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Green Jobs: Definition and Method of Appraisal of Chemical and Biological Risks

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ABSTRACT

In the wake of sustainable development, green jobs are developing rapidly, changing the work environment. However a green job is not automatically a safe job. The aim of the study was to define green jobs, and to establish a preliminary risk assessment of chemical substances and biological agents for workers in Quebec. An operational definition was developed, along with criteria and sustainable development principles to discriminate green jobs from regular jobs. The potential toxicity or hazard associated with their chemical and biological exposures was assessed, and the workers' exposure appraised using an expert assessment method. A control banding approach was then used to assess risks for workers in selected green jobs. A double entry model allowed us to set priorities in terms of chemical or biological risk. Among jobs that present the highest risk potential, several are related to waste management. The developed method is flexible and could be adapted to better appraise the risks that workers are facing or to propose control measures.

KEYWORDS: biological agents; chemical agents; control banding; green job; risk appraisal; waste management

INTRODUCTION

The concept of 'green economy', emerged in the last decades from the sustainable development movement, influences many political strategies globally. The United Nations Environment Program (UNEP) defines it as an economy 'that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities' (UNEP, 2011). In Canada and in the province of Quebec, sustainable development has been integrated in the economic development strategy, and the respective governments offer incentives to foster research and development and to promote job creation in sectors such as recycling, renewable energy sources, transport, natural resources management, or environmental protection and tourism (Government of Quebec, 2008; Government of Canada, 2010; ECO Canada, 2012). Jobs in these sectors are often referred to as green jobs or environmental jobs, and it is estimated that there were >162 000 such jobs in Quebec

and >730 000 in Canada in 2013 (ECO Canada, 2013). In 2014, the European Commission launched the Green Employment Initiative to help foster jobs opportunities in the green economy, estimating that up to 20 million jobs could be created until 2020 in European Union (European Commission, 2014). In the United States, the number of green jobs increased from 3 249 533 in 2010 to 3 401 279 in the fourth quarter of 2011. Construction sector had the largest increase in US green jobs employment from 2010 to 2011, up to 101 932 (Bureau of Labor Statistics, 2013).

Although industrialized countries and emerging economies are interested in green jobs, their related economic sectors face two challenges: definitions that remain elusive and working conditions and occupational health and safety issues that are not well documented. While many now speak of greening of the economy, it appears that different shades of green exist among jobs and sectors which are typically linked to engineering, communication, or training (ECO Canada, 2010; UNEP, 2011; ILO, 2012). Moreover, some of the green jobs imply working with dangerous or toxic materials, such as organic or non-organic compounds, biological agents, heavy metals or chemical contaminants in recycling, composting, or engineering of renewable energy technologies (Chen, 2010; UNEP, 2011). The photovoltaic industry is a compelling example as workers are potentially exposed to a wide range of hazardous materials, such as cadmium and arsenic, during solar panel manufacturing and recycling process (Bakhiyi *et al.*, 2014). Thus, despite a noble goal, the greenness of jobs does not guarantee a safe working environment since what is good for the environment is not necessary good for workers (Chen, 2010; Schulte *et al.*, 2010).

The rapid expansion of the green economy, using sometimes new technologies coming straight from research and development laboratories, demands a rapid adaptation. The resulting gaps in required skills or training could put the workers' safety and health at risk. Preserving the environment is clearly a priority, but it is even more urgent to assess the risks faced by the green workforce, and hence to synchronize, as much as possible, greening efforts and workers' safety.

The risk assessment of new or relatively unknown products has to rely on a qualitative or semi-quantitative method considering a lack of data. The control banding (CB) method, developed in the pharmaceutical industry to mitigate the risk posed by new compounds (Naumann, 2005), has not yet been used to provide guidance to manage potential occupational health risks for green jobs. Broadly speaking, each substance identified in a given job is assigned to a specific hazard group (also called hazard band), based on available information or its similarity to other better-known substances; the potential exposure to this substance is also appraised in a semi-quantitative way. Most models are based on four or five hazard groups, and an equivalent number of potential exposure strata, giving a total of 16–25 possible situations. A risk mitigation strategy (Naumann *et al.*, 1996; Naumann, 2005) that can be integrated in prevention programs is then attributed to each of these situations. This model has been improved and simplified by the British Health and Safety Executive (HSE) into an accessible tool called Control of Substances Hazardous to Health (*COSHH Essentials*) for small and medium enterprises (HSE, 2010). The Dutch have developed it further to create the *Stoffenmanager*, another web-based tool accessible to non-experts (Marquart *et al.*, 2008; The Netherlands' Ministry of Social Affairs and Employment, 2012). CB is particularly well adapted for new or emerging situations, for which limited data are available. It has been recently applied to nanotechnologies (Paik *et al.*, 2008; Ostiguy *et al.*, 2011), and it is included in an ISO standard (ISO/PDST 12901-2) (ISO, 2013) and in two Canadian Standards Association (CSA) Group standards (Z12885-12 – Nanotechnologies – Exposure Control Program for Engineered Nanomaterials in Occupational Settings and Z94.4–11 – Selection, Use and Care of respirators) (CSA, 2012; Lavoie *et al.*, 2013a) and further refined by Canadian investigators in 2013 (Lavoie *et al.*, 2013b; Neesham-Grenon *et al.*, 2013).

The aim of this study is to develop a method to identify green jobs in Quebec and to appraise their occupational health risks in order to prioritize areas/occupations for which it would be relevant to quantitatively assess occupational exposures. To achieve this goal, specific objectives are: (i) to define green sectors, industries, and jobs; (ii) to produce a list of green jobs in Quebec; (iii) to identify the chemical substances and biological agents associated with these jobs; and (iv) to qualitatively assess the health risks for workers.

METHODS

Definition and selection of green jobs

Several definitions of green jobs exist, according to the point of view of the observer. Our specific focus on workers' health and safety, an essential component of sustainable development, encouraged us to provide our own definition, based on definitions from the UNEP (2008), Environmental Careers Organization Canada (ECO Canada, 2010), the Government of Quebec (Government of Quebec, 2008), and the US Bureau of Labor Statistics (Bureau of Labor Statistics, 2013), and on five principles of sustainable development from the Sustainable Development Act of Quebec (Government of Quebec, 2014):

> Can be considered green any job that aims to reduce the environmental footprint of human activities and that subscribes to at least one of five main sustainable development principles: health and quality of life, environmental protection, access to knowledge, prevention or precaution. Green jobs, which may require specific skills and knowledge, involve the development, innovation or use of adapted techniques, technologies or processes.

This definition then served as the basis for a list of green job titles. We started with data from the 2006 Canadian Census to identify economic sectors and occupations in which Quebec workers were employed. Industrial sectors were coded according to the North American Industry Classification System (NAICS) (Statistics Canada, 2012a) and occupations according to the Canadian National Occupational Classification (NOC) (Statistics Canada, 2012b). The combination of these two classification systems gives a relatively precise classification of a job title. We then classified each of the 500 4-digit unit groups of the NOC (referred to as 'occupations' throughout this paper), according to criteria from our definition of a green job mentioned above. This resulted in a list of 71 occupations that contain >400 green job titles. Based on expert assessment, eight of the selected green jobs were assumed to present lower risks than other occupations in the same sectors (e.g. administrative occupations and architects vs. building and renovation managers) and were thus not further considered. This resulted in 63 occupations being analysed (see Supplementary data are available at Annals of Occupational Hygiene online) in terms of chemical or biological risk, together with their related job titles.

Risk appraisal

The level of risk was appraised using a CB method, which requires information on the hazard (chemical or biological in our case), and on the exposure to this hazard. The appraisal was based on knowledge of the workplace and expert judgement, not on quantitative data. Although CB can be applied to any type of hazard, as chemical contaminants and biological agents differ, together with the potential exposure to these potential hazards, they were therefore treated separately. As the focus was on chemical and biological risks, other hazards (physical, accidental) potentially related to green jobs, although real and numerous, were not addressed here.

Chemical agents

Our CB approach borrowed from three existing methodologies: the British *COSHH Essentials* (Brooke, 1998; Maidment, 1998; Garrod and Rajan-Sithamparanadarajah, 2003), the Dutch *Stoffenmanager* (Cherrie *et al.*, 1996; Cherrie and Schneider, 1999; Van-Wendel-de-Joode *et al.*, 2003; Marquart *et al.*, 2008; Van Duuren-Stuurman *et al.*, 2011; Van Niftrik, 2011), and the ISO/PDTS 12901–2 standard (ISO, 2013). As the other CB methodologies, the COSHH method is based on hazard and exposure bands. Hazard bands are classified based on risk phrases. Exposure bands are determined taking into account physico-chemical properties (dustiness and volatility) of the chemical agent, the process temperature and the amount of agent used, but not the frequency of exposure. For our CB approach, we focused on two readily available variables—dustiness and volatility, and the agent's frequency of use in a given occupation. The Stoffenmanager method not only uses the same hazard bands as the COSHH, but also takes into account frequency and duration of exposure; we assumed a worst-case scenario. An industrial hygienist (Robert Bourbonnais) and a chemist (Claude Ostiguy) appraised the chemical risks.

Attribution of hazard score

A level of toxicity (or hazard) was assigned to each agent using Risk Phrases (R-phrases are defined in

Annex III of European Union Directive 67/548/EEC: 'Nature of special risks attributed to dangerous substances and preparations'), based on information from different sources: Material Safety Data Sheets (MSDS) of SIGMA-ALDRICH, the toxicology registry ('Répertoire toxicologique' or REPTOX) of the Workmen Compensation Board of Quebec (CSST) and the threshold limit value (TLV) proposed by the American Conference of Governmental Industrial Hygienists (ACGIH®). When classifications differed between these sources, priority was first given to the ACGIH® TLVs, and second to the SIGMA-ALDRICH evaluation. Toxicity was ranked in one of five hazard bands, from 1 (minimum, very low) to 5 (maximum, very high) as presented in Table 1. The right-hand column of the Table also lists the hazard statements (H-statements) corresponding to the different hazard bands. This should allow a comparison between the newer H-statements and the R-phrases used in our assessment.

The assessment of the toxicity for chemical mixtures and groups [polycyclic aromatic hydrocarbons (PAHs), solvents, pigments, etc.] was generally based on the toxicity of one substance, the most likely to be used or found in the concerned occupation or industry. Agents classified as confirmed or probable carcinogens for humans (groups 1 and 2A) by the International Agency for Research on Cancer (IARC) were systematically attributed a maximal hazard score (i.e. 5).

Attribution of exposure

The information provided by the NAICS and NOC codes describes the broad responsibilities and skills to be expected in each occupation in a given industry. The database from the American National Occupational Exposure Survey (NOES) (NIOSH, 2002) and results from chemical analyses done at the 'Institut de recherche Robert-Sauvé en santé et en sécurité du travail' (IRSST) laboratories between 2001 and 2005 (Ostiguy *et al.*, 2007) helped us to list chemicals to which workers were likely to be exposed. Although this exposure data is not very recent, most chemicals to which workers now assigned to green jobs are potentially exposed are the same as those found in 'traditional' sectors. Only the objective of the jobs and the use of the end product differ. The list of chemicals was prepared for each occupation (NOC 4-digit code) (Statistics Canada, 2012b). Exposures were assessed one agent at a time for each occupation and not globally for all chemical agents. The likelihood of exposure to each agent was estimated as three categories: 'possible', 'likely', and 'certain' based on an expert assessment method developed by Gérin *et al.* (1985). Only chemicals whose presence was assessed as likely or certain were kept for further analysis. We thus did not list substances that were rarely met or were found at very low levels in the Quebec workplaces, retaining the ones that were likely or certainly present.

The intensity of exposure was also assessed by chemical, within each occupation. Two criteria were used to qualify exposure intensity: frequency of use (low, medium, high) and dustiness or volatility (low, medium, high). This assessment procedure resulted in four exposure outcomes, low, medium, high, and very high (or 1–4). A low frequency of use corresponds to a contact time of <10% of the working time, a medium frequency to a contact time between 10 and 80% of the working time, and a high frequency corresponds to a contact with the agent for >80% of the working time. On the other hand, a low dustiness/volatility refers to a low concentration of aerosolized solids (cloud of airborne dust) or a boiling point above 150°C; medium dustiness/volatility refers to a cloud of airborne dust that settles quickly (seconds) or a boiling point between 50 and 150°C; a high dustiness/volatility refers to a cloud of airborne dust that lasts several minutes or a boiling point <50°C. For chemicals that are present in vapour form or are naturally in a gaseous state, other properties such as vapour density and ambient temperature have been taken into account to assess the likelihood of the worker's exposure. A low vapour density of a chemical (≤1.0) refers generally to a higher exposure. A high ambient temperature (≥27°C) corresponds generally to a higher exposure.

Chemical risk control banding and prioritization models

Toxicity was classified in five hazard bands and exposure in four bands. The combination of these bands in our CB model results in 20 possible outcomes, grouped in four CB risk bands: low, medium, high, and very high (or from I to IV) as shown in Table 2. As toxicity and occupational exposure were assessed for each agent within a given occupation, several CB scores were obtained for this occupation. Two methods were used to obtain one

Table 1. Criteria of Hazard band ranks for chemicals

Hazard band (HB)	Human impact	Dust reference value (mg m^{-3})	Vapour reference value (p.p.m.)	Examples of risk phrases	Examples of hazard statement
HB1 very low hazard, no significant risk for health	Not classified; eye or skin irritant	1 to 10	50 to 500	R36, R38	H303, H304, H305, H313, H315, H316, H319, H320, H333, H336
HB2 low hazard, low toxic effects that rarely need medical follow-up	Harmful by single exposure	0.1 to 1.0	5 to 50	R20/21/22, R68/20/21/22	H302, H312, H332, H371
HB3 from moderate to significant risk that needs medical follow-up	Toxic, corrosive	0.01 to 0.1	0.5 to 5.0	R23/24/25, R34, R35, R37, R39/23/24/25, R41, R43, R48/20/21/22	H301, H311, H314, H317, H318, H331, H335, H370, H373
HB4 high risk	Very toxic, toxic for reproduction	<0.01	<0.5	R26/27/28, R39/26/27/28, R40, R48/23/24/25, R60, R61, R62, R63, R64	H300, H310, H330, H351, H360, H361, H362, H372
HB5 very high risk	Asthma, cancer, genetic damage	Requires expert advice	Requires expert advice	R42, R45, R46, R49, R68	H334, H340, H341, H350

Source: Adapted from COSHH essentials: www.coshh-essentials.org.uk and International Chemical Safety Cards: http://www.cdc.gov/niosh/ipcs

R-phrases	H-statements	
R34 Causes burns	**H300** Fatal if swallowed	**H332** Harmful if inhaled
R35 Causes severe burns	**H301** Toxic if swallowed	**H333** May be harmful if inhaled
R36 Irritating to eyes	**H302** Harmful if swallowed	**H334** May cause allergy or asthma symptoms or breathing difficulties if inhaled
R37 Irritating to respiratory system	**H303** May be harmful if swallowed	
R38 Irritating to skin	**H304** May be fatal if swallowed and enters airways	
R40 Limited evidence of a carcinogenic effect	**H305** May be harmful if swallowed and enters airways	

Table 1. *Continued*

Hazard band (HB)	Human impact	Dust reference value (mg m^{-3})	Vapour reference value (p.p.m.)	Examples of risk phrases	Examples of hazard statement
R41 Risk of serious damage to eyes			**H310** Fatal in contact with skin		**H335** May cause respiratory irritation
R42 May cause sensitization by inhalation			**H311** Toxic in contact with skin		**H336** May cause drowsiness or dizziness
R43 May cause sensitization by skin contact			**H312** Harmful in contact with skin		**H340** May cause genetic defects
R45 May cause cancer			**H313** May be harmful in contact with skin		**H341** Suspected of causing genetic defects
R46 May cause inheritable genetic damage			**H314** Causes severe skin burns and eye damage		**H350** May cause cancer
R49 May cause cancer by inhalation			**H315** Causes skin irritation		**H351** Suspected of causing cancer
R60 May impair fertility			**H316** Causes mild skin irritation		**H360** May damage fertility or the unborn child
R61 May cause harm to the unborn child			**H317** May cause an allergic skin reaction		**H361** Suspected of damaging fertility or the unborn child
R62 Possible risk of impaired fertility			**H318** Causes serious eye damage		**H362** May cause harm to breast-fed children
R63 Possible risk of harm to the unborn child			**H319** Causes serious eye irritation		**H370** Causes damage to organs
R64 May cause harm to breast-fed babies			**H320** Causes eye irritation		**H371** May cause damage to organs
R68 Possible risk of irreversible effects			**H330** Fatal if inhaled		**H372** Causes damage to organs through prolonged or repeated exposure
R20/21/22 Harmful by inhalation, in contact with skin and if swallowed			**H331** Toxic if inhaled		**H373** May cause damage to organs through prolonged or repeated exposure
R23/24/25 Toxic by inhalation, in contact with skin and if swallowed					
R26/27/28 Very toxic by inhalation, in contact with skin and if swallowed					
R39/23/24/25 Toxic: danger of very serious irreversible effects through inhalation, in contact with skin and if swallowed					
R39/26/27/28 Very Toxic: danger of very serious irreversible effects through inhalation, in contact with skin and if swallowed					
R48/20/21/22 Harmful: danger of serious damage to health by prolonged exposure through inhalation, in contact with skin and if swallowed					
R48/23/24/25 Toxic: danger of serious damage to health by prolonged exposure through inhalation, in contact with skin and if swallowed					
R68/20/21/22 Harmful: possible risk of irreversible effects through inhalation, in contact with skin and if swallowed					

global risk score for each occupation: (i) the multiplication of the CB scores for each agent and (ii) an ordering of scores taking into account the number of different chemical exposures per occupation, hereafter called 'prioritization model'. For the first method, multiplying the CB scores was preferred to adding them, to avoid giving too much importance to the low toxicity agents (hazard band 1). However, the number of identified agents and their risk scores can be both useful as risk indicators: is it more risky to be exposed to a few very toxic agents, or to be exposed to many less toxic substances? The second method considers these two indicators in one prioritization model. The number of agents is stratified in quartiles, and the proportion of CB scores equal or above III (corresponding to high and very high risks) is divided in four percentage strata: 0–24%, 25–49%, 50–74%, and 75–100%. The prioritization model presented in Table 3 results in 16 outcomes, according to three levels of priority, low, medium, and high.

Biological agents

The biological CB model is partly based on the British and Dutch chemical CB approaches (Maidment, 1998; Marquart *et al.*, 2008) and on nanoparticles models (Paik *et al.*, 2008; Truchon and Cloutier, 2009; Zalk *et al.*, 2009). But instead of using a list of risk phrases as used for chemicals, the CB model for biological agents is based on the international microorganisms classification in four risk groups according to their pathogenicity (The European Parliament and the Council of the European Union, 2000; Public Health Agency of Canada, 2004; Centers for Disease Control and Prevention & National Institutes of Health, 2009; CSA, 2011). The resulting biological model has already been published (McCullough and Brosseau, 1999; CSA, 2011; Lavoie et al., 2013a,b; Neesham-Grenon *et al.*, 2013). The biological risk was appraised by a biologist who is also an industrial hygienist (Jacques Lavoie).

Attribution of hazard score

Unlike the chemical toxicity assessment, the ranking of biological agents is subject to an international consensus (Public Health Agency of Canada, 2004), and the hazard score was divided in four bands according to the risk groups used in biosecurity. Green job titles and related occupations considered in this study reflect the reality

Table 2. Chemical risk control banding model (adapted from *COSHH Essentials*)

		Potential exposure band			
		1	**2**	**3**	**4**
Hazard band	1	Low (I)	Low (I)	Medium (II)	Medium (II)
	2	Low (I)	Medium (II)	Medium (II)	High (III)
	3	Medium (II)	High (III)	High (III)	Very high (IV)
	4	High (III)	Very high (IV)	Very high (IV)	Very high (IV)
	5	Very high (IV)	Very high (IV)	Very high (IV)	Very high (IV)

Table 3. Chemical risk prioritization model

		Number of agents (quartiles)			
		I	**II**	**III**	**IV**
Frequency of CB scores ≥ III (%)	0–24	Low priority	Low priority	Low priority	Medium priority
	25–49	Low priority	Medium priority	Medium priority	Medium priority
	50–74	Low priority	Medium priority	High priority	High priority
	75–100	Medium priority	Medium priority	High priority	High priority

in Quebec, and although biological risk group 4 agents such as the Ebola virus are potential hazards worldwide, they are probably not particularly present in green jobs. Following a worst-case scenario, we used the most pathogenic biological agent potentially present in the worker's environment to determine the hazard band.

Attribution of exposure

As published before in the use of CB for the evaluation of biological risks, the exposure was based on two criteria, the level of the control over the agent (C) and the level of the exposure (E) (McCullough and Brosseau, 1999; CSA, 2011). The exposure to biological agents was appraised for each green job title. The level of control is characterized by the time spent on risky tasks, taking into account the already implemented control measures. The level of exposure depends on the distance between the emission source and the worker and on the generation rate of biological agents. C and E are graded in five bands each: C is graded from 0 to 2; E is graded from 0 to 8 (see Table 4). E weighs more than C, as emission and generation are considered more important. According to the American Industrial Hygiene Association, AIHA (2009), exposure level at proximity of the emission source can be four times higher than at a distance from the source, so we decided to give a relative importance of 4:1 to E. The sum of C and E results in a global exposure score, ranging from 0 to 10. The principle of score adding was preferred because it better accounts for the reality associated with localized or point sources often observed in workplaces. Even ideal general ventilation does not reduce a worker's exposure if the workstation is located near the source, if there are projections, or if the worker blocks or protects the source by disturbing the ambient air flow profiles. A risk is always present in these situations and can never be reduced to zero by general ventilation in this additive model, as is the case in the models of McCullough and Brosseau (1999) and the CSA (2011), where ventilation divides the risk (Neesham-Grenon *et al.*, 2013; Lavoie et al., 2013a,b).

Biological risk control banding model

The global scores are ranked in four levels, low, medium, high, and very high as shown in Table 5. The biological risk assessment method allowed us to appraise the risk for each green job title. To attribute the risk to the occupation, we used a worst-case scenario, and the risk score attributed to an occupation is the worst score among the green job titles included in that occupation.

RESULTS

Considering both an occupation and the related industrial sectors characterizes various occupational situations and allowed the industrial hygiene experts to identify the potential chemical and biological agents to which workers could be exposed.

Chemical agents

A chemical hazard score could be attributed to 63 occupations (Supplementary data are available at Annals of Occupational Hygiene online). Chemical agents have been identified sometimes precisely (i.e. cadmium, benzene), sometimes in groups or classes (i.e. PAHs, soil particles). Between 5 and 29 agents were identified per occupation, for a total of 220 different chemicals. About a third of them were classified as having a very low toxicity (68/220), and the other chemicals are distributed as follows: low toxicity 48; medium toxicity 39; high toxicity 30; and very high toxicity 35. Among the agents with a very high toxicity, 30/35 (86%) are carcinogens from IARC group 1 or 2A.

The distribution of the 63 occupations according to our prioritization model shows that most occupations are classified within the low (n = 26) or medium (n = 24) priority categories. The 13 occupations in the highest priority category are listed in Table 6. It is important to remember that job titles have been selected as green, not occupations themselves. The occupation (4-digit NOC codes) groups several job titles, and among them are many non-green job titles as well.

Biological agents

As biological agents are ubiquitous on earth, the identification of all agents potentially present in a given occupational environment was not the goal of this study. It was more relevant to identify the most pathogenic agents and to assess the workers' exposure in order to appraise the health risk. Among the most pathogenic agents (group 3), we identified fungal agents such as *Histoplasma capsulatum* and viruses like *Hantavirus* or others in 30.2% of green occupations

Table 4. Control level and exposure scores for biological agents

Score	Description and comments
Control level (C)	
2.0	ACH ≤ 2; no or low ventilation, confined or other similar situations, continuous exposure to bioaerosols
1.5	2 < ACH ≤ 6; general ventilation or open windows or other similar situations, exposure to bioaerosols 75% of time
1.0	6 < ACH ≤ 12; room at negative pressure, laboratory ventilation, isolation chamber, displacement ventilation or other similar situations, exposure to bioaerosols 50% of time
0.5	ACH > 12; mechanized operations by, operations in a laboratory hood, some hospital departments (bronchoscopy, operating room; etc.), outdoor work or other similar situations, exposure to bioaerosols 25% of time
0	Operations in a laminar flow hood by, closed circuit sources or other similar situations, no abnormal exposure to bioaerosols
Exposure level (E)	
8.0	Uncontrolled exposure of the biological contaminant by, proximity to emission sources; work in the emission plumes by, procedures producing bioaerosols or other similar situations
6.0	High exposure by, decontamination work or other similar situations
4.0	Moderate exposure by, contact with the biological contaminant by, long distance from the source or other similar situations
2.0	Low exposure by, personnel assigned to other tasks
0	No exposure

ACH, air changes per hour.

(19/63). Most identified agents belong to group 2, such as fungal agents in genus *Aspergillus*, viruses in genera *Orthohepadna virus* (Hepatitis A, B, or C) or *Influenza*, bacteria in genera *Legionella* (e.g. *L. pneumophila*), *Escherichia* (e.g. *E. coli*), and *Clostridium* (e.g. *C. tetani*) (23/63 occupations). Group 1 agents consist mainly of moulds that are everywhere in the environment and human non-pathogenic bacteria (16/63 occupations). The risk was also considered 'not applicable' (NA) in five occupations, as exposure for these workers was not deemed to differ from the background exposure in the general population. Of the 63 occupations, 13 are considered to be in the highest priority category (Table 6): two of them are considered to present a high biological risk, and 11, a medium one.

DISCUSSION

Our exercise in prioritizing green job titles according to chemical and biological risks faced by workers identified 21 occupations at higher risk potential that will require further quantitative research and preventive interventions. The occupations are mainly distributed in two broad skill types, those of 'Occupations in manufacturing and utilities' and of 'Trades, transport, and equipment operators' and related occupations' that do not typically require a high level of training or knowledge.

This hazard appraisal did not take into account other important potential hazards such as physical agents and injuries; however, injury risks are real and may even be fatal, for instance, during installation of rooftop solar panels, following a fall or an electrocution

Table 5. Biological risk control banding model

		Global exposure score C + E (exposure band)			
		1 (0–5)	**2 (5.5–7)**	**3 (7.5–9)**	**4 (9.5–10)**
Biosecurity risk group (hazard band)	1	Low (I)	Medium (II)	Medium (II)	Medium (II)
	2	Low (I)	Medium (II)	High (III)	High (III)
	3	Low (I)	Medium (II)	High (III)	Very high (IV)
	4	Very high (IV)	Very high (IV)	Very high (IV)	Very high (IV)

(Bakhiyi *et al.*, 2014). This confirms that the greening of occupations does not necessarily mean safer and decent jobs. While it is true that a green economy may lead to the transformation of existing jobs, this can also be accompanied with a gradient of chemical and biological risks, with higher risks at the bottom of the occupational ladder. As rightly pointed out by Schulte *et al.* (2013), the occupational safety and health culture still need to be promoted in green sectors.

As mentioned in the Methods section, we used data from the 2006 Canadian Census to list economic sectors and occupations in which Quebec workers were employed. After identification of the high and medium priority occupations, the Census data were used to link occupations and industrial sectors. Among the industrial sectors related to the prioritized occupations are: waste management (NAICS 56), construction (NAICS 23), manufacturing (NAICS 31–33), and professional and technical services (NAICS 54). It is important to note that 8 of the 21 prioritized occupations are directly linked to waste management and many others can be indirectly linked to it. This is and will remain a very important sector to monitor in terms of workers' health, since waste management is among industries with the highest proportion of environmental employees in Canada (ECO Canada, 2013) and elsewhere. For example, of the 20 million jobs that could be created until 2020 in the European Union (EU), 400 000 are expected to be in the waste management and recycling sector. The review of the European waste legislation could also create an additional 180 000 jobs (European Commission, 2014). In particular, the e-recycling sector attracts increasing interest from the scientific community, owing to the potential mixture of toxic metals and other chemicals (Ceballos *et al.*, 2015), coupled to the projected increase in e-scrap all over the world (UNU/IAS, 2014).

To the best of our knowledge, a CB approach has never been used to assess potential risks associated with green jobs, nor has there been a systematic assessment of the chemical or biological health risks in these jobs. In this study, CB use was limited to prioritize research needs, but the possibilities are much wider, from macro-risk assessment to risk management in specific workstations. The adaptability of CB to new scientific knowledge and the fact that many preventive measures currently used can be adapted to green jobs make it a promising tool for the promotion of occupational health and safety.

Despite its reproducibility and adaptability, the developed method has some limitations that derive from the data and tools at our disposal and from certain methodological choices that were made. Data from the 2006 census of Statistics Canada are limited to coarse 4-digit industrial sector codes, preventing us from estimating the actual number of green workers in the province. Furthermore, the occupational codes available to us group different job titles with a variety of potential exposures to chemicals or biological agents. Our appraisal of the risk is a rather macroscopic view of the workplace reality and thus cannot represent equally every worker or every job title within a given occupation. As we lacked accurate exposure data, identification of the chemicals and biological agents results from experts' judgement, with its associated uncertainties. Moreover, only two experts appraised the chemical risk and one expert appraised the biological risk. The exhaustiveness of the list of agents identified by occupation was modulated by the experts' knowledge, and some newer exposures (such as to nanoparticles) have not been included in the assessment. It is important to

Table 6. Occupations and green jobs titles in the high priority category for chemical and biological risks

NOC[a] Code	Occupations and green jobs titles	Risk level	
		Chemical	Biological
9243	**Water and waste treatment plant operators** Filtration plant controller—water treatment; Water and wastewater technician; Wastewater collection system and treatment operator; Liquid waste process operator; Water plant pump operator; Sewage, wastewater and waste treatment plant operator.	H[b]	H
2263	**Inspectors in public and environmental health and occupational health and safety** Environmental officer; Environmental health officer, enforcement officer—environmental health; Environmental health inspector: hazardous waste—environmental health; safety and sanitary—public and environmental health; sewage disposal—environmental health; industrial waste control; Water, waste water treatment plant, pollution control or dangerous waste inspector.	H	M[c]
7293	**Insulators** Refrigeration and air conditioning equipment insulator; Building insulator; Heat and frost insulator.	H	M
7311	**Construction millwrights and industrial mechanics** Water treatment or water filtration plant mechanic; Windmills repairer.	H	M
9241	**Power engineers and power systems operators** Energy from waste plant operator; Energy recovery incinerator plant operator.	H	M
0712	**Home building and renovation managers** Residential home builder of homes contractor or renovation contractor	H	
2141	**Industrial and manufacturing engineers** Industrial efficiency engineer.	H	
7205	**Contractors and supervisors, other construction trades, installers, repairers, and servicers** Building insulation material installation or refrigeration and air conditioning equipment insulators contractor, supervisor or foreman/woman.	H	
7241	**Electricians (except industrial and power system)** Electrician.	H	

Table 6. *Continued*

NOC[a] Code	Occupations and green jobs titles	Risk level	
		Chemical	**Biological**
7242	**Industrial electricians**	H	
7291	Industrial electrician.	H	
	Roofers and shinglers		
	Flat or built-up flat roofer.		
7621	**Public works and maintenance labourers**		H
	Helper—garbage collection;		
	Sanitation man/women, labourer—sanitary service;		
	Sewer system maintenance worker or manual sewer pipe cleaner;		
	Garbage truck loader, dumpman/woman.		
9411	**Machine operators, mineral and metal processing**	H	
	Cadmium and thallium recoverer		
9523	**Electronics assemblers, fabricators, inspectors and testers**	H	
	Production operator—electronic equipment manufacturing.		
2134	**Chemical engineers**		M
	Chemical engineer, research;		
	Chemical engineer in environment or engineer in environmental chemistry;		
	Fuels engineer;		
	Waste treatment engineer (including industrial wastes);		
	Industrial hygiene engineer.		
2211	**Chemical technologists and technicians**		M
	Water purification technician;		
	Technologist, forest products;		
	Technologist, industrial hygiene		
4161	**Natural and applied science policy researchers, consultants and program officers**		M
	Waste reduction and recycling officer;		
	Waste reduction education program officer;		
	Environmental advisor or consultant (except engineer);		
	Environmental education consultant;		
	Waste diversion consultant;		
	Recycling, solid waste, waste management, waste diversion, waste/industrial waste reduction program coordinator or manager.		
7522	**Public works maintenance equipment operators and related workers**		M
	Utility arborist;		
	Garbage collector, garbage or collection truck driver, sewer flusher operator-driver, sewer jet cleaner operator—public works.		
9613	**Labourers in chemical products processing and utilities**		M
	Treater helper—chemical processing.		

Table 6. *Continued*

NOC[a] Code	Occupations and green jobs titles	Risk level	
		Chemical	Biological
9614	**Labourers in wood, pulp and paper processing** Recovery plant helper—pulp and paper.		M
9619	**Other labourers in processing, manufacturing and utilities** Oil reclamer; sorter, recyclable materials		M

[a]NOC, National Occupation Classification (Canadian version, 2011)—NOC codes are necessary to establish a correspondence with international occupational classifications.
[b]H, high risk.
[c]M, medium risk.

note that although the chemical interactions are of tremendous importance in terms of workers' health, the broad and qualitative approach used in this study did not allow a satisfactory integration of these variables in our CB method. However, chemical interactions remain extremely important for preventive intervention, especially if new products, albeit less toxic, are replacing others. We can say that the 2006 census data contributed significantly to the global picture we obtained. More precise and recent data would have brought more accurate and refined results. There are also substantial differences between the chemical and the biological approaches. The method to appraise the chemical risk allowed the distinction of particularities in toxicity and exposure between the diverse contaminants within the same occupation. However, this was only possible for the occupation, not the job title within the occupation. On the other hand, the biological risk was appraised for each job title, but with a global score of exposure, regardless of the biological agent. Our decision to present a global picture and the sample size (>400 job titles) guided these methodological choices.

CONCLUSION

Because it is a logical step towards sustainability, a green economy should also focus on both workers' health and safety and on the environment. However, technologies are changing rapidly, often faster than the worker's adaptability. Although these changes are desired and welcomed, it is important that everyone benefits from them. Most of the chemical and biological risks that we appraised are known and preventable. The tools that we developed and used are accessible. In this novel and fast-growing area, they could be applied to better understand the risks that workers are facing and to propose control measures. Green jobs are today and tomorrow's jobs, and the associated risks are the health and safety challenges of our society.

SUPPLEMENTARY DATA

Supplementary data can be found at http://annhyg.oxfordjournals.org/.

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REFERENCES

American Industrial Hygiene Association (AIHA). (2009) Mathematical models for estimating occupational exposure to chemicals. In Charles B. Keil, Chaterine E. Simmons, editors. 2nd ed., stock number KIT_AEAM09-379, Falls Church, VA: AIHA. 207 p.

Bakhiyi B, Labrèche F, Zayed J. (2014) The photovoltaic industry on the path to a sustainable future–environmental and occupational health issues. *Environ Int*; 73: 224–34.

Brooke IM. (1998) A UK scheme to help small firms control health risks from chemicals: toxicological considerations. *Ann Occup Hyg*; 42: 377–90.

Bureau of Labor Statistics. (2013) *Employment in green goods and services – 2011 [News Release]*. Washington, DC:

Bureau of Labor Statistic, U.S. Department of Labor. Available at http://www.bls.gov/news.release/pdf/ggqcew.pdf. Accessed 1 April 2015.

Canadian Standards Association (CSA). (2011) *CAN/CSA-Z94.4–11- Selection, use and care of respirators*. Mississauga, ON: Canadian Standards Association.

Canadian Standards Association (CSA). (2012) *Z12885-12 - Nanotechnologies – Health and safety practices in occupational settings relevant to nanotechnologies*. Mississauga, ON: Canadian Standards Association.

Ceballos DM, Gong W, Page E. (2015) A pilot assessment of occupational health hazards in the US electronic scrap recycling industry. *J Occup Environ Hyg*; 12: 482–8.

Centers for Disease Control and Prevention & National Institutes of Health. (2009) *Biosafety in microbiological and biomedical laboratories*. 5th ed. Atlanta, GA: US Department of Health and Human Services.

Chen H. (2010) *Green and healthy jobs*. Silver Spring, MD: CPWR - The Center for Construction Research and Training. Available at http://www.cpwr.com/sites/default/files/publications/Green-Healthy%20Jobs%20fnl%20for%20posting.pdf. Accessed 1 April 2015.

Cherrie JW, Schneider T. (1999) Validation of a new method for structured subjective assessment of past concentrations. *Ann Occup Hyg*; 43: 235–45.

Cherrie JW, Schneider T, Spankie S *et al.* (1996) New method for structured, subjective assessments of past concentrations. *Ann Occup Hyg*; 3: 75–83.

Environmental Careers Organization of Canada (ECO Canada). (2010) *Defining the green economy*. Calgary, AB: Environmental Careers Organization of Canada. Available at http://www.eco.ca/pdf/Defining-the-Green-Economy-2010.pdf. Accessed 14 March 2015.

Environmental Careers Organization of Canada (ECO Canada). (2012) The green jobs map, tracking employment through Canada's green economy. Available at http://www.eco.ca/ecoreports/pdf/2012-Green-Jobs-Map-Tracking-Employment-through-Canadas-Green-Economy.pdf. Accessed 17 October 2015.

Environmental Careers Organization of Canada (ECO Canada). (2013) *Profile of Canadian environmental employment*. Calgary, AB: Environmental Careers Organization of Canada. Available at http://www.eco.ca/ecoreports/pdf/2013-Profile-Canadian-Environmental-Employment-ECO-Canada.pdf. Accessed 14 March 2015.

European Commission. (2014) *Employment: Commission presents Green Employment Initiative to support structural shift to green growth by maximising job opportunities - frequently asked questions*. Brussels, Belgium: MEMO, 2 July 2014. Available at http://europa.eu/rapid/press-release_MEMO-14-446_en.pdf. Accessed 14 March 2015.

Garrod AN, Rajan-Sithamparanadarajah R. (2003) Developing COSHH Essentials: dermal exposure, personal protective equipment and first aid. *Ann Occup Hyg*; 47: 577–88.

Gérin M, Siemiatycki J, Kemper H *et al.* (1985) Obtaining occupation exposure histories in epidemiologic case-control studies, *J Occup Med*, 27: 420–6.

Government of Canada. (2010) *Planning for a sustainable future: a federal sustainable development strategy for Canada*. Gatineau, QC: Sustainable Development Office - Environment Canada. Available at https://www.ec.gc.ca/dd-sd/F93CD795-0035-4DAF-86D1-53099BD303F9/FSDS_v4_EN.pdf. Accessed 30 March 2015.

Government of Quebec. (2008) *Pour un Québec vert et prospère: stratégie de développement de l'industrie québécoise de l'environnement et des technologies vertes*. Québec, Canada, Ministère de l'Économie, de l'Innovation et des Exportations. Available at http://www.economie.gouv.qc.ca/objectifs/financement/environnement/. Accessed 16 December 2015.

Government of Québec. (2014) *Sustainable development act*. Québec, Canada: Québec Official Publisher, Bill 118, chapter 3. Available at http://www2.publicationsduquebec.gouv.qc.ca/dynamicSearch/telecharge.php?type=2&file=//D_8_1_1/D8_1_1_A.htm. Accessed 1 April 2015.

Health and Safety Executive (HSE). (2010) Health and safety in the new energy economy: meeting the challenge of major change. Health and Safety Executive. Available at http://www.hse.gov.uk/eet/new-energy-economy.pdf. Accessed 1 April 2015.

International Labour Office (ILO). (2012) *Promoting safety and health in a green economy*. Geneva, Switzerland: International Labour Office.

International Standard Organization (ISO). (2013) *ISO/PDTS 12901–2 – Nanotechnologies – Occupational risk management applied to engineered nanomaterials – Part 2: The use of the control banding approach in occupational risk management*. Geneva, Switzerland: International Standard Organization.

Lavoie J, Cloutier Y, Marchand G *et al.* (2013a) La protection respiratoire contre les bioaérosols. *Le Labexpert*; 3: 6–13.

Lavoie J, Neesham-Grenon E, Debia M *et al.* (2013b) *Development of a control banding method for selecting respiratory protection against bioaerosols*. Montreal, QC: Institut de recherche Robert-Sauvé en santé et en Sécurité du travail (IRSST), Rapport R-804.

Maidment SC. (1998) Occupational hygiene considerations in the development of a structured approach to select chemical control strategies. *Ann Occup Hyg*; 42: 391–400.

Marquart H, Heussen H, Le Feber M *et al.* (2008) 'Stoffenmanager', a web-based control banding tool using an exposure process model. *Ann Occup Hyg*; 52: 429–41.

McCullough NV, Brosseau LM. (1999) Selecting respirators for control of worker exposure to infectious aerosols. *Infect Cont Hosp Ep*; 20: 136–44.

Naumann BD. (2005) *Control banding in the pharmaceutical industry*. Occupational Hygienists Conference Proceedings 2005. Tullamarine, Australia: Australian Institute of Occupational Hygienists.

Naumann BD, Sargent EV, Starkman BS *et al.* (1996) Performance-based exposure control limits for pharmaceutical active ingredients. *Am Ind Hyg Assoc J*; 57: 33–42.

Neesham-Grenon E, Lavoie J, Cloutier Y *et al.* (2013) Bioprotect tool: a control banding method for respirator selection against bioaerosols. *J Int Soc Respir Prot*; 30: 21–32.

National Institute for Occupational Safety and Health (NIOSH). (2002) National Occupational Survey (1981–1983). Available at http://www.cdc.gov/noes/default.html. Accessed 31 March 2015.

Ostiguy C, Fournier M, Petitjean-Roget T *et al.* (2007) *Résultats des analyses de substances chimiques produites à l'IRSST pour la période 2001–2005*. Montreal, QC: Institut de recherche Robert-Sauvé en santé et en Sécurité du travail (IRSST), Rapport R-485.

Ostiguy C, Riediker M, Triolet J *et al.* (2011) *Développement d'un outil de gestion graduée des risques spécifiques au cas des nanomatériaux*. Paris, France: Agence nationale de santé sanitaire de l'alimentation de l'environnement et du travail (ANSES).

Paik SY, Zalk DM, Swuste P. (2008) Application of a pilot control banding tool for risk level assessment and control of nanoparticle exposures. *Ann Occup Hyg*; 52: 419–28.

Public Health Agency of Canada. (2004) *Laboratory biosafety guidelines*. Ottawa, ON: Health Canada.

Schulte PA, Heidel D, Okun A *et al.* (2010) Making green jobs safe. *Ind Health*; 48:377–9.

Schulte PA, McKernan LT, Heidel DS *et al.* (2013) Occupational safety and health, green chemistry, and sustainability: a review of areas of convergence. *Environ Health*; 12: 31.

Statistics Canada. (2012a) *North American Industry Classification System (NAICS) Canada 2012*. Ottawa, ON: Minister of Industry. Catalogue no. 12-501-X. p. 755.

Statistics Canada. (2012b) *National Occupational Classification (NOC) 2011*. Ottawa, ON: Minister of Industry. Catalogue no. 12-583-X. p. 1032.

The European Parliament and the Council of the European Union. (2000) Directive 2000/54/EC of the European Parliament and of the Council of 18 September 2000 on the protection of workers from risks related to exposure to biological agents at work (seventh individual directive within the meaning of Article 16(1) of Directive 89/391/EEC). *Off J Eur Commun*; 262: 21–45. Available at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32000L0054&from=EN. Accessed 31 March 2015.

The Netherlands' Ministry of Social Affaire and Employment. (2012) Stoffenmanager. Available at http://www.stoffenmanager.nl/Default.aspx. Accessed 14 April 2014.

Truchon G, Cloutier Y. (2009) Control banding et nanotechnologies. *Travail et santé*; 25: 15–16.

United Nations Environment Program (UNEP). (2008) *Green Jobs: Towards Decent Work in a Sustainable, Low-Carbon World*. Nairobi, Kenya: United Nations Environment Program. Available at http://www.unep.org/PDF/UNEPGreenjobs_report08.pdf. Accessed 2 April 2015.

United Nations Environment Program (UNEP). (2011) *Towards a green economy: pathways to sustainable development and poverty eradication*. Nairobi, Kenya: United Nations Environment Program. Available at http://www.unep.org/greeneconomy/Portals/88/documents/ger/ger_final_dec_2011/Green%20EconomyReport_Final_Dec2011.pdf. Accessed 2 April 2015.

United Nations University – Institute for the Advanced Study of Sustainability (UNU-IAS). (2014) The Global E-Waste Monitor 2014 - Quantities, flows and resources. Available at http://i.unu.edu/media/unu.edu/news/52624/UNU-1stGlobal-E-Waste-Monitor-2014-small.pdf. Accessed 1 September 2015.

Van Duuren-Stuurman B, Vink SR, Brouwer DH *et al.* (2011) Stoffenmanager Nano: Description of the conceptual control banding model. TNO report V9216 TNO, ArboUnie, The Netherlands: Zeist.

Van Niftrik M. (2011) *Stoffenmanager, The scientific basis of control banding*. BAuA Conference; 21/22 June 2011. Dortmund, Allemagne: BAuA. Available at http://www.baua.de/en/Topics-from-A-to-Z/Hazardous-Substances/Workshops/Control-Banding-2011/Control-Banding-2011.html. Accessed 31 March 2015.

Van-Wendel-de-Joode B, Brouwer DH, Vermeulen R *et al.* (2003) DREAM: A method for semi-quantitative dermal exposure assessment. *Ann Occup Hyg*; 47: 71–87.

Zalk DM, Paik SY, Swuste P. (2009) Evaluating the control banding nanotool: a qualitative risk assessment method for controlling nanoparticle exposures. *J Nanopart Res*; 11: 1685–704.