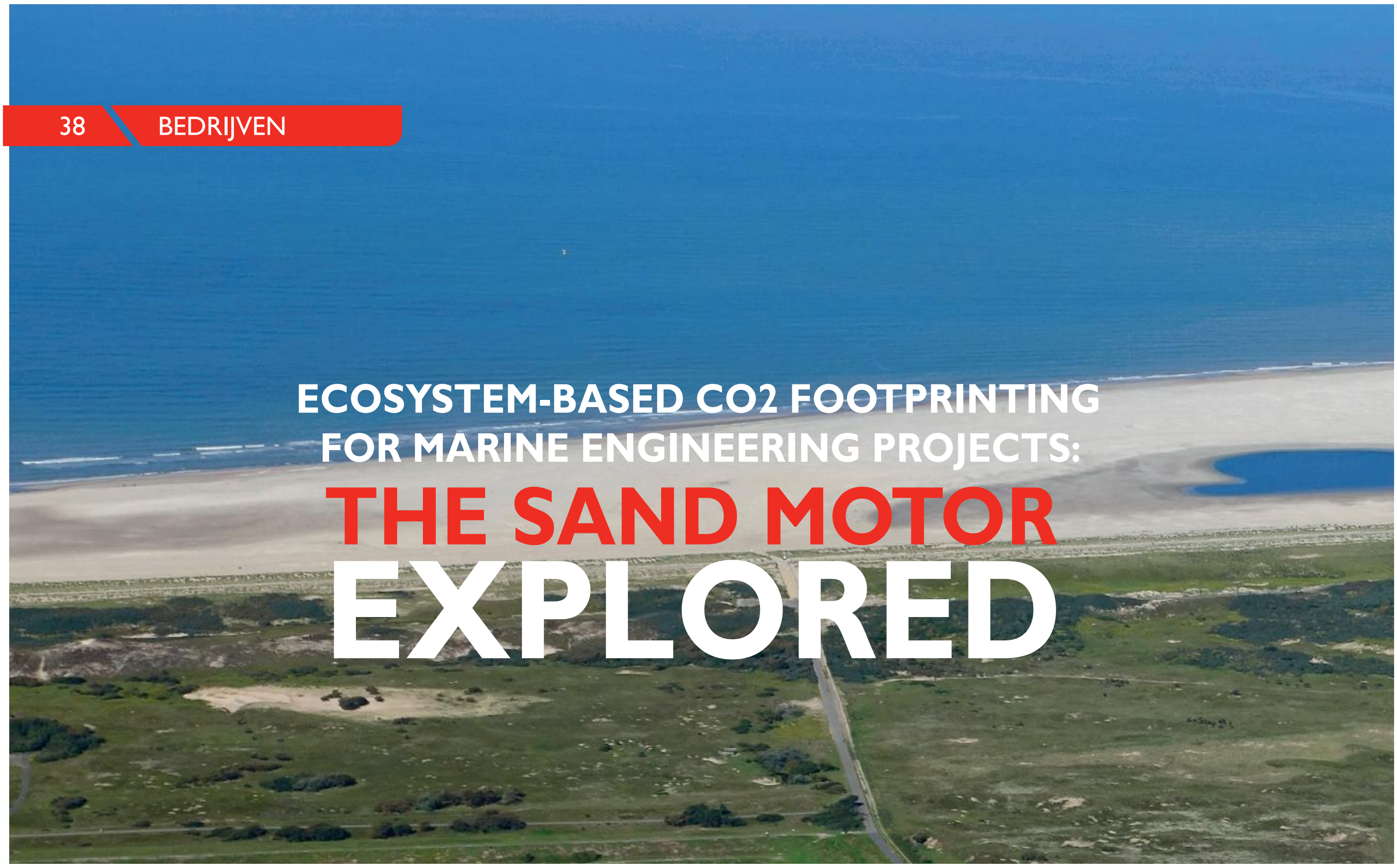

ECOSYSTEM-BASED CO2 FOOTPRINTING FOR MARINE ENGINEERING PROJECTS:

THE SAND MOTOR EXPLORED

Dredging uses substantial amounts of energy. According to Fiselier et al. (2015), equipment CO_2 emissions per cubic metre dredged may amount to 2–5 kg CO_2/m^3. This is for a dredging cycle that involves transport over 10–20 km. The total organic carbon content of sand used for nourishment amounts to 30–120 kg carbon dioxide equivalent. The potential CO_2 emission of 1 cubic metre of sand is therefore much larger than the CO_2 emission resulting from energy consumption by dredging equipment.

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That is why the Building with Nature (BwN) initiative, undertaken by the Ecoshape consortium, includes the development of ecosystem-based CO_2 footprinting. The purpose of this programme is to develop a design tool that focuses on CO_2 emission factors or 'buttons'. To that end, a partnership has been formed between two dredging contractors (Boskalis and Van Oord), NGOs (the North Sea Foundation and Wetlands International), engineering and consulting firms (Arcadis, Royal HaskoningDHV and Witteveen +Bos), Rijkswaterstaat and Deltares. The goal is to develop and construct innovative marine engineering solutions whose CO_2 footprint is 10-20% smaller than that of conventional solutions.

An illustrative example of recent BwN solutions is the Sand Motor. One of the research goals of the Sand Motor project is to investigate the potential for capturing CO_2 by mega-nourishments. That is the subject addressed in the present article, which is largely based on the MSc thesis by Wijnakker.

EXPLORING THE CO2 BUTTONS OF MARINE ENGINEERING PROJECTS

Building on the BwN Design Guidelines, a distinction is made between five major emission factors or 'buttons' that contribute significantly to reducing the CO_2 footprint of marine engineering projects (see Figure 1):
1. the equipment deployed
2. execution
3. project design
4. sandpit
5. the ecosystem in which the project is located.
The interpretation of these buttons is as follows:

Equipment
This refers to the dredging sector's efforts to develop more energy-efficient vessels and to use cleaner fuels to reduce CO_2 emissions. This efficiency-oriented effort is largely cost-driven, since a substantial share of the costs associated with dredging projects relates to fuel use. In recent years there has been a trend away from heavy fuel oil towards gas oil, in response to international laws and regulations exerting pressure on the industry to switch to cleaner fuels. For example, the first experiments with biofuel are currently underway. It is indicated that advances in equipment and fuel could reduce emissions by 10 to 15% over the next few decades.

Execution
This 'button' refers to the efficient (or more efficient) deployment of equipment and thus to reduced fuel use. Dredging companies are already making this change 'organically' because it has a direct effect on costs. For example, they are seeking to optimise execution, primarily in collaboration with customers, by reusing materials, reducing transport distances and other measures. These solutions, which involve direct placement rather than pressurised sand delivery, allow companies to deploy larger vessels and use them much more efficiently.

Project design
A project can be designed to require less sand, perhaps by optimising the balance between the construction and maintenance phases or between hard and soft elements, and by reusing materials within a project. Blue Carbon Ecosystems make it possible to actively sequester CO_2. Consideration may be given to using natural systems, such as salt marshes and mangroves, or to cultivating dunes and willow thickets. Thanks to clever design optimisations, dredging contractors can reduce the amount of sand needed for construction projects; this leads in turn to fewer trips between project location and sandpit, resulting in lower fuel consumption and lower emissions.

▲ The Sand Motor in aerial view, an artificial peninsula off the coast of Ter Heijde.

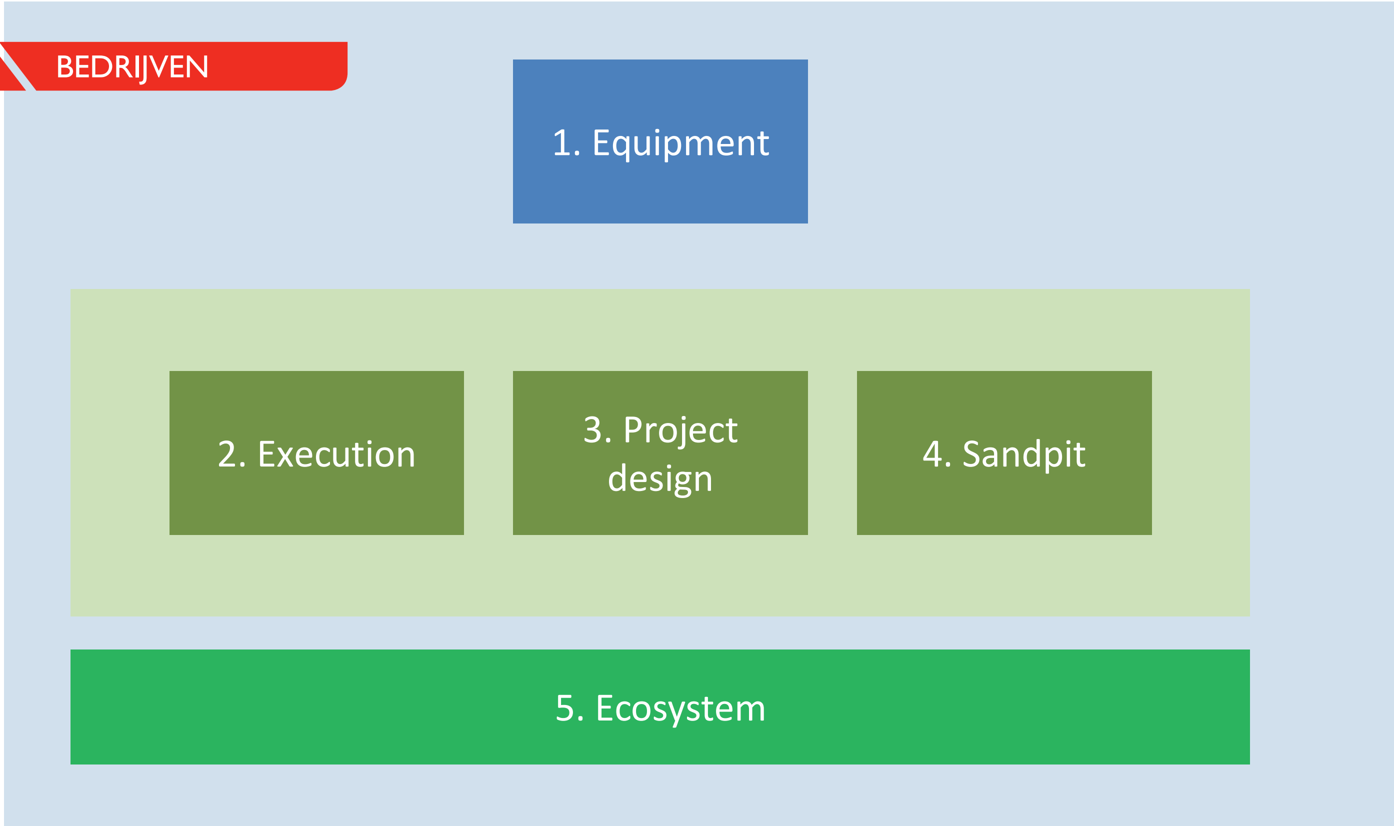

Figure 1: Building with Nature Design Guidelines.

Sandpit
This button relates to the selection of the extraction area, the transport distance between the extraction area and the project site, and extracted material that is brought to the surface – emission factors that cannot be ignored.
A sandpit, however, also creates a potential storage site for silt and organic substances, and thus for CO_2 as well. Location, orientation, shape, and method of extraction from the sandpit all impact the quantity of silt that is captured, both during and after extraction.

Ecosystem
This button refers to the natural system in which the project is located and with which it interacts. Nutrients released by activities such as dredging stimulate the growth of algae that absorb atmospheric CO_2. These algae are ultimately deposited with the silt in the salt marshes, where the CO_2 is then sequestered.
A sand replenishment project such as the Sand Motor can create a lee zone behind which a salt marsh can develop and, in turn, where CO_2 can be sequestered.
It is important to realise that pushing one of these CO_2 buttons always affects the others. For example, the combination of equipment deployment, design and sandpit impacts the ecosystem, and vice versa. The Sand Motor case study (see the next section) focuses specifically on the 'ecosystem' button, but the interaction with the other buttons should be kept in mind.

SAND MOTOR CASE STUDY

Boskalis and Van Oord constructed the Sand Motor between March and November 2011 at the request of Rijkswaterstaat and the Province of South Holland. Immediately after construction, the surface area was 128 hectares – the size of 256 football fields – and stretched one kilometre into the sea, with the beach being two kilometres in width. The sand used for construction – 21.5 million cubic meters, about 27 times the capacity of Feyenoord Football Stadium – was excavated from a sandpit located 10 kilometres off the coast. Over the next 20 years, this sand will gradually be deposited along the coast through tidal motions, currents and wind action.
A team of scientists is presently monitoring the evolution of the Sand Motor. One major goal is to define its CO_2 balance. The Sand Motor provides a sandy environment that is rich in shell fragments and calcite. Rain will dissolve calcite, with an impact on CO_2 sequestration. That inspired one of the authors to study its potential for Ca-carbon sequestration in more detail.

Methodology
To gain insight into the Sand Motor's potential for capturing CO_2, fieldwork, laboratory experiments and modelling have been used. Fieldwork conducted at the Sand Motor site itself involved collecting sand and groundwater samples for the experiments. The chemical characteristics of the collected sand and groundwater were determined, with calcite

levels as a major indicator. Experiments were conducted to determine the calcite dissolution rate of the Sand Motor sand samples, which can used to understand how much CO_2 can be captured by the sand in a certain period of time. The outcomes of the experiments were compared to the results of a geochemical reaction model (PHREEQC). A detailed description of sampling processes, laboratory protocols and experimental setup can be requested from the authors.

Results and discussion

The laboratory experiments showed that calcite dissolution does occur at the Sand Motor site during precipitation, but at a lower rate than when pure calcite is used in laboratory settings. The lower rate is probably due to foreign ions in the sand that slow down the dissolution reaction. The amount of CO_2 captured by the Sand Motor per year is estimated at $2.1\text{-}4.2 \times 10^5$ kg a year (about 4-8 Mkg CO_2 in twenty years). The geochemical model and fieldwork indicate that the amount of CO_2 captured by the Sand Motor is actually higher than the laboratory experiments showed. Long-term predictions are bound to contain uncertainties, since the Sand Motor itself will decrease/erode in time. In CO_2 footprint studies, the focus is often on sequestration of organic carbon. Organic carbon can be trapped in the sandpit, on the Sand Motor site and in adjacent and newly formed dunes. Since the Sand Motor has virtually no vegetation, its sequestration capacity for organic carbon is relatively low. The sandpit can trap large amounts of fine sediments and related organic matter and is a major factor in the project's CO_2 footprint. However, a sandpit is also needed for conventional nourishment schemes.

CONCLUSION

Marine engineers are presently discovering the potential of combining climate adaptation with climate mitigation measures. The BwN initiative thus includes a programme that focuses on ecosystem-based CO_2 footprinting. An explorative study investigating CO_2 capture by the Sand Motor confirmed the relevance of this programme. The study reveals the need for a better understanding of the sediment–water interface of mega-nourishments. This requires sampling and analysis of deeper sediment layers. In addition to the Sand Motor analysis, additional steps are being taken to fill in gaps in relevant information and to validate the design tool calculation scheme. Furthermore, specific calculation formats will be developed for different types of projects in different types of coastal environments. ■

For the references, the original article can be requested from the editor.

▼ The Sand Motor with low tide in 2013. Since then, it has already developed into another form.