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TNO-report

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Eco-efficiency and nutritional aspects of different product-packaging systems: an integrated approach towards sustainability

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1. Introduction

Nutrition is essential for human life. In modern society food processing and packaging play a highly important role with respect to this. The packaging is supposed to adequately protect the product, to facilitate handling and to carry information on the content.
In modern society food will be offered in various forms and also in various packaging systems, from fresh unpacked food to processed and preserved food in several packaging types. Each of the packaging systems has its own properties, its consumer benefits and impact on society due to economic, environmental and performance criteria. The Association of European Producers of Steel for Packaging (APEAL) wanted to gain a more detailed insight in the sustainability performance of a vegetable processed, packed and consumed in various ways.

The aim of the study is to compare the sustainability performance of several product-packaging systems. The consumer's point of view has been chosen as the perspective of the study and therefore not only environmental and economic aspects, but also food "quality" expressed as nutritional content, are of importance. This approach with a more central position of the consumer means a more society supported approach.

The function analysed in this study is providing the daily recommended quantity of vegetables for an average Dutch household of three persons. Following the guidelines of the Dutch Voedingscentrum (Centre for Nutrition), the functional unit is set to 600 grams. This is the recommended amount of vegetables for three people between 12 and 70 years of age. Carrots have been chosen as an example of a well defined food product. Carrots are a nutritional vegetable that is available in a wide range of processing-packaging combinations.
The Netherlands have been chosen only for ease of purchasing the products to be analysed as TNO is located in The Netherlands.

Functional unit
"A household serving quantity of 600 grams carrots prepared and consumed at home."

The carrots used in this study are carrots that are cultivated in open fields in The Netherlands and abroad. They are either sold as fresh products (bunched and peeled carrots) or as frozen or preserved ones. The fresh products are packed in plastic bags, while the frozen products are packed in plastic bags and in cartons. The preserved carrots are sold in a steel food can, a food pouch and in a Tetra Recart carton laminate (see Table 1). Although not currently on the Dutch market, the food pouch is included as a possible future packaging for preserved carrots.

Table 1 The seven packaging systems assessed in the study.

Fresh	Frozen	Preserved
Plastic bag (two types)	Plastic bag and carton	Steel can, pouch, and Tetra Recart[1] carton laminate

The mass of the packed product must be related to the amount of vegetables in the functional unit. The amount of product to be bought is higher than the 600 grams of the functional unit as the product losses have to be compensated for.

During the consumption stage the consumer prepares the carrots for a hot meal. The products bought are stored for a variable period of time before consumption. The actual preparation, including cooking or heating, depends on the nature of the product, fresh, frozen or preserved.

The products analysed with regard to eco-efficiency were bought in a large Dutch 'AH' supermarket. It appeared that not all of the packaging systems contained carrots as a single product available in the supermarket. This was the case for frozen products and for the Tetra Recart carton laminate. The frozen carrots are sold in combination with peas; in the Tetra Recart packaging they are sold in a vegetable mix. For the environmental and economic assessments, it was assumed that the packaging only contained carrots. For the nutritional analysis only the carrots were used. The nutritional analysis can only be indicative in case several vegetables are packed together in a sauce because of the potential risk of transfer of nutrients between products. This is the reason why we did not analyse the nutritional values of the carrots in the Tetra Recart carton. This is not the case for frozen food for which similar transfers do not exist.

[1] Tetra Recart™ is the world's first retortable food carton. The Tetra Recart is composed of a six-layer laminate structure and offers a new packaging option for prepared foods such as vegetables.

2. Environmental impact

To assess the environmental impact of the analysed packed food systems, the CML-2 impact assessment method[1] has been used.

When comparing the environmental impact of the seven food-packaging combinations for the Dutch non-imported products (see Figure 1), it appears that preserved carrots in the steel food can have an average impact except for the photochemical ozone creation potential (POCP), for which the impact is relatively high. The fresh peeled carrots show relatively low values for global warming potential (GWP) and POCP. The bunched carrots perform a little less well. The frozen products show relatively high impacts for all categories except for terrestrial ecotoxicity potential (TETP) and POCP, for which the impact is average. Finally, the Tetra Recart packaging performs on average for all categories, but for human toxicity potential (HTP) it shows an above average value.

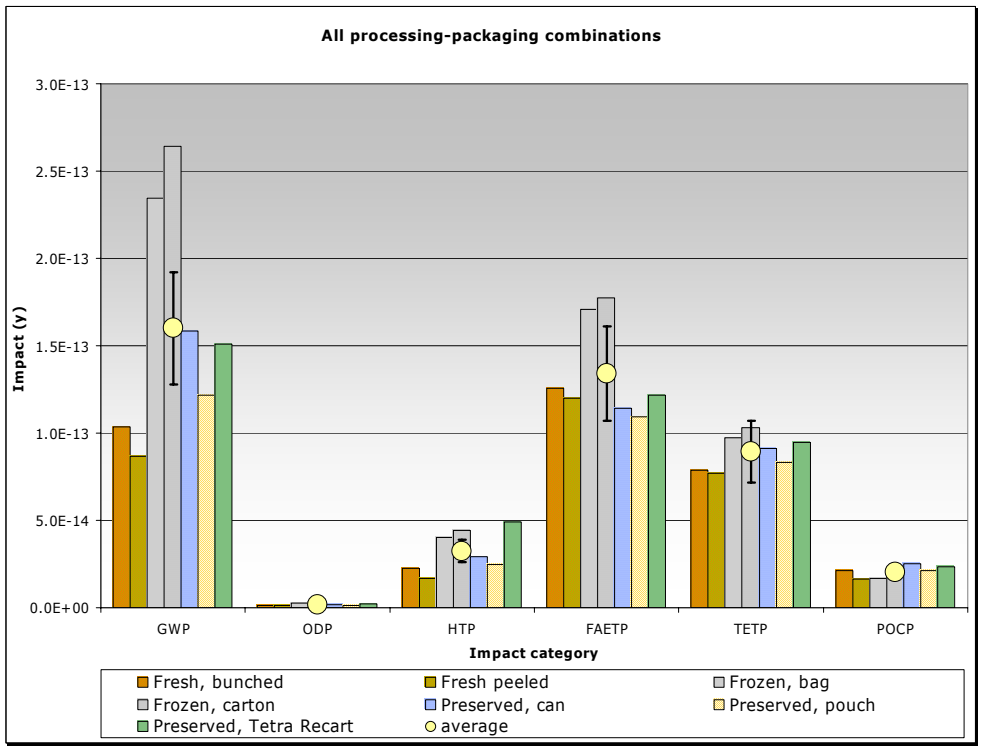

Figure 1 *The normalised environmental impact of the consumption of 0.6 kg carrots for the current ratio of landfill (22%) and municipal solid waste incineration, MSWI (78%). The average value for an impact category is shown with a plus and minus 20% bar.*

[1] The CML-2 method is an environmental impact assessment method developed by the Institute of Environmental Sciences (CML) of the Leiden University (NL).

The main contributing stages to the environmental impact are those that contribute on average 20% or more to the overall environmental impact. For both types of fresh carrots these main contributing stages (see Table 2) are the carrots cultivation and transportation. For both types of frozen carrots, the storage at the distribution centre and retailer becomes of importance. For the frozen carrots in a bag, also the consumption stage is of (relative) importance (storage and preparation).

For preserved carrots there is no impact of the storage anymore. The cultivation of carrots and their transportation are the most contributing life cycle stages in general (see Table 2). The impact of the steel food can itself is greatly reduced by the bonus of steel recycling. This recycling of steel avoids the environmental impact of virgin steel production.

Table 2 The life cycle stages mainly contributing to the total environmental impact of a product-packaging system. For these life cycle stages the main environmental impacts are shown between brackets.

System		Most contributing life cycle stages	
Fresh	Bunched	♦ Cultivation	(FAETP, TETP)
		♦ Transportation	(GWP, HTP, ODP, POCP)
	Peeled	♦ Cultivation	(FAETP, TETP)
		♦ Transportation	(GWP, HTP, ODP, POCP)
Frozen	Bag	♦ Distri. & retail	(GWP, ODP, HTP, FAETP)
		♦ Consumption	(GWP, ODP, HTP)
		♦ Transportation	(HTP, ODP, POCP)
	Carton	♦ Distri. & retail	(GWP, ODP, HTP, FAETP)
		♦ Transportation	(HTP, ODP, POCP
Preserved	Steel food can	♦ Cultivation	(FAETP, TETP)
		♦ Packaging	(GWP, ODP, HTP, POCP)
		♦ Transportation	(GWP, ODP, HTP, POCP)
	Food pouch	♦ Cultivation	(FAETP, TETP)
		♦ Transportation	(GWP, ODP, HTP, POCP)
	Tetra Recart	♦ Packaging	(GWP, ODP, HTP)
		♦ Transportation	(GWP, ODP, HTP, POCP)

FAETP, freshwater aquatic ecotoxicity; TETP, terrestrial ecotoxicity; GWP, global warming; HTP, human toxicity; ODP, ozone depletion; POCP, photochemical ozone creation.

The main impacts of the cultivation of carrots are the fresh water ecotoxicity and terrestrial ecotoxicity. These impacts are caused by the use of fertilizers and the use of crop protection substances.

Transportation is a dominant stage for all studied systems. Especially the transportation by the consumer is shown to be of importance. In general, transportation does contribute to a large extent to global warming, human toxicity, ozone depletion and photochemical ozone creation.

Three items that appeared to be of importance to assess the environmental impact of the product-packaging systems and for which alternative background data were available became the subject of sensitivity analyses.

For the steel food can, the sensitivity analysed is the LCI data set used for the steel production process. Using the IISI (International Iron and Steel Institute) data for steel for packaging, instead of the BUWAL 250 data, that were used for the base assessment, shows only small variations in the environmental profile.

For fresh and frozen products, the electricity consumption of a fridge and freezer at home is a key parameter. Alternative data for these have been used in a sensitivity analysis. This results only in minor differences in the environmental profile of the total life cycle of fresh and frozen products.
The amount of food losses is under discussion. Using higher food losses for all, but especially for the fresh products, shows for the latter an increase of the environmental impact up to 15%. For the other products the increase is smaller.

3. Economical impact

An analysis of the economic costs including all costs incurred to get a portion (600 gr.) of cooked carrots ready for eating from the selected packaging systems was made. These costs include the retail price, costs of transportation, storage, preparation & cooking, etc. The costs for the product itself was the price at the supermarket, the other costs are calculated from average consumer prices for car use, use of electricity and gas, drinking water and the average Dutch costs for waste treatment.

Preserved carrots sold in a steel food can have below average economic costs as can be seen in Figure 2. From this figure the dominance of the retail price is very clear. The carrots sold in Tetra Recart clearly have the highest price. The price of carrots sold in pouch is assumed to be equal to that of carrots sold in Tetra Recart.

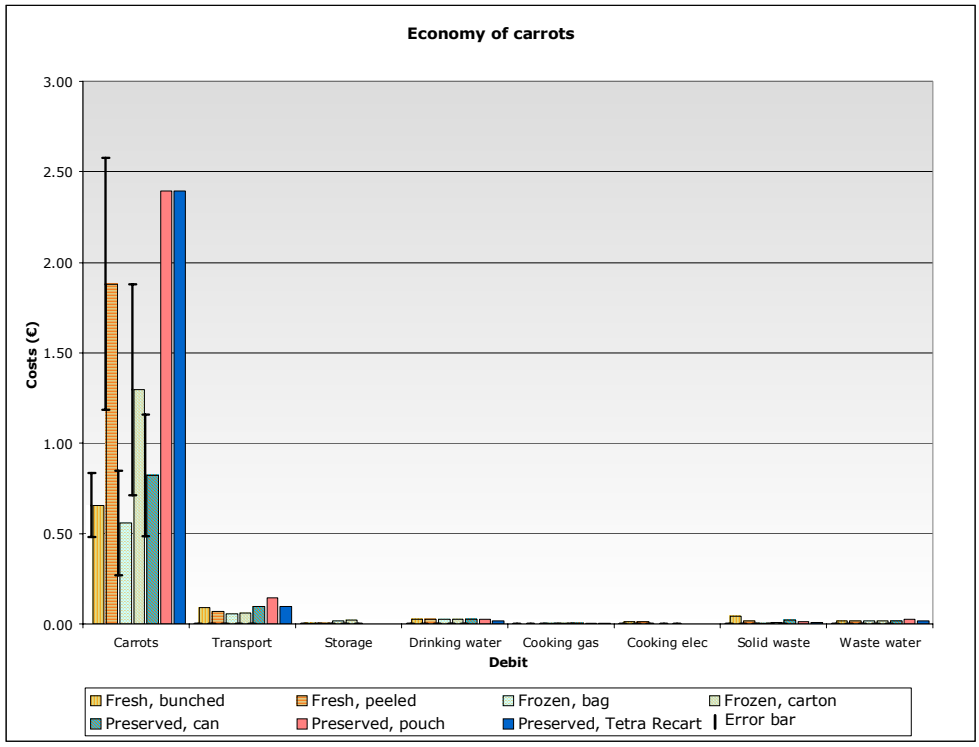

Figure 2 Composition of consumer costs for the alternatives. The error bar gives the spread in plus or minus of the standard deviation in the costs of the product itself.

What is clear moreover is that there is a large spread in product prices. This large spread indicates that not all price differences between the different products are of significance. Due to this spread the fresh bunched carrots, the frozen carrots in a bag, and the canned carrots do not have a significant price difference.

4. Eco-efficiency

4.1 Eco-efficiency of Dutch products

To be able to draw the eco-efficiency diagram both the economic and the environmental axis have to be expressed in a single unit. For the economic axis this is not an issue since all costs are given in euros. The environmental impact however is described in several equivalents like, CO_2-equivalents for global warming and 1,4 DCB-equivalents for toxicity[1].

To aggregate the environmental impact to a single indicator the use of shadow prices is one of the approaches used. Shadow prices are based on the costs needed to abate the impact of each single environmental impact, e.g. it costs € 0.05 to reduce 1 kg CO_2-equivalent using the most expensive Best Available Technique (BAT) to achieve the policy goal. By multiplying the value of each category with its shadow price the total shadow costs can be found. The use of shadow prices is a relatively objective way to aggregate the environmental impact to a single unit.

Table 3 shows that the average shadow costs are approximately 1/25th of that of the average consumer costs. Analysis of the contribution of each impact category shows that the global warming potential (GWP) is responsible for circa 60% of the total shadow costs, while the human toxicity potential (HTP) has a contribution of around 35%.

Table 3 The shadow costs of the product-packaging systems compared to their economic costs for 600 gr. carrots cooked, ready to eat.

System	Shadow costs (€)	Costs (€)
Fresh, bunched	0.042	0.85
Fresh, peeled	0.034	2.02
Frozen, bag	0.087	0.69
Frozen, carton	0.096	1.43
Food can	0.060	0.99
Pouch	0.048	2.45
Tetra Recart	0.072	2.38
Average	**0.063**	**1.54**

The canned carrots have average shadow costs (see Figure 3). The least performing system, regarding the environmental impact, is frozen carrots packed in a carton. It has shadow costs of over 1.5 times the average. It is however a relatively cheap product to use by the consumer.

[1] 1,4-DCB stands for 1,4-dichlorobenzene. It is widely used as a moth killer and in deodorizers. It is used in the CML2 method as a reference substance to express the human toxicity and the ecotoxicity.

The carrots sold in a food can, the fresh peeled carrots and the frozen carrots sold in a bag have a comparable, and slightly above average eco-efficiency (see Figure 3). They are all positioned slightly above the diagonal in Figure 3. The fresh bunched carrots perform, due to their scores below average costs and below average environmental impact, the best. The least performing alternatives are the frozen carrots sold in a carton, the carrots in a food pouch and the carrots sold in a Tetra Recart carton laminate.

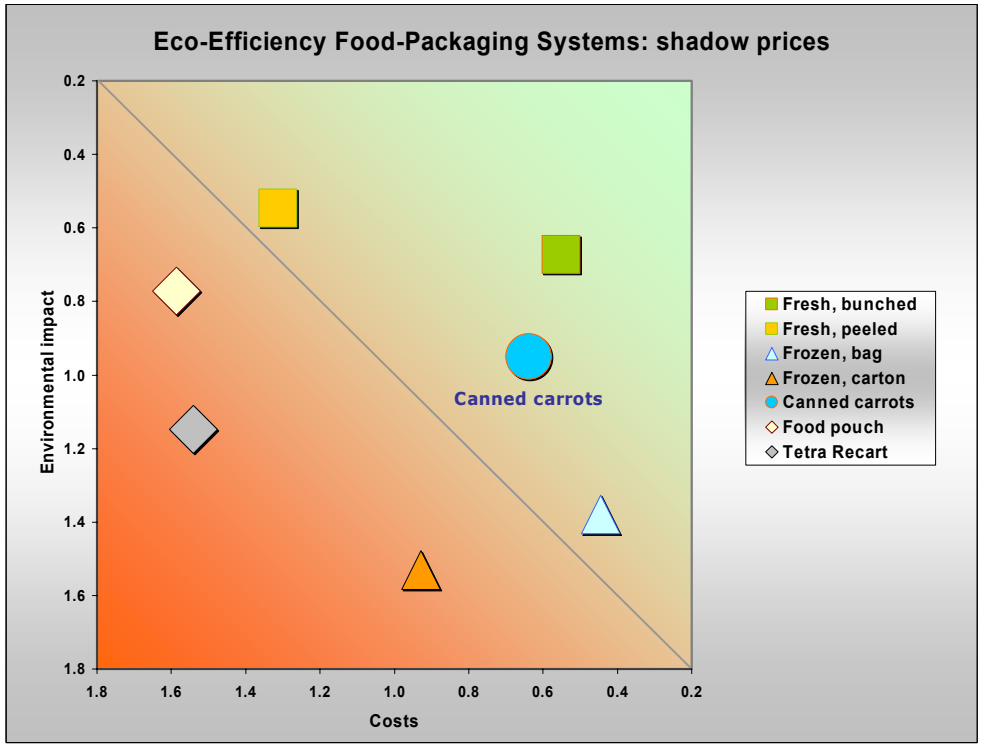

Figure 3 *Eco-efficiency of Dutch products using the shadow prices for each impact category. Both the axes are scaled around the average impact (=1).*

The use of other methods to aggregate the environmental impact into a single value shows no strong changes in the eco-efficiency diagram.

4.2 Eco-efficiency of Dutch market products

As the Dutch market is an open market for the considered food-packaging systems an eco-efficiency analysis was also made including the import of packed carrots. This is indeed the only real situation the consumer is confronted with all year round. Placing the consumer central and having as a consequence a more society supported approach pushes towards this second eco-efficiency approach.

This includes imported fresh carrots originate from France, Italy and Spain[1]. It has been assumed that for these fresh products the market shares are respectively 20, 7.5 and 7.5% of the total market. For frozen and preserved products it is likely that they originate to a lesser extent from abroad as these products can be stored for a much longer period. This reduces the needs for imports outside the Dutch cultivation season. Foreign products are, however, certainly present on the Dutch market. It has been assumed that frozen and preserved Dutch products make up 90% of the market, while the remaining 10% are imported from France. It has been assumed that the imported products do not differ in price.

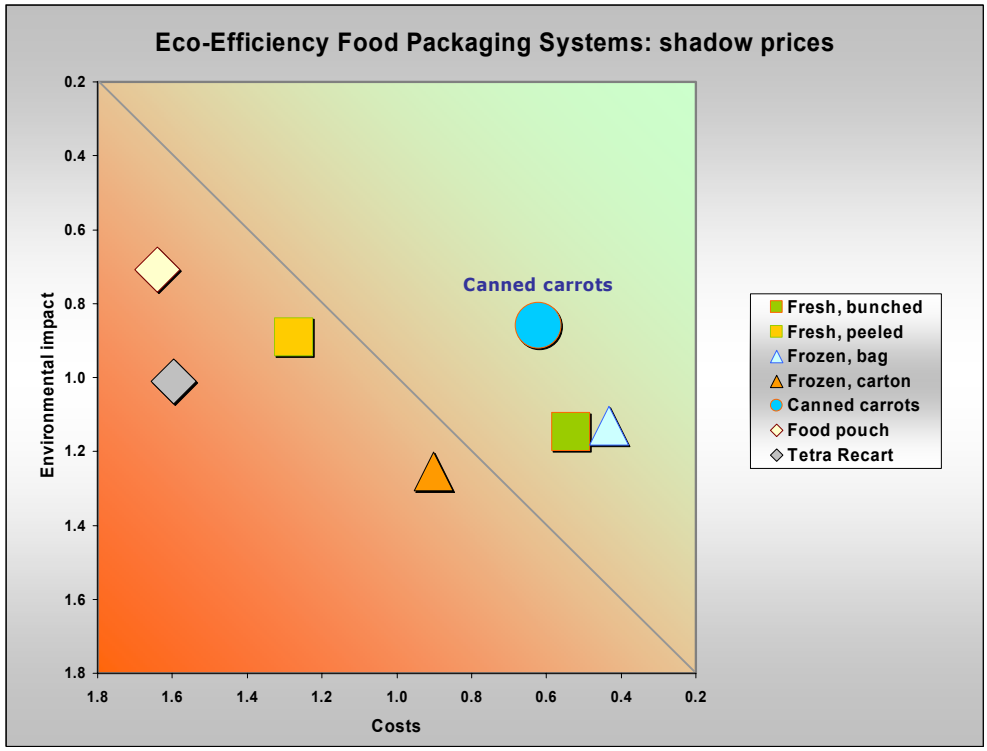

Figure 4 *Eco-efficiency of products on the Dutch market using the shadow prices for each impact category. Both the axes are scaled around the average impact (=1).*

The import of carrots form abroad leads to an increased environmental impact due to the increased need for transport. The fresh bunched carrots, for instance, show a doubling of the shadow costs (compare Table 3 with Table 4).

[1] Langfruit Producten, 2004, Bospeen. http://www.langfruit.nl/proddb/products.asp?action=groupby&productgroup=Knolgroenten&product=Bospeen

Table 4 Environmental results, expressed as shadow costs, for products on the Dutch markets.

System	Shadow costs (€)
Fresh, bunched	0.09
Fresh, peeled	0.07
Frozen, bag	0.09
Frozen, carton	0.10
Canned carrots	0.07
Pouch	0.06
Tetra Recart	0.08
Average	**0.08**

Though the environmental impact of all the alternatives has increased, the relative differences in-between have decreased. Thus in Figure 4 the alternatives are less spread over the environmental axis and lie, consequently, closer together compared to the positions in Figure 3. The relative differences in eco-efficiency of the products thus also decrease.

The canned carrots system now has the best eco-efficiency as the need for climate controlled import of fresh carrots has decreased the performance of these carrots. The canned carrots form a group of the best performing products with the fresh bunched carrots and the frozen carrots in a bag. The canned carrots obtain this position due to its low environmental impact and its low costs. In this group the canned carrots have the lowest environmental impact. The canned carrots clearly perform better than the fresh peeled carrots, the pouch and the Tetra Recart carrots.

5. Nutritional aspects

An investigation into the nutritional components of 5 of the six carrots-packaging systems has also been carried out. The carrots were bought in a shop and are packed in the different packaging systems. The different packaging concepts were: 1) fresh carrots in open plastic, 2) fresh peeled carrots in sealed plastic bag 3) frozen peas/carrots packed in carton, 4) canned carrots, 5) frozen carrots/peas in sealed plastic bag. The Tetra Recart packaging contains peas, onions, sauce and small carrot slices; due to possibility of nutrients to migrate from the carrots to the other components, and vice versa, the analyses of this food product have been excluded. For the frozen products this migration is not to be expected.

At the moment after buying (t = 0) and after a 4 days storage (t = 4) under appropriate normal household conditions the products were cooked under appropriate conditions and the nutritional parameters of the carrots were measured. The 13 parameters selected are:

- Vitamin B1,
- Vitamin B2,
- Vitamin B6,
- Folic acid,
- Vitamin C,
- Total carotenoids including alpha and beta carotene,
- Vitamin E (tocopherol) isomers,
- Moisture,
- Sugars (incl. fructose),
- Total Protein,
- Total Lipids (fat),
- Headspace atmosphere composition of cans and cartons.

The nutritional energy has been derived from the protein and the sugar contents.

Due to small sampling sizes (2 measurements at t=0 and 2 at t=4 days) and the large natural nutritional content variability in carrots, the nutritional content measured at t=0 and at t=4 is not significantly different. Therefore, an average figure has been calculated out of all four measurements.
For all the product-packaging systems the carrots show to have relatively high amounts of sugars, vitamin E and vitamin A (see Table 5).

6. Integration of the nutritional aspect into eco-efficiency

The contents of the nutrients were related to the amount of each nutrient in the USDA[1] Food Guide diet. This diet suggests amounts of food to consume from the basic food groups, subgroups, and oils to meet the recommended nutrient intakes at 12 different calorie-levels. From these amounts of foods the intake of nutrients has been calculated by the USDA. By relating the nutrient contents to this standard diet the relative contribution of for instance prepared fresh bunched carrots or canned carrots to a specific nutrient is found (see Table 5). The contributions to each nutrient can then be averaged to give a single indicator.

To treat the nutritional contents in the same way as the environmental impact and the costs (i.e. the lowest value indicates the best score), the relative contribution was subtracted from the recommended 100% amount of the nutrients in the diet. This expresses the nutritional value as a deficit.

*Table 5 Relative contribution of the nutrients to the USDA Food Guide diet (at 2000 calories) for all samples (t=0, t=4) for each of the product-packaging systems per 200 g of product. Contributions of over 20% are shown **bold**.*

Nutrient	Fresh, bunched	Fresh, peeled	Frozen, bag	Frozen, carton	Canned food
Nutritional energy	**40%**	**25%**	**27%**	**26%**	**22%**
Protein	2%	1%	2%	2%	1%
Carbohydrate (sugars)	3%	2%	2%	2%	2%
Total fat	0%	0%	0%	0%	0%
Thiamin, B1	1%	2%	4%	4%	1%
Riboflavin, B2	3%	1%	3%	3%	2%
Vitamin B6	5%	5%	5%	5%	2%
Vitamin C	5%	3%	4%	5%	0%
Vitamin E	7%	**20%**	**21%**	**20%**	16%
Vitamin A,	**104%**	**142%**	**154%**	**159%**	**149%**
Average contribution	**16.9%**	**20.1%**	**22.4%**	**22.5%**	**19.5%**
Average deficit	**83%**	**80%**	**78%**	**78%**	**81%**

The average deficit of all product-packaging systems is 80%. The differences are in general too small to be significant.

The sustainability diagram (see Figure 5) has three axes: the economic, the environmental and the nutritional axis. As in the eco-efficiency diagram low values

[1] USDA United States Department of Agriculture

mean that a system performs well. The costs are low, the environmental impact is low and the nutritional deficit is low. The best performing systems are found in the green top hand corner closest to the viewer, the least performing are in the bottom red corner.

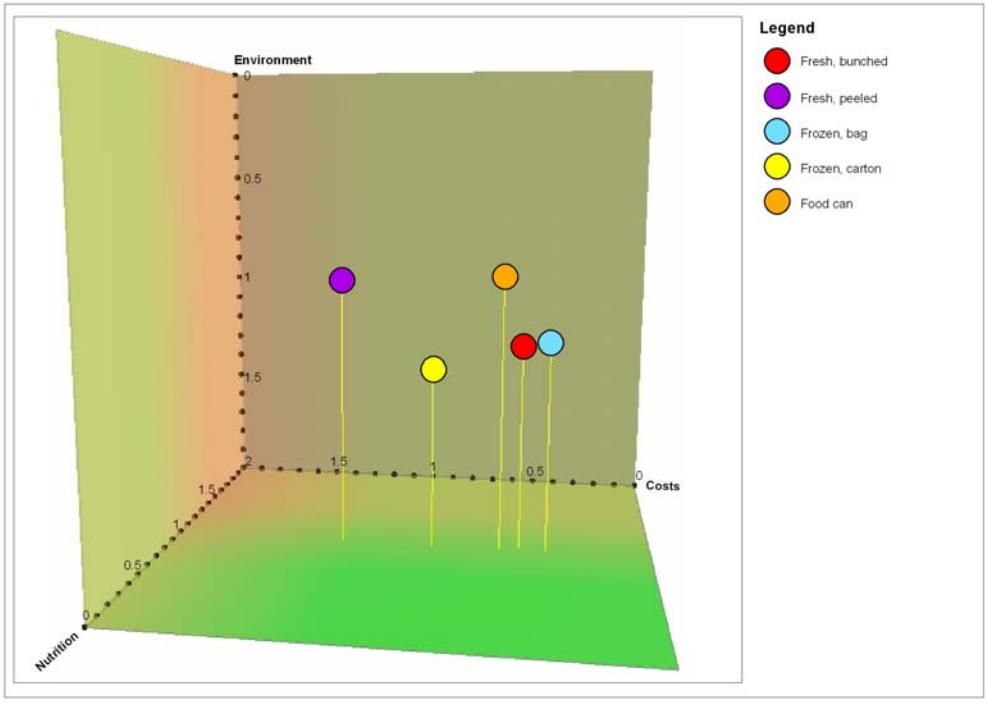

Figure 5 *The sustainability of canned food and its alternatives (Dutch market products). The sustainability is determined by the environmental performance, the economic performance and the nutritional performance.*

Due to insignificance of the most differences in the nutritional value between the several product-packaging systems the sustainability is mainly determined by the eco-efficiency. The canned carrots obtain the best performance.

7. Conclusions

Life cycle impact assessment of life cycle stages

1. The environmental profile of the cultivation of carrots is dominated by fresh water ecotoxicity (FAETP) and terrestrial ecotoxicity. FAETP is mainly caused by the emissions of crop protection substances.
2. The consumption of frozen products has a considerably higher environmental impact than that of fresh products. The preserved products show the least impact in the consumption stage.
3. The recycling of the steel food can clearly shows an environmental benefit, regarding the waste stage.
4. The import of products from abroad which is a daily reality in an open market system leads to an increased environmental impact.

Life cycle impact assessment of full life cycles

1. Transportation, especially by the consumer, is a main contributor to the impact of the two fresh products. Carrot cultivation, the consumption stage and the waste treatment are other main contributors for fresh products.
2. For frozen products, the distribution and retail stages as well as the consumption stage are of great importance. Due to the relatively high energy consumption for storage, the environmental impact is high. Transportation, carrot cultivation and the waste treatment are other important contributors for frozen products.
3. The environmental profile of canned food shows the packaging as one of the main contributors. This impact is offset by the beneficial effect of the recycling of the steel can. Transportation and agriculture are other main contributors for canned carrots.
4. Transportation and packaging itself are the main contributors to the environmental profile of the food pouch and the Tetra Recart carton laminate. The carrot cultivation and the waste treatment are other important contributors for these types of packaging.
5. The food can has, compared to the alternatives, a slightly below average environmental impact for nearly all impact categories. The photochemical ozone creation potential is the only exception.

Sensitivity analysis of the life cycle impact assessment

1. The steel can shows only small variations in its environmental profile when using the IISI data set for steel for packaging instead of the BUWAL 250 data that have been used for the base assessment.
2. The use of other data for the electricity consumption of a fridge and freezer at home shows only minor differences in the environmental profile of the total life cycle of fresh and frozen products.

3. Using higher food losses especially for the fresh products shows for them an increase in the environmental impact up to 15%. For the other products, the environmental impact due to food losses is close to 5%.

Life cycle cost assessment

1. The costs for the product itself are, with a contribution of around 80%, by far the most important cost share of the total life cycle costs;
2. Canned carrots, fresh bunched carrots and frozen carrots in a plastic bag are the products with the lowest price. The price variation between different brands is considerable.

Eco-efficiency

1. Canned carrots, fresh peeled carrots and frozen carrots sold in a bag have a comparable, and slightly above average eco-efficiency. Fresh bunched carrots perform, due to their below average costs and below average environmental impact, the best when considering the Dutch products The least performing alternatives are frozen carrots sold in a carton, carrots in a pouch and carrots sold in Tetra Recart carton laminate. When considering the Dutch market products, the canned carrots are the best performing products.

Nutritional aspect

1. The energy values range from 44 to 102 kJ per 100 gr. The highest values are obtained with fresh carrots.
2. The protein content ranges from 0.5 to 1.4 g per 100g. For fresh carrots at t=0, one sample had the maximum content while the other sample only contained half the amount. This might be caused by natural variation or by the presence of for example a high nitrate content as the protein content is calculated from the total N-content of the carrots.
3. The vitamin-C content is high for the fresh carrots and even higher for one of the frozen carrots packed in carton. For vitamin-B, a more or less similar pattern is seen across all selected systems.
4. The vitamin E content, expressed as tocopherol activity, is very high for frozen products packed in carton and is the lowest for fresh carrots. Canned products have a relative high activity because of a high alfa-tocopherol content.
5. The total carotenoid contents are highest for one of the frozen carrots product packed in carton. Especially the beta-carotene content of the frozen carrots is high. The lowest values are obtained for the fresh products.
6. Regarding the data it can be concluded that storage effects are not clearly present, but that for the different individual nutrients large variations exist within and between the different carrots/packaging combinations.

Sustainability from the consumer's viewpoint

Due to insignificance of the most differences in the nutritional value between the several product-packaging systems the sustainability is almost fully determined by the eco-efficiency. The fresh bunched carrots, together with the canned carrots, the frozen carrots in bag and the fresh peeled carrots, obtain an above average eco-efficiency. When considering the Dutch market offer the consumer is confronted with everyday, the canned carrots present the best eco-efficiency profile.

8. Authentication

Name and address of the principal:
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Names and establishments to which part of the research was put out to contract:
-

Date upon which, or period in which, the research took place:
September 2004 – October 2005

Signature:	Approved by:
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Project Leader	Team Manager