International Journal of Critical Infrastructure Protection 32 (2021) 100405

Contents lists available at ScienceDirect

International Journal of Critical Infrastructure Protection

journal homepage: www.elsevier.com/locate/ijcip

Changes in inoperability for interdependent industry sectors in Norway from 2012 to 2017

Stig Rune Sellevåg

Norwegian Defence Research Establishment (FFI), P.O. Box 25, 2027 Kjeller, Norway

ARTICLE INFO

Article history:
Received 27 May 2020
Revised 14 August 2020
Accepted 10 December 2020
Available online 19 December 2020

Keywords:
Inoperability input-output model
National security
Critical infrastructure protection
Resilience

ABSTRACT

The purpose of this work has been to investigate changes in interdependencies between Norway's mainland industry sectors and how it might affect national security. To this end, the interdependencies were analysed by using the demand-reduction inoperability input-output model and national account data for the time period 2012–2017. The construction sector and the food industry sector are very important industries for mainland Norway. The construction sector has also increased its influence from 2012 to 2017. Because of the large influence these sectors exercise on other sectors, disruptions to the construction sector or the food industry may seriously impact the national security of Norway. Norway's agricultural sector, in particular, is very fragile towards disruptions to the food industry. Efforts to enhance the resilience of the agriculture and the food industry should therefore continue. With increasing digitisation and automation of the construction industry, it is necessary to get more knowledge on how this will affect the interdependencies between the construction industry and other sectors, and the potential vulnerabilities that follows. It is also recommended to gain more knowledge about the importance of the construction sector and construction workers for maintaining critical national infrastructures during crises.

1. Introduction

The COVID-19 pandemic has shown that supply of services by critical national infrastructures (CNI) under pressing conditions and without major failure is of utmost importance to our society. Infrastructure disruptions can directly or indirectly affect other infrastructures through a complicated web of interdependencies across different industries and business sectors. The effects of the disruptions may impact large geographical regions and send ripples throughout the national and global economy as well as affect national security [1]. Understanding the fragility induced by multiple interdependencies is therefore considered as one of the major challenges when it comes to protection of CNIs [2–4].

The situation is exacerbated by the proliferation of digital technologies and increased electrification which continue to add complexity to our CNIs [5,6]. Furthermore, CNIs in free market economies do not have one single entity in control of the system. CNIs are therefore open sociotechnical systems that are influenced by inward and outward flow of goods, services and capital, as well as undergoing constant interaction and exchange with their economic, social and natural environments [5]. CNIs should therefore be characterised as complex adaptive systems [2,5]. Consequently, understanding the properties of complex adaptive systems is of importance when informing policy makers and decision makers on national security issues related to CNIs [5]. In addition, effective crisis management of disruptions of CNIs at the national level requires situational awareness across all CNI sectors [7].

Improving the resilience of our CNI sectors is therefore a priority of national security. However, in order to assess the future national security implications of digital transformation and increased electrification, it is necessary to gain better understanding of how interdependencies between CNI sectors have changed up till now.

The purpose of this work has been to investigate changes in interdependencies between CNI sectors at the national level. In the literature, several frameworks and modelling approaches have been proposed for describing interdependencies between CNIs; see *e.g.* Ouyang [8] and references therein. For the purpose of this study, the inoperability input-output model (IIM) was chosen. The IIM is an economic theory-based approach that assumes that the level of economic interdependencies between CNI sectors is also representative to the flow of commodities (goods and services), by physical and/or cyber interconnections [2,8], between the CNI sectors. The risk of failure for a CNI and the cascading effects following a perturbation that is triggered by, *e.g.*, an accident, a natural disaster or

---

E-mail address: stig-rune.sellevag@ffi.no

https://doi.org/10.1016/j.ijcip.2020.100405

a malicious attack, is measured in terms of the system's inoperability, where inoperability is defined as "the inability of the system to perform its intended natural or engineered functions" [9]. Thus, the inoperability measures the normalised production loss given as the ratio of unrealised production with respect to the "as-planned" production level [9]. By exploiting national input-output (I-O) accounts for describing interconnections between different sectors, the IIM offers an easy and intuitive model for analysing interdependencies between CNI sectors at the national level for different types of perturbations. The IIM is therefore useful for industry-level interdependency analysis of natural, accidental or deliberate events [8], and has been successfully applied to cases related to, *e.g.*, terrorism [10,11], the impact of high-altitude electromagnetic pulse [12], blackouts [13], hurricanes [14] and cyber-attacks [15], as well as analysing interdependencies between Italy's economic sectors [16] (see also ref. [17]).

In this work we have, for the first time, analysed changes in interdependencies between Norway's mainland industry sectors over the time period 2012–2017. Following Setola's study of Italy's economic sectors [16], the demand-reduction IIM of Haimes et al. [9,11] was chosen. The timeframe was selected on the basis of the availability of comparable national I-O accounts data. On the basis of the findings, implications for the national security of Norway are discussed. Data for the United Kingdom (UK) have been included for comparison.

2. Methods

IIM for interdependent infrastructure sectors is described elsewhere [9,11,18], so only brief details will be given. The Leontief input-output model is given in Eq. (1). In this formulation, x_i is the total production output of industry i, a_{ij} is the Leontief technical coefficient, *i.e.* the proportion of industry i's input to j with respect to the "as-planned" total production of j ($\hat{x}_j$), and c_i is the final demand for i's output [9,11].

$$\boldsymbol{x} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{c} \;\Leftrightarrow\; \left\{ x_i = \sum_{j} a_{ij} x_j + c_i \right\} \forall\, i \tag{1}$$

In the demand-reduction IIM, Eq. (1) is transformed into Eq. (2) [9,11]:

$$\boldsymbol{q} = \boldsymbol{A}^{*}\boldsymbol{q} + \boldsymbol{c}^{*} \;\Rightarrow\; \boldsymbol{q} = [\boldsymbol{I} - \boldsymbol{A}^{*}]^{-1}\boldsymbol{c}^{*} = \boldsymbol{S}\boldsymbol{c}^{*} \tag{2}$$

Here, the inoperability $\boldsymbol{q} \in [0,\ 1]^n$ is a vector specifying the normalised production losses for each of the n infrastructures that can be potentially realised after a prolonged demand-side perturbation $\boldsymbol{c}^{*}$ [9,11]. An inoperability of $q_i = 0$ means that the production output of i is "as planned", while $q_i = 1$ implies that i is 100% inoperable [11]. The $n \times n$ matrix $\boldsymbol{A}^{*}$ describes the interdependencies between industry sectors and relates to the Leontief technical coefficients as given in Eq. (3) [9,11]:

$$a^{*}_{ij} = a_{ij}\frac{\hat{x}_j}{\hat{x}_i} \tag{3}$$

In order to quantify the role of each infrastructure sector, the dependency index (δ_i) and the influence gain (ρ_j) have also been calculated. The dependency index is defined as given in Eq. (4) [19]:

$$\delta_i = \frac{1}{n-1}\sum_{j \neq i}^{n} a^{*}_{ij} \tag{4}$$

while the influence gain is defined as (Eq. (5)) [19]:

$$\rho_j = \frac{1}{n-1}\sum_{i \neq j}^{n} a^{*}_{ij} \tag{5}$$

The dependency index measures the exposure of the i-th infrastructure sector to failures in the other sectors, while the influence gain expresses the j's ability to propagate inoperability to the other sectors. As discussed by Setola et al. [19], δ_i and ρ_j does not take into account second- or higher-order dependencies. This can be done by evaluating the normalised row and column sum of the $\boldsymbol{S}$ matrix coefficients since [19]:

$$\boldsymbol{S} = [\boldsymbol{I} - \boldsymbol{A}^{*}]^{-1} = \boldsymbol{I} + \boldsymbol{A}^{*} + \boldsymbol{A}^{*2} + \boldsymbol{A}^{*3} + \cdots \tag{6}$$

Analogously to Eqs. (4) and (5), the overall dependency index ($\delta_i^{\text{overall}}$) and influence gain ($\rho_j^{\text{overall}}$) are defined according to Eqs. (7) and (8), respectively [19]:

$$\delta_i^{\text{overall}} = \frac{1}{n-1}\sum_{j \neq i}^{n} s_{ij} \tag{7}$$

$$\rho_j^{\text{overall}} = \frac{1}{n-1}\sum_{i \neq j}^{n} s_{ij} \tag{8}$$

By comparing the $\delta_i^{\text{overall}}$ and δ_i (or the ρ_j^{overall} and ρ_j) values, information about the importance of second- and higher-order interdependencies can be obtained. The value for the maximum n-th order interdependency of i can be calculated in accordance with Eq. (9):

$$\gamma_i^{(n)} = \max_j\left(a^{*n}_{ij}\right)\ \forall\ i, j \tag{9}$$

According to Setola et al. [19], $\delta_i^{\text{overall}}$ and ρ_j^{overall} expresses the resilience of the i-th infrastructure sector and the influence that j exercises on the entire system. However, given that resilience is often interpreted as "the ability of the system to sustain or restore its basic functionality following a risk source or an event" [20], it can be argued that a more suitable, yet related, interpretation of $\delta_i^{\text{overall}}$ is that it expresses the fragility of i that is induced by the multiple interdependencies to other sectors [2–4]. Under this interpretation, a large value of $\delta_i^{\text{overall}}$ would imply that i is more fragile (less resilient) towards disruptions of other sectors than a sector with a low δ^{overall} value.

Following Haimes et al. [9], the Leontief technical coefficients (a_{ij}) were obtained from the Norwegian national accounts I-O tables for domestic use (industry-by-industry; ESA Questionnaire 1850) that are published by Statistics Norway (SSB) [21]. According to SSB, the I-O tables are derived from the supply and use tables under the assumption of a fixed product sales structure [21]. The I-O tables consist of 64 different mainland industry sectors that represent all domestic production activity except the shipping and petroleum sectors. Their descriptions and accompanying codes are given in ref. [22] (Table S1). Based on the obtained a_{ij} coefficients, the $\boldsymbol{A}^{*}$ matrix was calculated in accordance with Eq. (3) for the years 2012–2017. This time frame was selected because comparable I-O tables have been made available by SSB over this period. Caveat: For confidentiality reasons, the data for R19, R20 and R21 have been presented together in the column for R21 in the datasets provided by SSB.

3. Results and discussions

3.1. Dependency and influence

As a first exploration of the datasets, δ_i (Eq. (4)) values have been calculated for the different sectors for the years 2012–2017. The δ_i values for 2012 and 2017 are displayed in Fig. 1 (a plot of $\delta_i(2017) - \delta_i(2012)$ values is given in ref. [22], Fig. S1). Of particular interest to CNIs in Norway [23], is "Products of agriculture, hunting and related services (R01)" since the sector relates to the security of food supply and it has a high dependency index compared to the other sectors. Taking 2012 as the reference

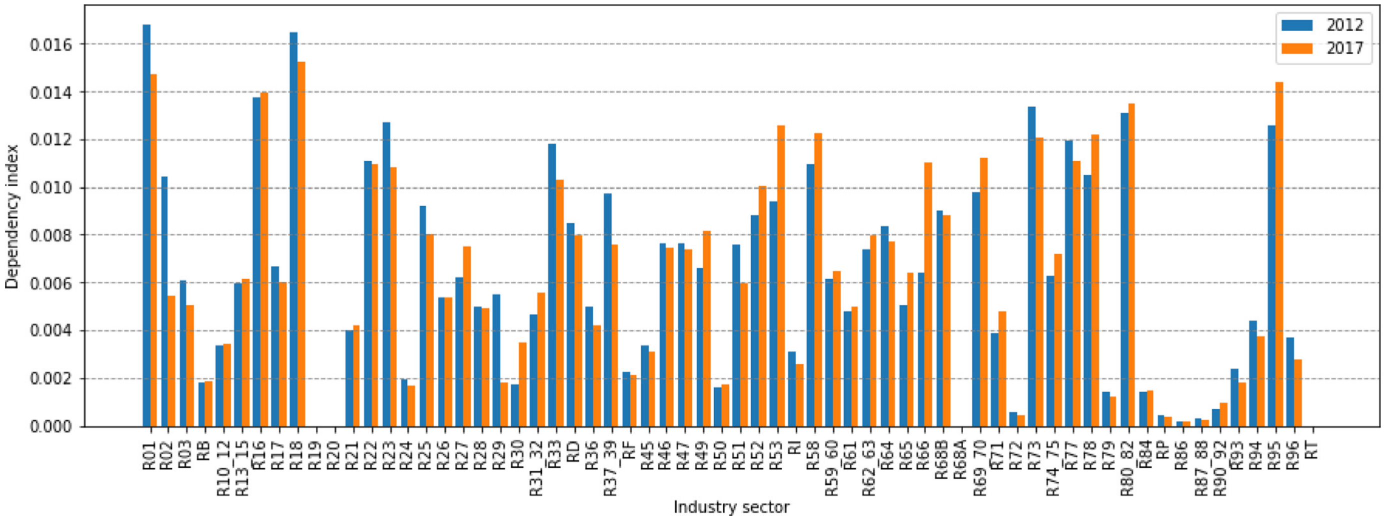

Fig. 1. Dependency indices for different Norwegian industry sectors for the years 2012 and 2017. A description of the different sectors is given in ref. [22] (Table S1).

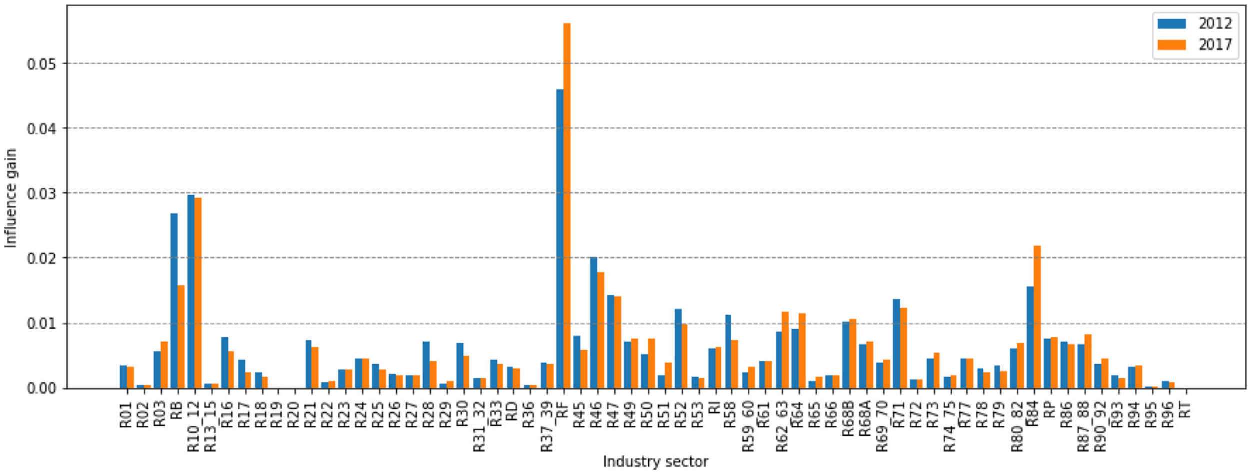

Fig. 2. Influence gains for different Norwegian industry sectors for the years 2012 and 2017. A description of the different sectors is given in ref. [22] (Table S1).

year, a one-sample t-test on the δ_{R01} values from 2013 to 2017 shows that the mean δ_{R01} value (0.016) is different from the 2012 value ($\delta_{\mathrm{R01}} = 0.017$) (statistically significant with $p = 0.015$ for $N = 5$ and $\alpha = 0.05$). Furthermore, linear regression shows that the slope is significantly different from zero ($\beta_\delta = -3.7 \times 10^{-4}$, $p = 0.04$). Thus, R01's dependency to other sectors has declined over the time period 2013–2017 compared to 2012. If we look at the $\delta_{\mathrm{R01}}^{\mathrm{overall}}$ values, on the other hand, no such change is observed.

Another industry of interest is "Services auxiliary to financial services and insurance services (R66)" since financial services is a CNI [23]. Here, we find that the dependency index has increased from 0.006 in 2012 to 0.011 in 2017. The slope of the increase was 7.3×10^{-4} ($p = 0.01$) (see also ref. [22], Fig. S1). No change is found for $\delta_{\mathrm{R66}}^{\mathrm{overall}}$ over the period 2013–2017 compared to the 2012 value (0.018).

The ρ_j (Eq. (5)) values for the industry sectors for 2012 and 2017 are plotted in Fig. 2 (a plot of $\rho_j(2017) - \rho_j(2012)$ values is given in ref. [22], Fig. S2). As can be seen, "Constructions and construction works (RF)" is the sector that exercises largest influence on the other sectors. Linear regression shows that RF has increased its influence gain from 0.046 in 2012 to 0.056 in 2017 with $\beta_\rho = 3 \times 10^{-4}$ ($p = 0.009$ for $N = 5$). The same trend is found for $\rho_{\mathrm{RF}}^{\mathrm{overall}}$. Furthermore, the $\rho_{\mathrm{RF}}^{\mathrm{overall}}$ values are substantially larger (0.114 for 2017 and 0.097 for 2012), implying that second- and higher-order dependencies are of importance (see $\gamma_i^{(2)}$ and $\gamma_i^{(3)}$ values involving RF in ref. [22], Table S2).

From Fig. 2, we also see that the sector "Food products, beverages and tobacco products (R10_12)" has a large influence gain value (0.054 and 0.055 for 2012 and 2017, respectively). No change in influence gain was observed over the period 2012–2017 (ref. [22], Fig. S2), neither for the $\rho_{\mathrm{R10\_12}}$ nor the $\rho_{\mathrm{R10\_12}}^{\mathrm{overall}}$ values. The large influence of R10_12 in view of the large dependency index of R01, is of interest in the perspective of security of food supply and will be investigated in the following of this paper.

In a CNI perspective, it is interesting to note that the sector "Public administration and defence services; compulsory social security services (R84)" has gained influence over the period investigated. From 2012 to 2017, ρ_{R84} has increased from 0.016 (0.028) for 2012 to 0.022 (0.037) for 2017 with $\beta_\rho = 1.4 \times 10^{-3}$ ($p = 0.02$ for $N = 5$); the $\rho_{\mathrm{R84}}^{\mathrm{overall}}$ values are given in parenthesis.

3.2. Changes in inoperability

In order to gain insight into the interdependencies between Norwegian infrastructure sectors, inoperabilities associated with perturbations of sectors of interest have been calculated (Eq. (2)). The list of perturbed sectors to be investigated, was selected on the basis of the sectors' dependency index and influence gain as well

Table 1
List of perturbed Norwegian industry sectors for domestic use of products.

Code	Industry sector
R01	Products of agriculture, hunting and related services
R10_12	Food products, beverages and tobacco products
RD	Electricity, gas, steam and air-conditioning
RF	Constructions and construction works
R49	Land transport services and transport services via pipelines
R50	Water transport services
R51	Air transport services
R61	Telecommunications services
R64	Financial services, except insurance and pension funding
R84	Public administration and defence services; compulsory social security services
R86	Human health services

as their relevance to Norwegian CNIs [23]. From this, 11 sectors were selected (Table 1). These sectors are related to manufacture of foodstuff, electricity supply, telecommunications services, financial services, transport services, human health services, public administration and defence services, and constructions and construction works. Supply of water was excluded from this study on the basis of small δ_i and ρ_j values for the R36 sector ("Natural water; water treatment and supply services).

Since the purpose of this work is to investigate how the interdependencies may have changed from 2012 to 2017, the sector k selected for experimentation was perturbed by a notional 10% demand reduction ($c^*_k = 0.1$). Only one sector was perturbed in each experiment ($c^*_{i \neq k} = 0.0$). The demand reduction can be caused by, *e.g.*, failures, accidents, natural hazards or malicious acts like terrorism [10–15]. The main results from the experiments are summarised in Table 2 and discussed in the following. Additional data from the experiments are provided in ref. [22] (Fig. S3).

3.2.1. Manufacture of foodstuff

The inoperabilities caused by a notional 10% demand reduction for sector R10_12 ("Food products etc."; $c^*_{\mathrm{R10\_12}} = 0.1$) are summarised in Table 2. Some notable effects can be observed. Firstly, the inoperability of R10_12 is amplified from 0.1 to 0.13. Secondly, R01 ("Products of agriculture etc.") is highly affected with an inoperability of 0.12. That is, the inoperability of R01 is of the same order of magnitude as the initially perturbed sector (R10_12) due to cascading effects. This can be understood in terms of the large $\gamma_i^{(1)}$, $\gamma_i^{(2)}$ and $\gamma_i^{(3)}$ values between R01 and R10_12 (ref. [22], Table S2). Thirdly, the sector "Fish and other fishing products; aquaculture products; support services to fishing (R03)" is also substantially affected with an inoperability of 0.04. If we look at the change in inoperability ($\Delta q_i = q_i - q_i(2012)$) for the sectors R01, R03 and R10_12 over the years 2013–2017 relative to 2012, no significant change is observed (ref. [22], Fig. S4).

If the R01 sector is perturbed by a notional 10% demand reduction ($c^*_{\mathrm{R01}} = 0.1$), the inoperability of R10_12 is only around 0.005 while the inoperability of R01 is around 0.11 (Table 2). There has, however, been a slight yet statistically significant decline in Δq_{R01} (slope $\beta_q = -2.4 \times 10^{-4}$; $p = 0.005$ for $N = 5$) and for $\Delta q_{\mathrm{R10\_12}}$ ($\beta_q = -1.5 \times 10^{-4}$; $p = 0.04$) over the years 2013–2017 compared to 2012 (ref. [22], Fig. S4). Thus, both R01 and R10_12 have become less fragile towards disruptions of the R01 sector.

3.2.2. Electricity, gas, steam and air conditioning supply

In Norway, production and distribution of electricity are the principal parts of the sector "Electricity, gas, steam and air-conditioning (RD)". As can be seen from Table 2, the inoperability of RD following a notional 10% demand reduction ($c^*_{\mathrm{RD}} = 0.1$) is 0.104 which implies that RD is only slightly affected by interdependencies to other sectors (the $\gamma_{\mathrm{RD}}^{(n)}$ values are small; see ref. [22], Table S2). Furthermore, the impact on other sectors is also limited with inoperability values being 0.002 or less.

There has been a small, yet statistically significant drop in the mean Δq_{RD} ($\overline{\Delta q}_{\mathrm{RD}} = -6.7 \times 10^{-4}$; $p = 0.003$ for $N = 5$) over the period 2013–2017 compared to 2012. However, linear regression shows that the slope is not significantly different from zero (ref. [22], Fig. S4). Furthermore, the dependency index for RD has not changed significantly over the time period. It is therefore to be seen whether RD has become less fragile towards cascading effects.

3.2.3. Telecommunications services

Turning to the telecommunications services sector (R61), q_{R61} caused by a notional 10% demand reduction ($c^*_{\mathrm{R61}} = 0.1$) was 0.128 for the year 2017 (0.139 in 2012). R61 has a quite large first-order self-dependency ($\gamma_{\mathrm{R61}}^{(1)} = 0.22$ [22]), which explains the amplification of the inoperability for R61. By comparing the δ_{R61} (0.005) and $\delta_{\mathrm{R61}}^{\mathrm{overall}}$ (0.014) values, the inoperability for R61 is also substantially affected by second- and higher-order dependencies to other sectors. Furthermore, the inoperability of R61 has also a considerable impact on the sectors R58 ("Publishing services") and R73 ("Advertising and market research services"); see Table 2.

If we look at the trend over the years 2013–2017 compared to 2012, Δq_{R61} has significantly declined ($\beta_q = -3 \times 10^{-3}$; $p = 0.027$ for $N = 5$; see ref. [22], Fig. S4). A decline in Δq_{R73} is also observed ($\beta_q = -4 \times 10^{-4}$; $p = 0.004$). No significant change is observed for R58.

3.2.4. Financial services

The inoperabilities caused by a notional 10% demand reduction for the sector "Financial services, except insurance and pension

Table 2
Inoperabilities (q_k) for different Norwegian industry sectors that are caused by a notional 10% demand reduction for the sectors, together with cascading effects to other sectors (year 2017)[a].

Perturbed sector (k)	Inoperability perturbed sector (q_k)	Cascading effects to other sectors ($q_{i \neq k}$)		
		Most affected[b] sector	Second-most affected sector[b]	All other sectors
R10_12	0.130	R01 (0.115)	R03 (0.04)	< 0.02
R01	0.106	R10_12 (0.0042)	R02 (0.0036)	< 0.0035
RD	0.104	R73 (0.0025)	R53 (0.0022)	< 0.0022
R61	0.128	R58 (0.006)	R73 (0.005)	< 0.004
R64	0.110	R66 (0.043)	R62_63 (0.008)	< 0.008
R49	0.105	R77 (0.008)	R33 (0.007)	< 0.005
R50	0.106	R52 (0.016)	R65 (0.011)	< 0.008
R51	0.101	R52 (0.007)	R77 (0.005)	< 0.004
R86	0.100	R96 (0.006)	R62_63 (0.004)	< 0.003
R84	0.101	R95 (0.028)	R49 (0.017)	< 0.01
RF	0.129	R16 (0.101)	R23 (0.071)	< 0.04

[a] See ref. [22] (Table S1) for a description of the sectors.
[b] Inoperabilities are given in parenthesis.

funding (R64)” ($c^*_{\mathrm{R64}} = 0.1$) for the year 2017 are summarised in Table 2. Several impacts can be observed. Firstly, the inoperability of R64 is amplified to 0.11. Secondly, the sector “Services auxiliary to financial services and insurance services (R66)” is substantially affected with an inoperability of 0.04. Lastly, the sectors “Postal and courier services (R53)”, “Publishing services (R58)”, “Computer programming, consultancy and related services; information services (R62_62)” and R73 all suffer inoperabilities in the order of 0.006−0.008.

When it comes to changes in inoperabilities over the years 2013–2017 compared to 2012, one-sample *t*-tests show that several $\overline{\Delta q_i}$ values are significantly different from zero: $\overline{\Delta q_i}$ has increased for R53 ($\overline{\Delta q}_{\mathrm{R53}} = 0.0012,\ \ p = 0.003$), R58 ($\overline{\Delta q}_{\mathrm{R58}} = 0.0012,\ \ p = 0.029$), R62_63 ($\overline{\Delta q}_{\mathrm{R62\_63}} = 0.0029,\ \ p = 0.006$), R64 ($\overline{\Delta q}_{\mathrm{R64}} = 0.0022,\ \ p = 0.003$) and R73 ($\overline{\Delta q}_{\mathrm{R73}} = 0.0014,\ \ p = 0.008$). The $\overline{\Delta q}_{\mathrm{R66}}$ value is not different from zero over the years 2013–2017, but $\overline{\Delta q}_{\mathrm{R66}} = -0.011$ over the years 2014–2017 ($p < 0.001$, $N = 4$) (see ref. [22] for details).

3.2.5. Transport services

The effects of a notional 10% demand reduction for the sectors “Land transport services and transport services via pipelines (R49)”, “Water transport services (R50)” and “Air transport services (R51)” are summarised in Table 2 (year 2017). Of the three transport services, disruption of R50 has the greatest impact on the other sectors, followed by R49. As can be seen in Table 2, the disruption of R50 causes inoperabilities of around 0.02 and 0.01 for the sectors “Warehousing and support services for transportation (R52)” and “Insurance, reinsurance and pension funding services, except compulsory social security (R65)”, respectively.

Data on changes in inoperabilities for the three transport sectors R49, R50 and R51 over the years 2013–2017 relative to 2012 are given in ref. [22] (Fig. S4). Only a few significant changes are observed for the sectors that are substantially affected by the perturbation. Starting with the perturbation of R49 experiment, one-sample *t*-test shows that $\overline{\Delta q}_{\mathrm{R45}}$ for the sector “Wholesale and retail trade and repair services of motor vehicles and motorcycles (R45)” is lower compared to the q_{R45} value for 2012 ($\overline{\Delta q}_{\mathrm{R45}} = -5.3 \times 10^{-4},\ \ p = 0.009$). If we look at the R51 experiment, $\overline{\Delta q}_{\mathrm{R77}} = 4.7 \times 10^{-3}$ ($p = 0.02$) for the sector “Rental and leasing services (R77)”. No significant changes are observed for the R50 experiment.

3.2.6. Human health services

A notional 10% demand reduction in the sector “Human health services (R86)” does not yield a substantial amplification of q_{R86} because of small interdependencies to other sectors (ref. [22], Table S2). Furthermore, only very small inoperabilities are induced in other sectors (Table 2). The sector that is affected the most is “Other personal services (R96)”, suffering an inoperability of 0.006 (year 2017). When it comes to changes in inoperabilities over the period 2013–2017, q_{R96} has dropped from 0.012 in 2012 to an average value of 0.006 from 2015 onwards to 2017 (ref. [22], Fig. S4). No significant change in inoperability for R86 is seen from 2012 to 2017.

3.2.7. Public administration and defence services

Several effects are seen following a notional 10% demand reduction in the sector “Public administration and defence services; compulsory social security services (R84)” for 2017 (Table 2). The sector that suffers the greatest impact due to cascading effects, is “Repair services of computers and personal and household goods (R95)” with $q_{\mathrm{R95}} = 0.028$, followed by R49 ($q_{\mathrm{R49}} = 0.017$) and R66 ($q_{\mathrm{R66}} = 0.01$). Impacts on other sectors of interest include: RD ($q_{\mathrm{RD}} = 0.007$), R36 ($q_{\mathrm{R36}} = 0.008$), RF ($q_{\mathrm{RF}} = 0.006$), R53 ($q_{\mathrm{R53}} = 0.007$) and “Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services (R80_82)” ($q_{\mathrm{R80\_82}} = 0.009$).

Data on changes in the inoperabilities for the abovementioned sectors over the period 2013–2017 compared to 2012 values are reported in ref. [22] (Fig. S4). First of all, $\overline{\Delta q}_{\mathrm{R36}}$ has reduced slightly over the period ($\overline{\Delta q}_{\mathrm{R36}} = -5.0 \times 10^{-4},\ \ p = 0.009$). The sectors R53, R66, R80_82 and R95 have become more affected by cascading effects following the perturbation of the R84 sector with $\beta_q(\mathrm{R53}) = 6.6 \times 10^{-4}$ ($p = 0.027$), $\beta_q(\mathrm{R66}) = 1.0 \times 10^{-3}$ ($p = 0.045$), $\beta_q(\mathrm{R80\_82}) = 3.5 \times 10^{-4}$ ($p < 0.001$) and $\beta_q(\mathrm{R95}) = 3.8 \times 10^{-3}$ ($p = 0.009$). For the sectors RD, RF, R49 and R84 no significant changes are observed, but the inoperability of R49 changed substantially from 0.0023 in 2016 to 0.017 in 2017. It is yet to be seen if this trend continues.

3.2.8. Constructions and construction works

As previously discussed, RF is the sector with the largest influence gain. The cascading effects following a notional 10% demand reduction in RF have substantial impacts on a number of other sectors (Table 2). Most notably are the sectors “Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials (R16)” and “Other non-metallic mineral products (R23)” with inoperabilities of 0.101 and 0.07, respectively. Other sectors that experience $q_i > 0.02$ are [22]: “Products of forestry, logging and related services (R02)” ($q_{\mathrm{R02}} = 0.03$); “Rubber and plastics products (R22)” ($q_{\mathrm{R22}} = 0.037$); “Electrical equipment (R27)” ($q_{\mathrm{R27}} = 0.028$); “Architectural and engineering services; technical testing and analysis services (R71)” ($q_{\mathrm{R71}} = 0.029$); “Employment services (R78)” ($q_{\mathrm{R78}} = 0.033$). Due to RF’s self-dependency as well as its dependencies to other sectors, the inoperability of RF is amplified to 0.129.

The changes in inoperabilities for the sectors with $q_i > 0.02$ are reported in ref. [22] (Fig. S4) and summarised in the following. Starting with R02, q_{R02} dropped from 0.047 in 2013 to 0.032 in 2014. From 2014 onwards to 2017, the R02 sector is less affected by the cascading effects from the perturbation of RF with $\overline{\Delta q}_{\mathrm{R02}} = -0.012$ ($p = 0.001$) compared to the 2012 value. The $\overline{\Delta q}_{\mathrm{R16}}$ and $\overline{\Delta q}_{\mathrm{R78}}$ values have increased by 0.009 ($p = 0.009$) and 0.008 ($p = 0.024$), respectively, while no significant changes are observed for R22 and R27 over the period 2012–2017. Linear regressions of the Δq_{R23} and Δq_{R71} values show that both R23 and R71 are becoming more affected by the perturbation of RF; both sectors with a slope of $\beta_q = 3 \times 10^{-3}$ ($p < 0.02$).

3.3. Effects of perturbations to multiple sectors

The sectors R01, R03 and R10_12 were selected for experimentation in order to investigate the effects of perturbations to multiple sectors. R01 and R10_12 were chosen because they have large dependency index and influence gain values, respectively. In addition, both R01 and R03 are highly dependant upon R10_12 (ref. [22], Table S2). Obviously, the inoperabilities for the different sectors will increase if the $\boldsymbol{c}^*$ values increase. We have therefore kept $c^*_{\mathrm{tot}} = \sum_i c^*_i$ constant in the different experiments, while varying the c^*_i values. Eight different experiments were carried out where R01, R03 and R10_12 were perturbed by $c^*_i \in \{0.0,\ 0.01,\ 0.025,\ 0.04,\ 0.05,\ 0.10\}$, while maintaining $c^*_{\mathrm{tot}} = 0.1$. As a metric for the total impact of the perturbations on all sectors, we have used $q_{\mathrm{tot}} = \sum_i q_i$. The I-O table for 2017 was used in the experiments.

The results from the experiments are summarised in Table 3. If only R01 is perturbed (experiment 1), R01 suffers a substantial inoperability, but q_{tot} is the lowest for all experiments. On the other hand, if R10_12 is perturbed by a notional 10% demand reduction (experiment 3), both q_{R01} and q_{tot} have the largest values for all experiments investigated. The experiments 1 and 3 clearly

Table 3
Inoperabilities (q_k) resulting from perturbations (c^*) of the Norwegian R01, R03 and R10_12 sectors for domestic use (2017 data)[a].

Experiment	c^*_{R01}	c^*_{R03}	$c^*_{R10\_12}$	q_{R01}	q_{R03}	q_{R10_12}	q_{tot}
#1	0.1	0.0	0.0	0.106	0.001	0.004	0.144
#2	0.0	0.1	0.0	0.011	0.116	0.012	0.213
#3	0.0	0.0	0.1	0.115	0.044	0.130	0.478
#4	0.05	0.05	0.0	0.059	0.059	0.008	0.178
#5	0.05	0.04	0.01	0.069	0.051	0.020	0.205
#6	0.05	0.025	0.025	0.085	0.041	0.038	0.244
#7	0.05	0.01	0.04	0.100	0.030	0.055	0.284
#8	0.05	0.0	0.05	0.111	0.023	0.067	0.311

[a] See ref. [22] (Table S1) for a description of the sectors.

demonstrate the difference if a sector with high influence gain is perturbed *vs*. a sector with a large dependency index. The same trend is observed in experiments 4–8; the more the high-influence sector R10_12 is perturbed, the higher is the total inoperability of the whole system compared to experiment 1. However, q_{R01} was lower in the experiments 4–7 where $c^*_{R01} = 0.05$, than in experiment 1 where $c^*_{R01} = 0.1$. Similar results are observed for perturbations of, *e.g.*, RD and R61 (results not shown).

3.4. Comparison to United Kingdom

UK was chosen as the country to compare with for the following reasons: Firstly, UK is one of Norway's most important trading partners. Secondly, both countries being NATO members, Norway and UK have a long-lasting defence and national security collaboration. Thirdly, comparable input-output tables for domestic use are available for the two countries. Lastly, it is of interest to compare Norway as a small European country with an open economy to the second largest economy in Europe in terms of Gross Domestic Product (GDP). The UK 2016 input-output table for domestic use was used in the analysis [24].

Dependency indices (Eq. (4)) and influence gains (Eq. (5)) for the different UK industry sectors for the year 2016 are shown in Figs. 3a and b, respectively. Norwegian 2016 values have been included in the plots for comparison. The UK sectors with largest δ_i value are R02 (0.0145), "Repair and installation services of machinery and equipment (R33)" (0.0142) and R23 (0.0137). When it

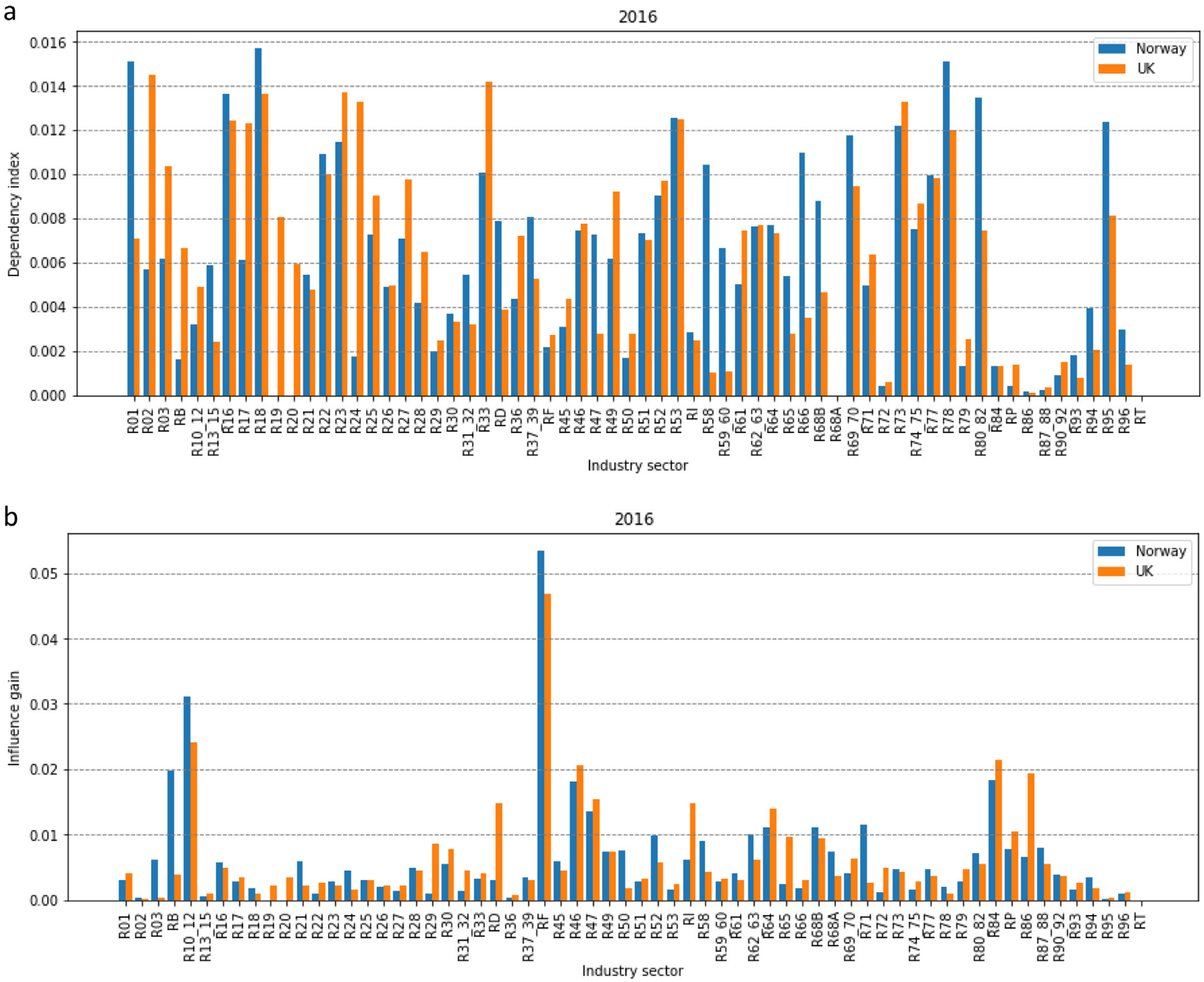

Fig. 3. Dependency indices (a) and influence gains (b) for Norwegian and UK industry sectors for the year 2016. A description of the different sectors is given in ref. [22] (Table S1).

comes to influence gain, the UK sectors RF (0.047), R10_12 (0.024), “Wholesale trade services, except of motor vehicles and motorcycles (R46)” (0.021) and R84 (0.021) exercise largest influence on the other sectors. A few notable differences between Norway and UK can be seen. The Norwegian sectors R01 and R66 have larger δ_i values than in UK. On the opposite side, the sectors R02 and R24 (“Basic metals”) in particular, have larger δ_i values in UK than in Norway. If we look at the influence gain, RB (“Mining and quarrying”) exercises larger influence in Norway than in the UK, while RD and R86 have substantially larger influence gains in the UK than in Norway.

We have also compared the inoperabilities following a notional 10% demand reduction for the sectors enlisted in Table 1 (year 2016). Selected results where substantial differences between Norway and UK are found, are shown in Fig. 4a-e (the rest of the results are given in ref. [22]). Starting with the perturbation of R10_12, we see in Fig. 4a that the inoperability of R01 in Norway is more than two times larger than in the UK. This difference can be understood in terms of the $\gamma_{\mathrm{R01}}^{(n)}$ values for Norway and UK; R01 has a much larger first-order dependency on R10_12 in Norway (0.89) than in the UK (0.39) [22]. This is also reflected in differences in exports of products of agriculture for Norway and the UK, where the fraction of exports of products from R01 in the UK (relative to the total exports from all sectors) is an order of magnitude larger than the corresponding value for the Norwegian R01 sector [21,24].

The second case where substantial differences are seen between Norway and the UK, is perturbation of RD. As can be seen in Fig. 4b, the cascading effects following a notional 10% demand reduction for RD are minor in Norway, but severe in the UK. First and foremost, we see that the inoperability of RD in its self is amplified to 0.203. Moreover, R02, RB and R33 suffer inoperabilities of 0.109, 0.04 and 0.026, respectively. If we compare the $\gamma_{\mathrm{RD}}^{(n)}$ values for Norway and the UK, some notable differences are seen (ref. [22]; Tables S2 and S3, respectively). RD in Norway has a small first-order interdependency with R24 (0.08) and second- and third-order interdependencies with RF in the order of 0.03 and 0.01, respectively. RD in UK, on the other hand, has strong first-, second- and third-order self-dependencies with values of 0.51, 0.26 and 0.13, respectively. In Norway, production and distribution of electricity are the principal parts of RD, while the use of gas is much more important in the UK [25]. Furthermore, electricity-intensive industries in Norway have favourable long-term electricity contracts and receive governmental support to invest in energy-efficient technologies [26].

Differences between Norway and the UK are also seen for perturbation of R64 (Fig. 4c). Most noticeable is that R66 is much more dependant upon R64 in Norway than in the UK with first-order interdependencies of 0.38 and 0.06, respectively, and inoperabilities of 0.044 and 0.008. However, if we look at the total impact on all sectors, q_{tot} is in fact slightly larger for UK (0.25) than for Norway (0.22).

As seen in Fig. 4d, manufacture of basic pharmaceutical products and pharmaceutical preparations (R21) in the UK is more than eight times more affected by perturbation in R86 than in Norway. This is caused by the strong first-order dependency between the pharmaceutical industry and the human health services sector in the UK [22]. Norway, on the other hand, is heavily reliant upon imports of pharmaceuticals. Furthermore, a notional 10% demand reduction for R86 gives a higher q_{tot} value in UK (0.29) than in Norway (0.17).

The last case where substantial differences are observed, is disruption of RF (Fig. 4e). Firstly, a notional 10% demand reduction for RF has a substantial impact on both the UK and Norway with q_{tot} values of 0.74 and 0.82, respectively. Secondly, sectors related to non-metallic mineral products (R23), basic metals (R24) and electrical equipment (R27) are more affected in the UK than in Norway ($|\Delta q| > 0.02$). Lastly, manufacture of wood and wood products (R16) and employment services (R78) are more affected in Norway than in the UK ($|\Delta q| > 0.02$).

3.5. Implications for the national security of Norway

In order to assess the implications for the national security of Norway, impacts in terms of total economic losses (δx_{tot}) have also been calculated from Eq. (10) [11]:

$$\delta x_{\mathrm{tot}} = \sum_i q_i \widehat{x}_i \ \forall\ i \tag{10}$$

where the economic loss of sector i (δx_i) is the product of the inoperability of sector i (q_i) (triggered by the perturbation of sector k) and its “as-planned” production ($\widehat{x}_i$).

The total economic losses for Norway following a notional 10% demand reduction for the sectors enlisted in Table 1, are summarised in Fig. 5a (the q_{tot} values are shown in Fig. 5b). The total economic losses are by far the largest for perturbation of the RF sector ($c_{\mathrm{RF}}^* = 0.1$), which amounted to more than 110 billion Norwegian kroner (NOK) for the 2017 data. The next sectors that trigger large economic losses are R84 and R10_12 with δx_{tot} values in the order of 50 billion NOK. Of the investigated sectors, δx_{tot} is smallest for the perturbation of the R51 sector (6.7 billion NOK). If we compare to the UK, we find again that RF triggers the largest δx_{tot} value [22].

On the basis of the findings in this work, a few comments on the implications for Norway’s national security can be made. Since 2000 the societal dependency on CNI services like electricity supply, telecommunications services and financial services has gained increased focus in Norway and elsewhere. The need for reducing vulnerabilities in these sectors has therefore been highlighted in several commissions on critical infrastructure security in Norway [27,28]. Indeed, this study finds that the cascading effects following a disruption in electricity supply (the RD sector) or in telecommunications services (the R61 sector) have not increased over the years 2013–2017 compared to 2012, neither with respect to δx_{tot} or q_{tot} (Fig. 5a and 5b, respectively). However, as mentioned in Section 3.2.2 for the RD sector, it is yet to be seen if this situation continues. Information beyond 2017 about cascading effects following disruption of the RD or the R61 sectors is therefore needed. When it comes to financial services (R64), a decline in q_{tot} values following disruption of the R64 sector is observed for the time period investigated (Fig. 5b). Despite this decline, the total economic loss following disruption of the R64 sector has increased over the same time period (Fig. 5a). Efforts to improve the resilience of financial services and to minimise cascading effects should therefore continue.

Moving to the RF sector, this sector is not defined as a CNI sector in Norway [23], in the UK [29] or in the United States (US) [30]. In order to assess the impact of perturbation of the RF sector on national security, it is of use to revisit the definition for critical infrastructure. Acknowledging that several definitions exist, it is helpful for this work to use the UK definition: “Those critical elements of Infrastructure (facilities, systems, sites, property, information, people, networks and processes), the loss or compromise of which would result in major detrimental impact on the availability, delivery or integrity of essential services, leading to severe economic or social consequences or to loss of life” [29]. Thus, CNI not only includes, *e.g.*, facilities, systems and information, but also the essential CNI workers. Although RF is not a CNI sector in itself, it is an underpinning function for the construction and maintenance of CNIs. Construction workers have therefore been included in the list of essential critical infrastructure workers in the US related to the COVID-19 response [31]. However, this is

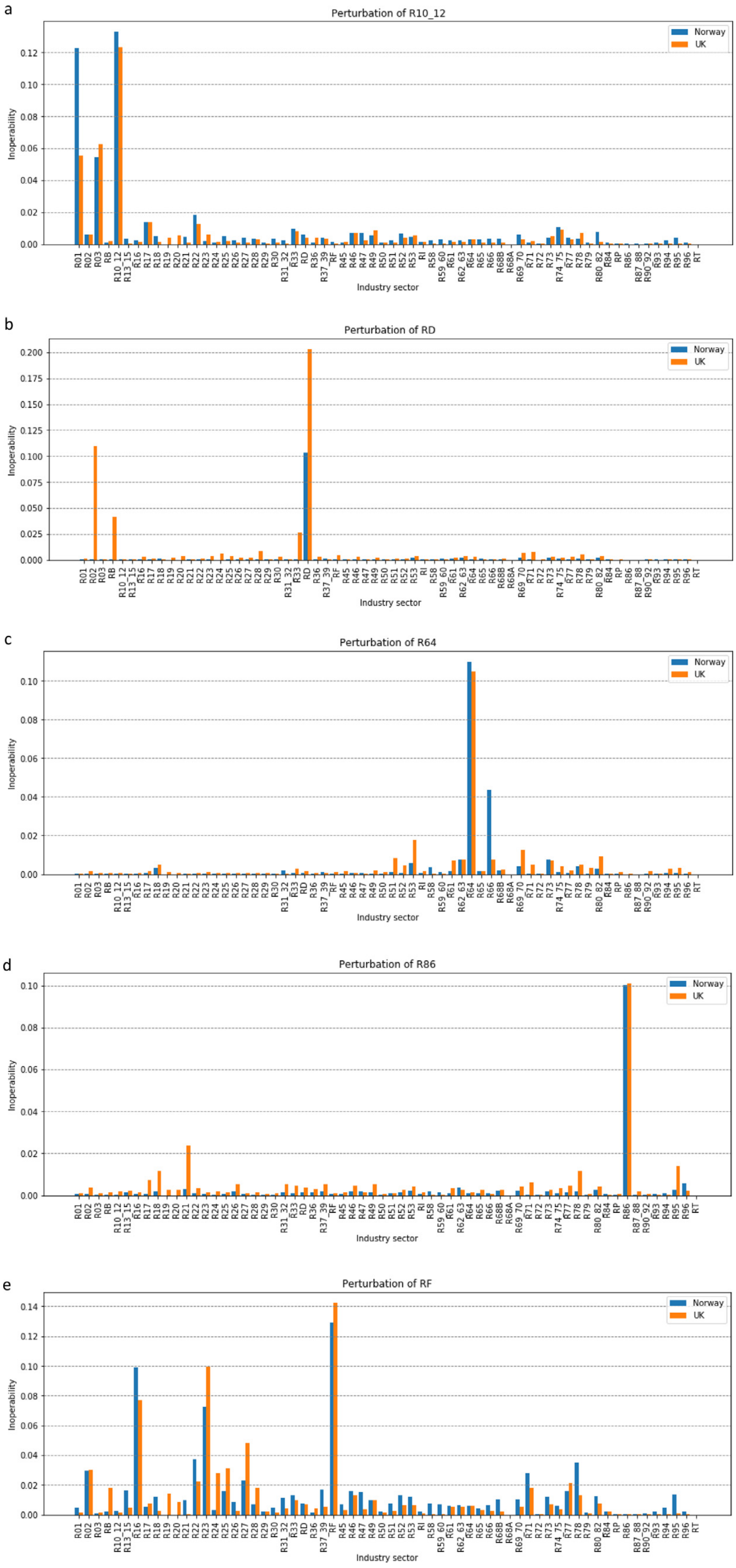

Fig. 4. Comparison of inoperabilities in Norway and United Kingdom (UK) that are caused by a notional 10% demand reduction for the sectors (year 2016): (a) R10_12, (b) RD, (c) R64, (d) R86 and (e) RF.

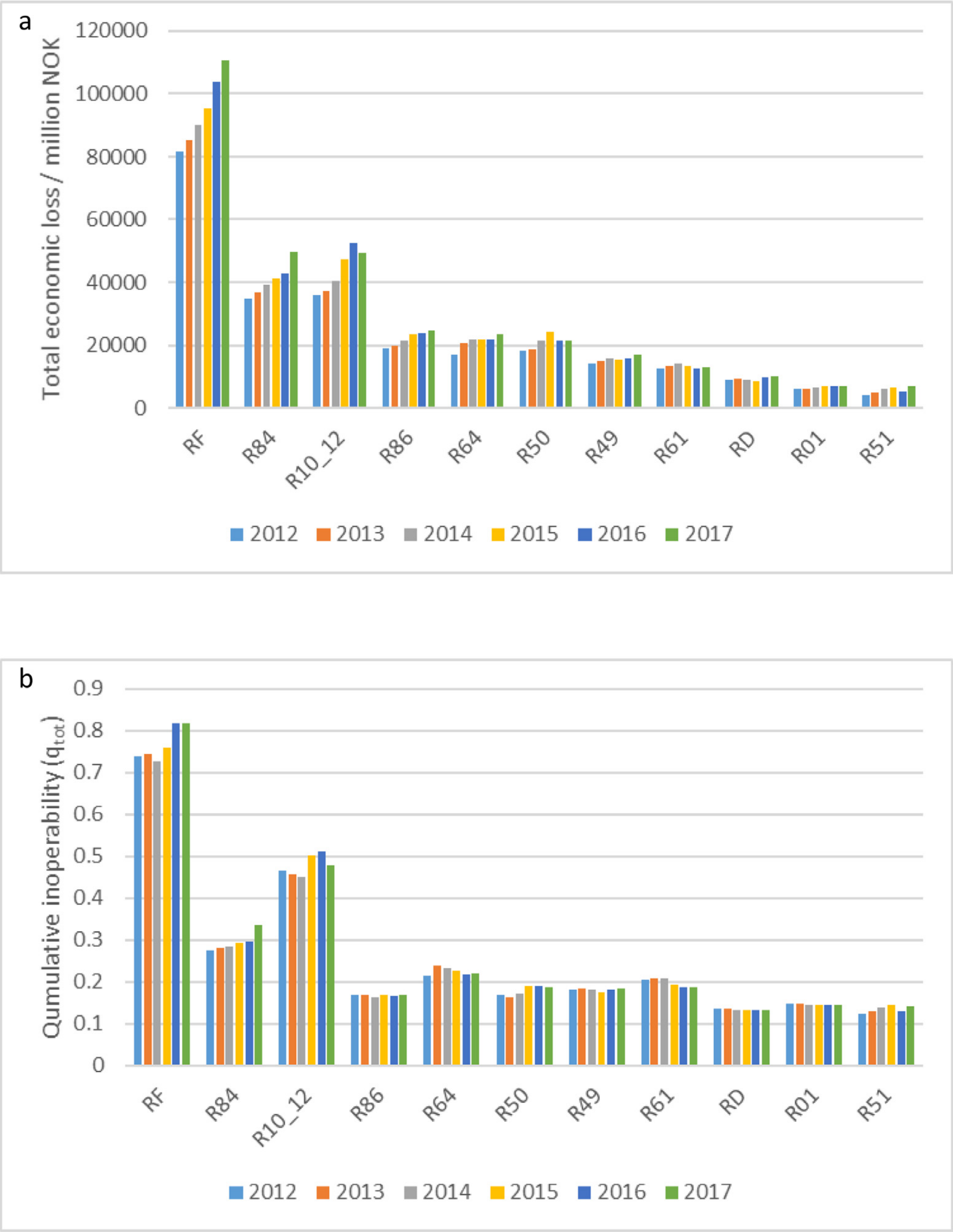

Fig. 5. (a) Total economic losses and (b) cumulative inoperabilities (q_{tot}) for all sectors following a notional 10% demand reduction for the Norwegian industry sectors RF, R84, R10_12, R86, R64, R50, R49, R61, RD, R01 and R51 (see Table 1 for a description).

not the case for Norway [32], which is likely related to how CNI sectors are identified in Norway [23]. With increasing digitisation and automation of the construction industry [33,34], there is a need for more knowledge on how this will affect the interdependencies between the construction industry and other sectors, and the potential vulnerabilities that follows. There is also a need for more information on the importance of the construction industry and construction workers for maintaining CNIs during crises, to better inform civil contingency planning.

Lastly, the food supply chain is vulnerable to a multitude of threats and hazards [35–37]. Contamination of the food supply chain or outbreaks in the agricultural sector can not only cause production losses and reduced exports, but also temporal changes in consumers' demand for the affected products [38,39]. Thus, previous European incidents that have affected the food supply chain, have not only had significant economic impact on the food industry, but also led to consumers' questioning the food safety [36]. Although food defence has gained increased awareness in Europe, there are still shortcomings with respect to incorporation of food defence principles in legal frameworks [37] as well as tools and methods for ensuring food supply chain integrity [36]. In addition, food availability, access, utilisation and stability may be affected by climate change [35,40]. Given the significant impact triggered by disruption of the Norwegian food industry, also taking into account that the food industry is the largest mainland industry in Norway, enhancing the resilience of the food industry should continue. Furthermore, given that Norway is a net importer of agricultural products and that the vast majority of Norway's agricultural production is consumed domestically with very little exports [41], the fragility of the agricultural sector should continue to be reduced.

3.6. Limitations

Most of the limitations to this study pertain to the applicability of the IIM itself [42,43]; the main limitation being the assumption that economic change is representative for the interdependencies between the industry sectors (eq. (3)). Still, economic factors are important because such factors play a major role in shaping the operating environment of CNIs [2]. Secondly, the IIM only covers parts of the six dimensions proposed by Rinaldi et al. [2] for analysing infrastructure interdependencies. Given that the IIM applied in this work is a static, linear model, temporal and non-linear behaviours are for example not addressed. However, since the purpose of this work is to gain insight into interdependency changes over the period 2012–2017, the use of a static model is considered sufficient. Furthermore, as argued by Kelly [42], large, widespread disasters may change the underlying structure of the economy and consequently also the technical coefficients. To avoid problems associated with large perturbations, the upper limit of $\boldsymbol{c}^*$ has been restricted to a maximum of 10% as used in other studies [11,16]. This leads, however, to other limitations. In particular, the effects of, *e.g.*, large-scale power outages or loss of telecommunication services are not properly addressed in this study. Lastly, infrastructure disruptions typically occur on the supply-side of the economy [42], which in the demand-reduction IIM is modelled as a forced demand-reduction with impacts cascading to other sectors by backwards linkages [42,43]. However, as argued by Oosterhaven [43], the use of the supply-driven IIM is more problematic than the demand-reduction IIM. The demand-reduction IIM was therefore applied in this work, also taking into consideration that the public's security concerns related to, *e.g.*, terrorism may cause demand perturbations [11,44].

On the basis of these limitations, care should be exercised when interpreting the results. Following arguments by Oosterhaven [43], the results cannot be used to prioritise CNI resilience initiatives at the national level, nor can the results be used to assess the wider economic impacts after CNI disruptions. The results do, however, provide insight into the interdependency trends for Norway's mainland industry sectors in view of national security. The results can also inform researchers, stakeholders and policy makers on CNI sectors that should receive more attention in future studies.

4. Conclusions

For the first time, changes in interdependencies between Norway's mainland industry sectors have been analysed in terms of the demand-reduction inoperability input-output model [9,11]. The time period 2012–2017 was selected on the basis of the availability of comparable national I-O accounts data.

The sectors RF (constructions and construction works) and R10_12 (manufacture of food products) are very important industry sectors for mainland Norway. Because of the large influence these sector exercise on other sectors, disruptions of RF or R10_12 may have significant effects on the national security of Norway. Norway's agricultural sector, in particular, is very fragile towards disruptions to the food industry. Furthermore, the RF sector has increased its influence gain from 2012 to 2017.

The inoperability of the telecommunication services sector (R61) has significantly declined over the years 2013–2017 compared to 2012. Financial services (R64), on the other hand, has become more fragile towards cascading effects over the same time period. For the electricity supply sector (RD), only minor changes are observed.

If we look at land (R49), water (R50) and air (R51) transport services, disruption of water transport services has the greatest impact on the other sectors followed by land transport services. Only minor changes in inoperabilities are observed from 2012 to 2017.

Perturbation of public administration and defence services (R84) has substantial impact on many of the other sectors. In addition, several sectors have become more affected by the perturbation of the R84 sector over the time period 2012–2017, while the inoperabilities of RD, RF, R49 and R84 have remained unchanged over the same time period. If we look at perturbation of human health services (R86), no significant changes are seen from 2012 to 2017.

On the basis of the results in this work, it is recommended to gain more knowledge about the importance of the construction industry and construction workers for maintaining CNIs during crises. In addition, with increasing digitisation and automation of the construction industry [33,34], there is a need for more knowledge on how this will affect the interdependencies between the construction industry and other sectors, and the potential vulnerabilities that follows. Norway should also continue to enhance the resilience of its agriculture and food industry.

Declaration of Competing Interest

None.

Acknowledgements

This work was funded by the Norwegian Ministry of Defence through project grant 1539.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijcip.2020.100405.

References

[1] A.M. Lewis, D. Ward, L. Cyra, N. Kourti, European reference network for critical infrastructure protection, Int. J. Crit. Infrastruct. Prot. 6 (2013) 51–60 https://doi.org/, doi:10.1016/j.ijcip.2013.02.004.

[2] S.M. Rinaldi, J.P. Peerenboom, T.K. Kelly, Identifying, understanding, and analyzing critical infrastructure interdependencies, IEEE Control Syst. Mag. 21 (2001) 11–25.

[3] S.E. Chang, Infrastructure resilience to disasters, Bridge (Kans City) 39 (2009) 36–41.

[4] A. Vespignani, The fragility of interdependency, Nature 464 (2010) 984–985.

[5] E.J. Oughton, W. Usher, P. Tyler, J.W. Hall, Infrastructure as a complex adaptive system, Complexity 2018 (2018) 3427826, doi:10.1155/2018/3427826.

[6] D. Helbing, Globally networked risks and how to respond, Nature 497 (2013) 51–59, doi:10.1038/nature12047.

[7] S. Puuska, L. Rummukainen, J. Timonen, L. Lääperi, M. Klemetti, L. Oksama, J. Vankka, Nationwide critical infrastructure monitoring using a common operating picture framework, Int. J. Crit. Infrastruct. Prot. 20 (2018) 28–47 https://doi.org/, doi:10.1016/j.ijcip.2017.11.005.

[8] M. Ouyang, Review on modeling and simulation of interdependent critical infrastructure systems, Reliab. Eng. Syst. Saf. 121 (2014) 43–60.

[9] Y.Y. Haimes, B.M. Horowitz, J.H. Lambert, J.R. Santos, C. Lian, K.G. Crowther, Inoperability input-output model for interdependent infrastructure sectors. I: theory and methodology, J. Infrastruct. Syst. 11 (2005) 67–79.

[10] J.R. Santos, Inoperability input-output modeling of disruptions to interdependent economic systems, Systems Engineering 9 (2006) 20–34, doi:10.1002/sys.20040.

[11] J.R. Santos, Y.Y. Haimes, Modeling the demand reduction input-output (I-O) inoperability due to terrorism of interconnected infrastructures, Risk Anal. 24 (2004) 1437–1451.

[12] Y.Y. Haimes, B.M. Horowitz, J.H. Lambert, J. Santos, K. Crowther, C. Lian, Inoperability input-output model for interdependent infrastructure sectors. II: case studies, J. Infrastruct. Syst. 11 (2005) 80–92, doi:10.1061/(ASCE)1076-0342(2005)11:2(80).

[13] C.W. Anderson, J.R. Santos, Y.Y. Haimes, A risk-based input–output methodology for measuring the effects of the august 2003 northeast blackout, Econ. Syst. Res. 19 (2007) 183–204, doi:10.1080/09535310701330233.

[14] K.G. Crowther, Y.Y. Haimes, G. Taub, Systemic valuation of strategic preparedness through application of the inoperability input-output model with lessons learned from hurricane Katrina, Risk Anal. 27 (2007) 1345–1364, doi:10.1111/j.1539-6924.2007.00965.x.

[15] J.R. Santos, Y.Y. Haimes, C. Lian, A framework for linking cybersecurity metrics to the modeling of macroeconomic interdependencies, Risk Anal. 27 (2007) 1283–1297, doi:10.1111/j.1539-6924.2007.00957.x.

[16] R. Setola, Analysis of interdependencies between Italy's economic sectors, in: E. Goetz, S. Shenoi (Eds.), Critical Infrastructure Protection, Springer US, Boston, MA, 2008, pp. 311–321.

[17] L. Galbusera, G. Giannopoulos, On input-output economic models in disaster impact assessment, Int. J. Disaster Risk Reduct. 30 (2018) 186–198 https://doi.org/, doi:10.1016/j.ijdrr.2018.04.030.

[18] Y.Y. Haimes, P. Jiang, Leontief-based model of risk in complex interconnected infrastructures, J. Infrastruct. Syst. 7 (2001) 1–12.

[19] R. Setola, S. De Porcellinis, M. Sforna, Critical infrastructure dependency assessment using the input-output inoperability model, Int. J. Crit. Infrastruct. Prot. 2 (2009) 170–178.

[20] T. Aven, Y. Ben-Haim, H.B. Andersen, T. Cox, E.L. Droguett, M. Greenberg, S. Guikema, W. Kröger, O. Renn, K.M. Thompson, E. Zio, Society For Risk Analysis Glossary, Society for Risk Analysis, 2018 https://sra.org/sites/default/files/pdf/SRA%20Glossary%20-%20FINAL.pdf.

[21] [dataset]Supply and Use and Input-Output tables, Statistics Norway, 2019 https://www.ssb.no/en/nasjonalregnskap-og-konjunkturer/tables/supply-and-use-and-input-output.

[22] S.R. Sellevåg, Supplementary data on changes in inoperability for interdependent industry sectors in Norway from 2012 to 2017, Data in Brief. In Press.

[23] Vital functions in society, Norwegian Directorate for Civil Protection, 2017. https://www.dsb.no/rapporter-og-evalueringer/vital-functions-in-society/.

[24] [dataset]UK Input-Output Analytical tables, UK Office for National Statistics, 2020 https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/ukinputoutputanalyticaltablesdetailed.

[25] UK Energy in Brief 2019, UK Department for Business, Energy & Industrial Strategy, 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/857027/UK_Energy_in_Brief_2019.pdf.

[26] B. Breitschopf, K. Grave, C. Bourgault, Electricity Costs of Energy-Intensive Industries in Norway - a comparison With Energy-Intensive Industries in Selected countries, Fraunhofer ISI & Ecofys GmbH, 2016 https://www.energinorge.no/contentassets/525e77b1feff4203a94ef6d1f94cfd03/electricity-costs-of-energy-intensive-industries-in-norway.pdf.

[27] Et Sårbart samfunn. Utfordringer for sikkerhets- og beredskapsarbeidet i Samfunnet, 2000 https://www.regjeringen.no/contentassets/1c557161b3884335b4f9b89bbd32b27e/no/pdfa/nou200020000024000dddpdfa.pdf.

[28] Når sikkerhet er viktigstBeskyttelse Av Landets Kritiske Infrastrukturer Og Kritiske Samfunnsfunksjoner, 2006 https://www.regjeringen.no/contentassets/c8b710be1a284bab8aea8fd955b39fa0/no/pdfs/nou200620060006000dddpdfs.pdf.

[29] Public Summary of Sector Security and Resilience Plans, UK Cabinet Office, 2017 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/678927/Public_Summary_of_Sector_Security_and_Resilience_Plans_2017__FINAL_pdf___002_.pdf.

[30] U. S. Department of Homeland SecurityCybersecurity & Infrastructure Security Agency, 2020 https://www.cisa.gov/critical-infrastructure-sectors accessed 24th March 2020.

[31] Advisory Memorandum on Identification of Essential Critical Infrastructure Workers During COVID-19 Response, US Department of Homeland Security, Cybersecurity & Infrastructure Security Agency, 2020 https://www.cisa.gov/sites/default/files/publications/Version_3.0_CISA_Guidance_on_Essential_Critical_Infrastructure_Workers_4.pdf.

[32] List of Vital Societal Functions, Norwegian Ministry of Justice and Public Security, 2020 in Norwegian https://www.regjeringen.no/no/tema/samfunnssikkerhet-og-beredskap/innsikt/liste-over-kritiske-samfunnsfunksjoner/id2695609/?expand=factbox2695617 accessed 5th May 2020.

[33] B. Mantha, B.García de Soto, Cyber security challenges and vulnerability assessment in the construction industry, in: M.J. Skibniewski, M. Hajdu (Eds.), Proceedings of the Creative Construction Conference, 2019 https://doi.org/, doi:10.3311/CCC2019-005.

[34] Imagining Construction's Digital future, McKinsey & Company, Capital Projects & Infrastructure, 2016 https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future accessed 12th May 2020.

[35] C. Mbow, C. Rosenzweig, L.G. Barioni, T.G. Benton, M. Herrero, M. Krishnapillai, E. Liwenga, P. Pradhan, M.G. Rivera-Ferre, T. Sapkota, F.N. Tubiello, Y. Xu, et al., Food Security, in: P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, et al. (Eds.), Climate Change and Land: an IPCC Special Report On Climate change, desertification, Land degradation, Sustainable Land management, Food security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems, 2019, p. 5. in pressCh..

[36] R.K. Davidson, W. Antunes, E.H. Madslien, J. Belenguer, M. Gerevini, T. Torroba Perez, R. Prugger, From food defence to food supply chain integrity, Brit. Food J. 119 (2017) 52–66, doi:10.1108/BFJ-04-2016-0138.

[37] N.P. Bogadi, M. Banović, I. Babić, Food defence system in food industry: perspective of the EU countries, J. Verbrauch. Lebensm. 11 (2016) 217–226, doi:10.1007/s00003-016-1022-8.

[38] D.L. Pendell, J.L. Lusk, T.L. Marsh, K.H. Coble, S.C. Szmania, Economic assessment of zoonotic diseases: an illustrative study of rift valley fever in the United States, Transbound Emerg Dis 63 (2016) 203–214, doi:10.1111/tbed.12246.

[39] G. Oladosu, Economic impacts of potential foot and mouth disease agroterrorism in the USA: a general equilibrium analysis, J Bioterror Biodef (2012) s12, doi:10.4172/2157-2526.S12-001.

[40] A. Heslin, M.J. Puma, P. Marchand, J.A. Carr, J. Dell'Angelo, P. D'Odorico, J.A. Gephart, M. Kummu, M. Porkka, M.C. Rulli, D.A. Seekell, S. Suweis, A. Tavoni, Simulating the cascading effects of an extreme agricultural production shock: global implications of a contemporary US dust bowl event, Front. Sustain. Food Syst. (2020) 4, doi:10.3389/fsufs.2020.00026.

[41] OECDAgricultural Policy Monitoring and Evaluation 2019, OECD Publishing, Paris, 2019 https://doi.org/, doi:10.1787/39bfe6f3-en.

[42] S. Kelly, Estimating economic loss from cascading infrastructure failure: a perspective on modelling interdependency, Infrastruct. Complex. 2 (2015) 7, doi:10.1186/s40551-015-0010-y.

[43] J. Oosterhaven, On the limited usability of the inoperability IO model, Econ. Syst. Res. 29 (2017) 452–461, doi:10.1080/09535314.2017.1301395.

[44] J.E. Araña, C.J. León, The impact of terrorism on tourism demand, Annals of Tourism Research 35 (2008) 299–315 https://doi.org/, doi:10.1016/j.annals.2007.08.003.