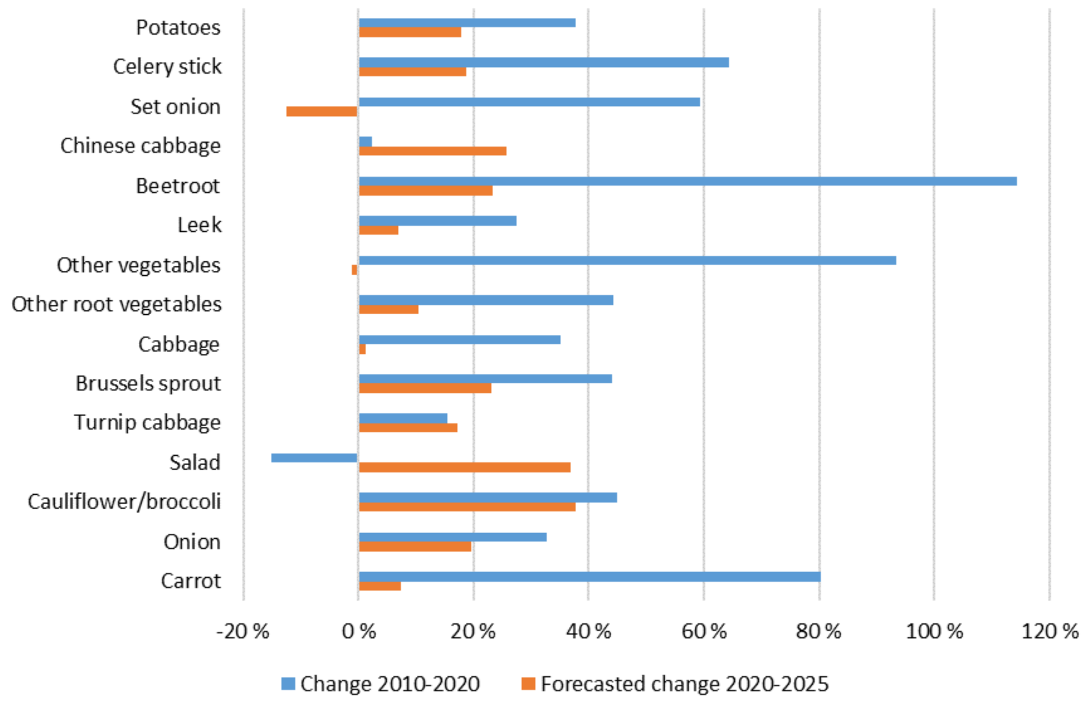


Figure 10: Relative change in supply volume by type of vegetable for producers within survey between 2010-2020, including forecasted change 2020-2025

Figure 10 shows that the relative change in supply (volume) has increased for most vegetable groups from 2010 to 2020, with the exception of salad, with an average growth of 45% across vegetable groups. Furthermore, when asked to forecast numbers in 2025, all groups of vegetable are set to grow (except 'other vegetables' and 'set onion'). Across all vegetable groups, a growth of 15% is forecasted by producers within survey by 2025 (compared to 2020 numbers).

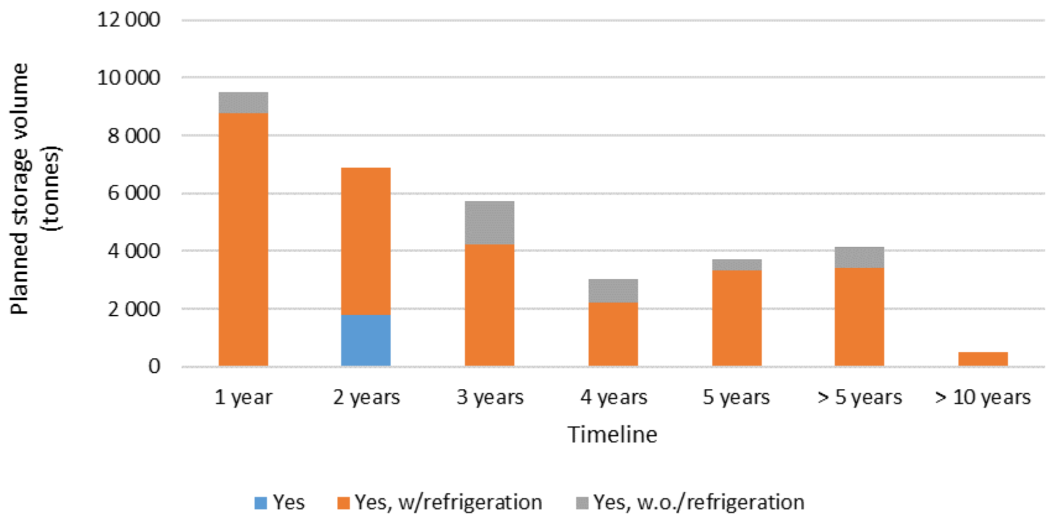


Figure 11: Investment plans in new storages for the next 10+ years amongst producers within the survey, grouped by planned building horizon

Producers were asked to report on plans for building new storages, whereof 206 of the 279 valid respondents had no such plans. Of those planning to build new storages, a total of 33 530 tonnes storage volume are planned for the next 10+ years as can be seen in Figure 11. Of this volume, above 80% is planned to be refrigerated. By type of vegetable, the largest share of the planned volume is held by potatoes and carrots, with 64% and 23% respectively. If we consider that the plans held by producers within the survey is representable for all of Norway, given that the survey covers 37% of the total vegetable volume, then by extrapolation we can assume that 90 600 tonnes of storage volume is planned for the next decade.

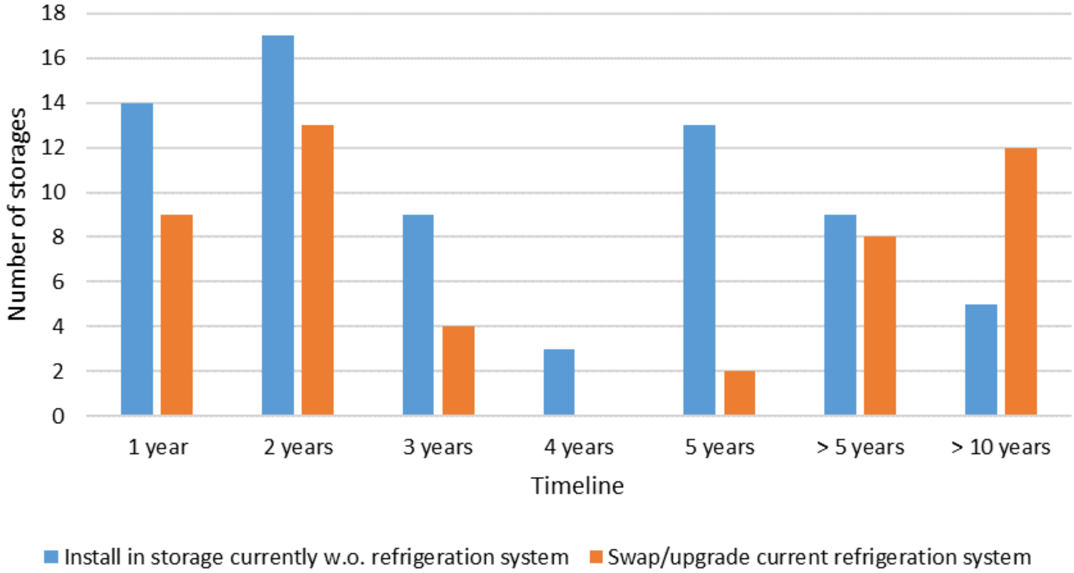
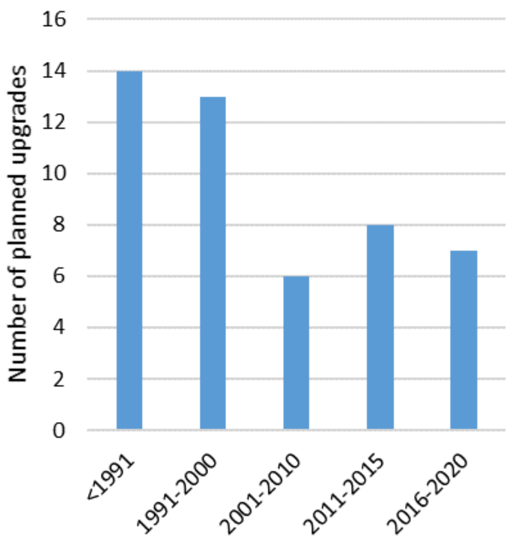


Figure 12: Investment plans for current storages: swap/upgrade or install refrigeration systems

Producers were also asked to report on plans for installing or upgrading refrigeration systems in current storages, whereof the majority reported no plans. Of those who reported plans, planned execution time can be seen in Figure 12, grouped by whether refrigeration system is currently installed. A total of 70 storages are reported to be retrofitted with refrigeration systems, whereof 60 of the storages have reported issues in reducing and maintaining temperature levels.



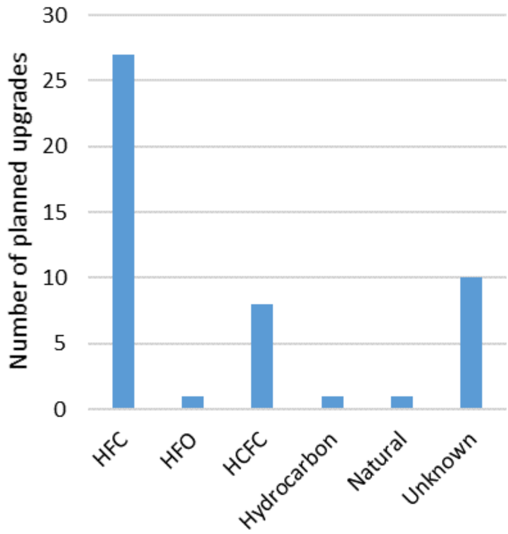


Figure 13: Left: Number of planned swaps/upgrades for storages with refrigeration systems, by installation year. Right: Number of planned swaps/upgrades for storages with refrigeration systems, by refrigerant type

Figure 13 breaks down the 48 planned swaps/upgrades for storages that currently employs a refrigeration system, by age of refrigeration system and refrigerant type. It is a sensible assumption that the systems age is a factor on whether to upgrade, which is partly observed in the leftmost graph: 27 of the 48 planned upgrades are on systems more than 20 years old. However, 15 systems aged 10 year or less is also planned for renewal. With respect to which refrigerant type is employed in current systems that are planned for renewal, systems using HFC and HCFC holds the highest share of known refrigerants within the survey, while only a total of 3 upgrades are planned for the low-GWP groups. Even though no data is available on which type of refrigerant is included in the upgrade plans, it is likely to assume that it follows the trend which can be seen in Table 1 where newer systems employ low-GWP refrigerants.

5. CONCLUSIONS

This paper has covered the status and future outlook on Norwegian vegetable storages with a special focus on refrigeration systems, based on results and findings from a national survey administered among vegetable producers. Receiving responses from 290 producers owning a total of 594 storages, the survey represents 37% of the total vegetable storage volume. The sector is planning for growth, forecasting an increase in produced and supplied volume of 66% by 2025 compared to 2010 numbers.

The survey shows that almost half of the storages (48%) are 30 years or older, while 22% are built within the last 10 years. However, with respect to share of total storage volume, 40% is held in storages newer than 10 years, while 28% is covered by storages 30 years or older. Evidently, structure of the storages has gone from many and small to fewer, but larger. Amongst producers within the survey, 74 new storages are planned to be built within the next 10 years with a total storage volume of 33 530 tonnes. By extrapolation, we can assume that 90 600 tonnes of storage volume is planned for the whole sector.

Only 48% of the storages within the survey employs refrigeration systems, covering 59% of the total storage volume. Newer storages tend more often to employ refrigeration systems compared to older storages, with approximately two-thirds of storages built the last decade (>2011) employing such systems. In addition, by comparing share of systems vs storage volume by age of refrigeration system, it could be observed that the newer systems hold a larger share of vegetable volume. Almost one-third of the refrigeration systems in the survey was installed in the last 5 years (>2016). With respect to type of vegetable, potato storages are the only group of storages where the fraction of non-refrigerated storages is dominant. Of the non-refrigerated storages, 70 are planned to be retrofitted with refrigeration systems within the next 10 years. Additionally, 48 of current refrigeration systems are to be renewed within the same timeline. Of the latter group, most of the systems are more than 20 years old.

Several observations and possible interpretations regarding refrigeration capacity were made. Firstly, out of the 279 producers only 184 were able to report capacity of their systems. After reviewing the responses, the sample had to be further reduced by the authors to contain only 'reasonable' answers. This in itself can be interpreted as a lack of knowledge on the refrigeration topic amongst producers. Furthermore, comparing the reported capacities against the refrigeration demands as calculated by the authors, a significant mismatch was observed in many cases. A possible interpretation for the seemingly oversized systems is that a 'better safe than sorry'-strategy has been implemented, with the possible drawback of poor performance at part load operation. Whatever the reasons, the large variation indicates that knowledge on best practice should be established and communicated to producers/stakeholders.

A positive trend was observed in use of refrigerants, were newer systems employed climate friendly, low-GWP fluids – in particular natural refrigerants such as CO_2, NH_3 and hydrocarbons (mainly propane). For example, CO_2 is only employed in 11% of the systems, but covers over 25% of the refrigerated storage volume. There are however also several systems employing the phased-out HCFC R22, which means there is a ban on refilling these systems. Of the 48 current refrigeration systems that are reported to be renewed, 8 out these are currently employing R22, and given the old average age of these systems more are likely to be renewed within the following years given in order to abide with regulations. Refrigerants in the HFC category holds the largest share of systems within the survey but are also apt to be renewed within the following years, going by both regulations and findings from this survey.

Even though no data was collected on food waste in the survey, unpublished numbers indicates that as much as 15-30% (dependent on vegetable type) goes to waste during storage annually. Almost half of the storages within this survey are older than 30 years, and almost half are non-refrigerated – meanwhile climate changes are increasing the average global temperature. To reduce food waste and ensure a sustainable production of vegetables in the coming years, stakeholders within this sector must employ readily available technology for maintaining optimized storage conditions – namely refrigeration systems using natural refrigerants.

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NOMENCLATURE

GHG	Greenhouse gases	GWP	Global warming potential

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